DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2011/50

Low- and intermediate level radioactive waste from Risø, Denmark. Location studies for potential disposal areas. Report no. 10

Characterization and description of areas Nordjylland

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

GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
MINISTRY OF CLIMATE AND ENERGY

GEUS

DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2011/50

Low- and intermediate level radioactive waste from Risø, Denmark. Location studies for potential disposal areas. Report no. 10

Characterization and description of areas Nordjylland

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

GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
MINISTRY OF CLIMATE AND ENERGY

GEUS

1. Introduction

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

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

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

2. Background

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

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

3. Data and methods

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

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

4. Selection of areas

Selection of potential areas in Nordjylland/Vendsyssel is solely based on the occurrence of Quaternary marine clay and meltwater clay which can fulfil the criteria and answer the questions described and put forwards in Gravesen et al., (2010).

The area is relatively small and situated west of Ålbæk and Ålbæk klitplantage.

The 250 m thick Quaternary deposits are relevant to investigate and analyse because the geological situation may fit a potential disposal area.

5. Area 22. Ålbæk

5.1 The location of the area

The area is located on the eastern part of Nordjylland west of Ålbæk (Fig. 1). Details of the location of the area can be seen in fig. 2.

Figure 1. Location of the area. The area is located in eastern part of Nordjylland, Denmark.

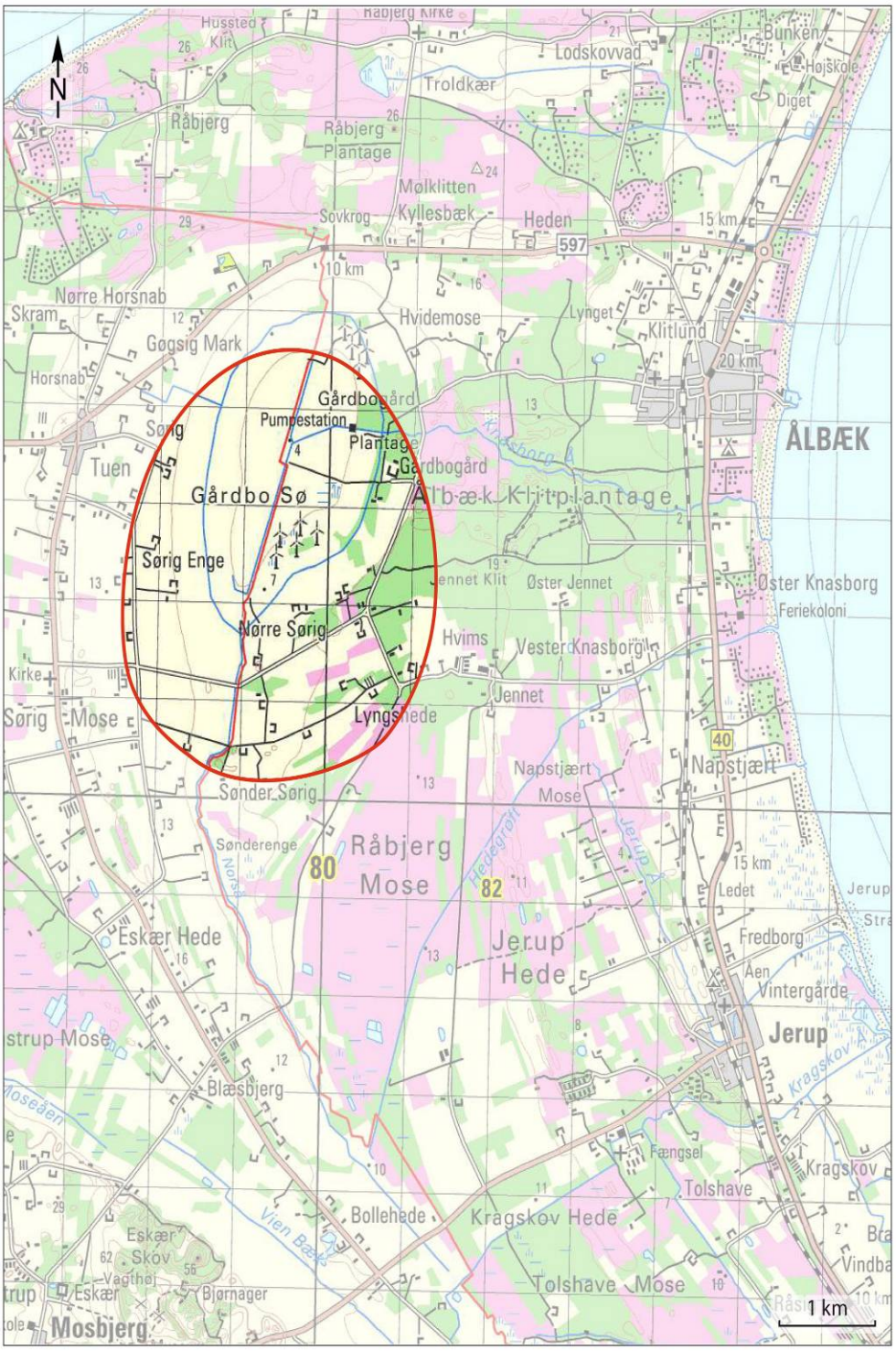


Figure 2. Detailed map of area 22. Area 22 is located between Tuen and Ålbæk klitplantage around Gårdbo Sø.

5.2 Terrain, topography and surface processes

The area is located in the northern part of Jylland, in the proximal/south part of the large spit complex, Skagen Odde. The size of the area is c. 12.6 km^2. The area includes a major part of the drained dune/lagoon, Gårdbo Sø and the surrounding areas west, east and south of the drained lagoon. Therefore, it is a level and relatively low-lying area. The central part, the ground in the former lagoon, is situated c. 4 m above sea level (m.a.s.). Toward south-west and south-east, the landscabe gently raises to levels of 10 m.a.s or a little more. The stream Knasborg Å is located in the north-eastern part of the area. Channels and a pumping station keep the central area dry. No lakes are found in the area.

The predominant part of the area is used for agriculture. Some 10-15 % is covered by dune plantation and heath. Few minor roads are located toward the south, west and eastern parts of the area. Scattered houses are located along the roads. A cluster of wind mills is found in the central part of the area.

Owing to the low relief, the cultivation and plantation, the surface processes (soil creep, frost – thaw processes, soil development etc.) proceed slowly and undramatic.

A minor area toward south-east is included in an area of National Geological Interest (no. 3).

5.3 Surface geology and profiles

The surface geology is dominated by Quaternary deposits. The deposits mainly consist of Holocene marine sand and clay, over large areas covered by Holocene freshwater deposits and Aeolian sand. Part of the area is build up as curved beach ridges and swells (Fig. 3).

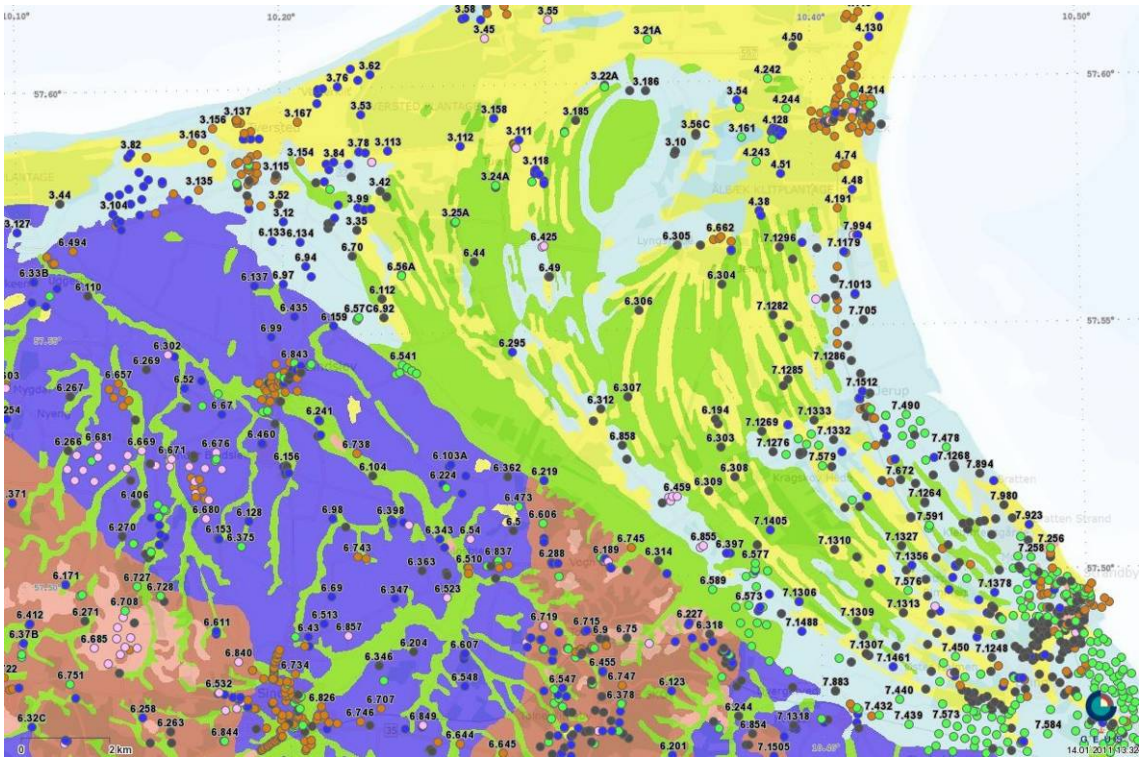


Figure 3. Maps of the Quaternary deposits (From GEUS Homepage, after Pedersen, 1989). The legend for the boreholes: See fig. 4. Legend: Brown: Clayey till; Light brown: Sandy till; Purple: Marine Late glacial deposits; Light blue: Marine Holocene deposits; Green: Holocene freshwater deposits; Yellow: Holocene aeolian sand.

5.4 Boreholes

The area is penetrated by many boreholes. The drilling methods normally produce fair samples of the Quaternary sediments.

Within the map area (Fig. 3 and 4), several boreholes have been investigated and sediment cores and ditch samples are described lithological and related to lithostratigraphical units. Moreover, many samples also are dated by biostratigraphy and OSL-datings.

More than 1000 relatively deep boreholes have been drilled for methane gas exploration and gas has been exploited some years in the mid 1900 in the large Frederikshavn area.

Geophysical surveys are mainly conducted in relation underlying layers but TEM is used for mapping of the surface layers.

Several wells are drilled for supply of 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 in shallow depth.

Only few boreholes have been drilled in Area 22 but results from the boreholes outside the area have been included in this preliminary investigation.

The locations of the boreholes in the area are seen in fig. 4.

Examples of borehole logs are found in figs. 5 and 6. One of the deepest boreholes in the area, DGU no. 6.30 (Fig. 5) can be compared with a 235 m deep borehole outside the area at Åsted, DGU no. 10.934 (Fig. 6).This relatively new borehole is demonstrating the Quaternary succession in the Vendsyssel area based on detailed sample investigations.

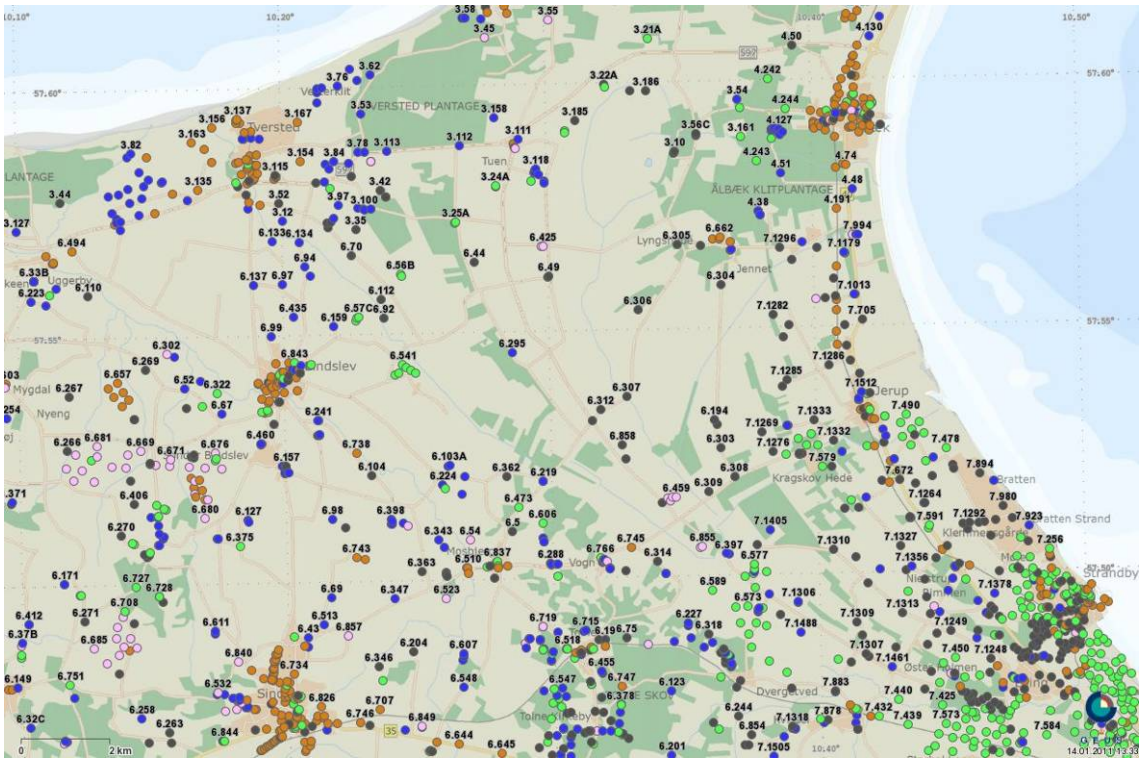
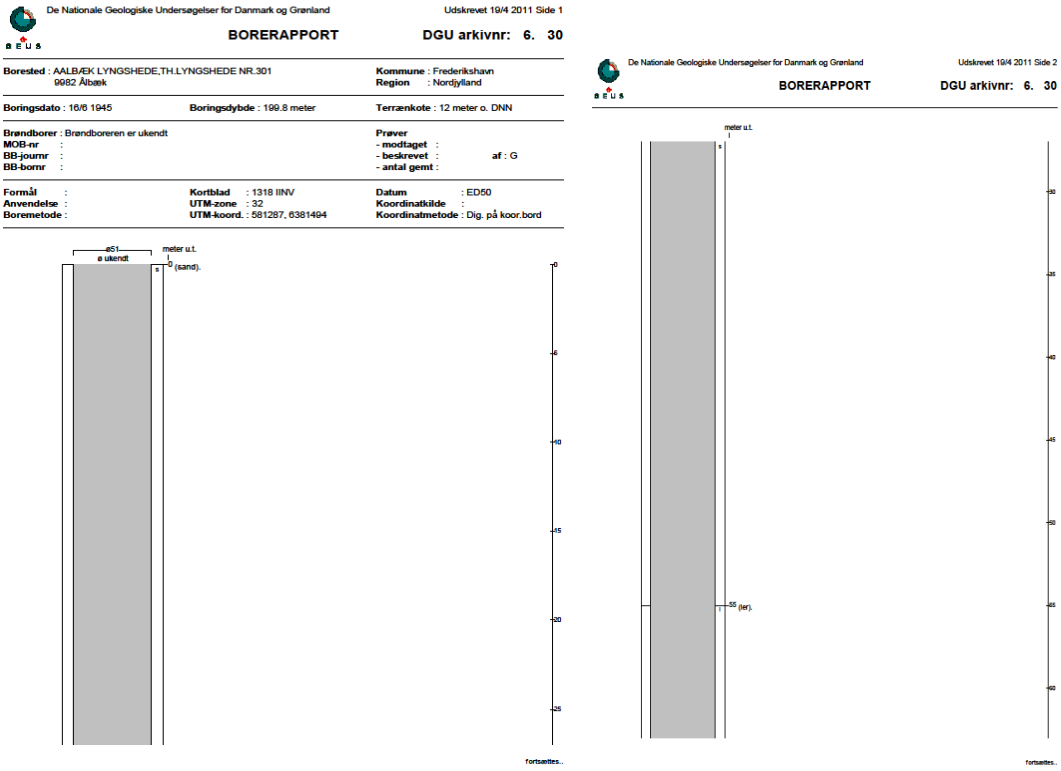


Figure 4. Map of the locations of boreholes from the Jupiter Database at GEUS.
Legend: 6. 30: DGU no.; Blue dot: Water supply well; Red dot: Geotechnical borehole; Pink dot: Raw material borehole; Green dot: Other borehole; Light red dot: Abandoned borehole; Black dot: Unknown purpose.


De Nationale Geologiske Undersøgelser for Danmark og Grønland

Udskrevet 19/4 2011 Side 1

BORERAPPORT **DGU arkivnr: 6. 30**

Borested : AALBÆK LYNGSHEDE,TH.LYNGSHEDE NR.301
9982 Ålbæk

Kommune : Frederikshavn
Region : Nordjylland

Boringsdato : 16/6 1945 **Boringsdybde** : 199.8 meter **Terrænkote** : 12 meter o. DNN

Brøndborer : Brøndboreren er ukendt
MOB-nr :
BB-journr :
BB-bornr :

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

Formål :
Anvendelse :
Boremetode :

Kortblad : 1318 IINV
UTM-zone : 32
UTM-koord. : 581287, 6381494

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

ø51
ø ukendt
meter u.t.
0
(sand).
0
5
10
15
20
25
fortsættes..

De Nationale Geologiske Undersøgelser for Danmark og Grønland

Udskrevet 19/4 2011 Side 2

BORERAPPORT **DGU arkivnr: 6. 30**

meter u.t.
55
(ler).
30
35
40
45
50
55
60
fortsættes..

Figure 5. Example of borehole log from DGU no. 6.30. The upper approx. 135 m of the 199.8 m deep borehole. The log covers three pages. Legend: yg: Late Glacial marine deposits, dl: meltwater clay and silt, ds: meltwater sand and gravel, ql: marine interglacial clay, qs: Interglacial sand deposits, s: sand, l: clay, v: small layers.

BORERAPPORT **DGU arkivnr: 6. 30**

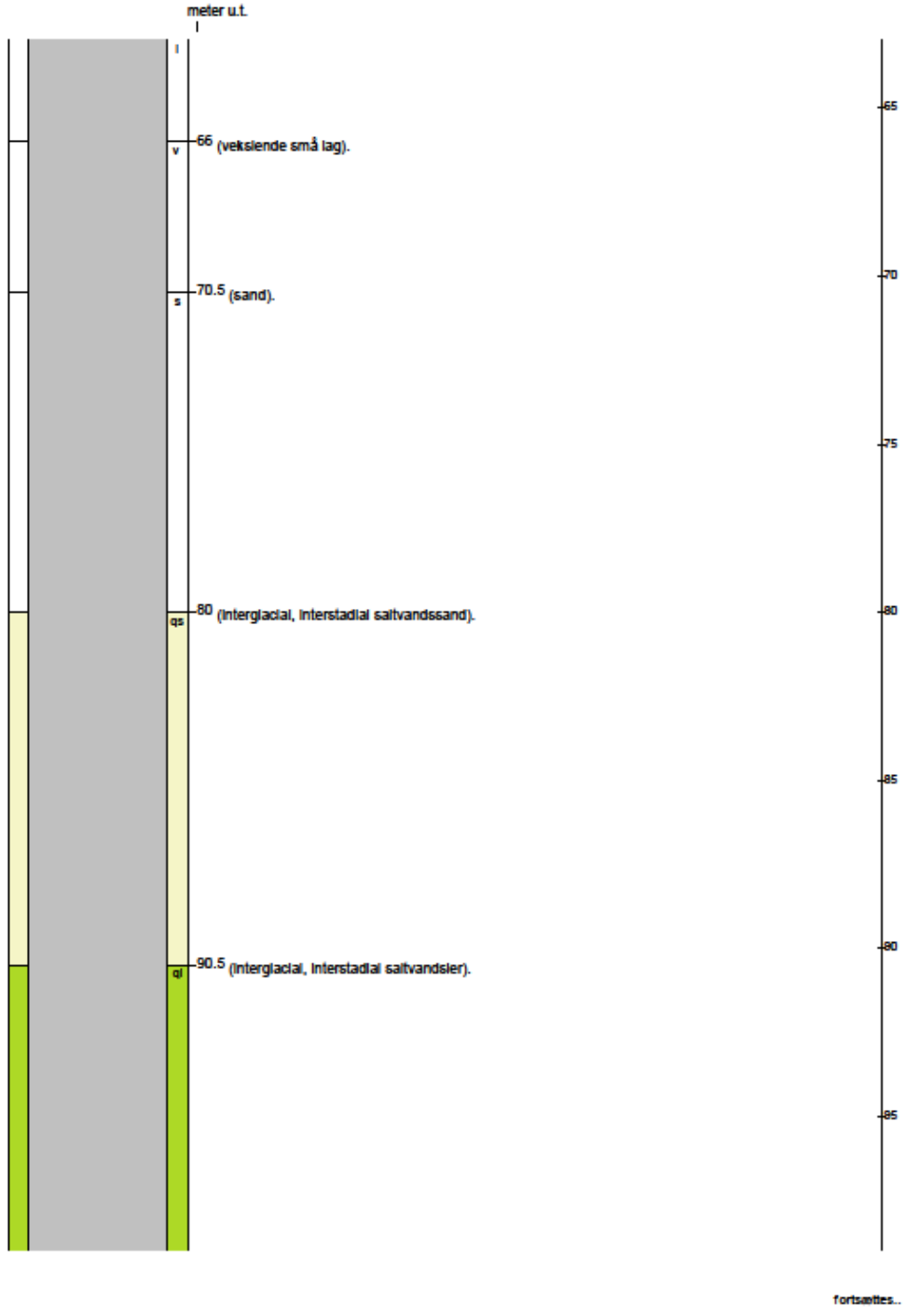


Figure 5. Continued.

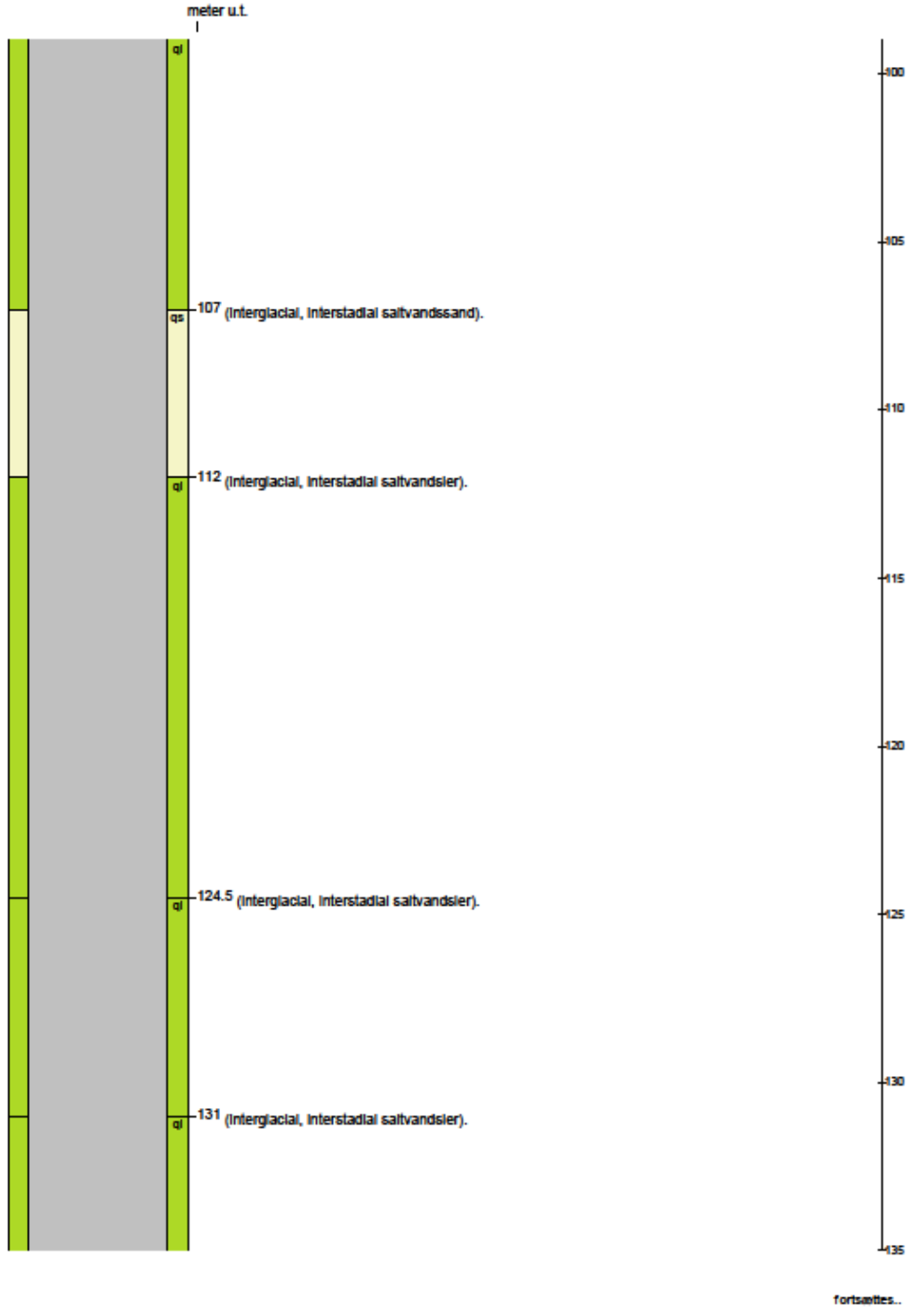


Figure 5. Continued.

De Nationale Geologiske Undersøgelser for Danmark og Grønland — Udskrevet 31/1 2011 Side 1

BORERAPPORT — **DGU arkivnr: 10. 934**

Borested : Lille Håbendal, Lendunven 106, Åsted
9900 Frederikshavn
3a åsted vest

Kommune : Frederikshavn
Region : Nordjylland

Boringsdato : 1/7 2005 — **Boringsdybde** : 235 meter — **Terrænkote** : 62,3 meter o. DNN

Brøndborer : A. Højfeldt A/S
MOB-nr :
BB-journr :
BB-bornr : B1 åsted

Prøver
- **modtaget** : 16/8 2005 **antal** : 235
- **beskrevet** : 13/12 2006 **af** : TC
- **antal gemt** : 13

Formål : Undersøg./videnskab
Anvendelse : Sløjfet/opgivet bor
Boremetode : Sugeboring

Kortblad : 1317 IVNØ
UTM-zone : 32
UTM-koord. : 582547, 6366418

Datum : WGS84
Koordinatkilde : Brøndborer
Koordinatmetode : GPS

		Ro-vandstand	Pejledato	Ydelse	Sænkning	Pumpetid
Indtag 1	(seneste)	30,02 meter u.t.	11/10 2006			
	(første)	31,04 meter u.t.	8/7 2005			
Indtag 2	(seneste)	30,83 meter u.t.	20/2 2006			
	(første)	26,68 meter u.t.	8/7 2005			

Notater : Filter 2 bevares.

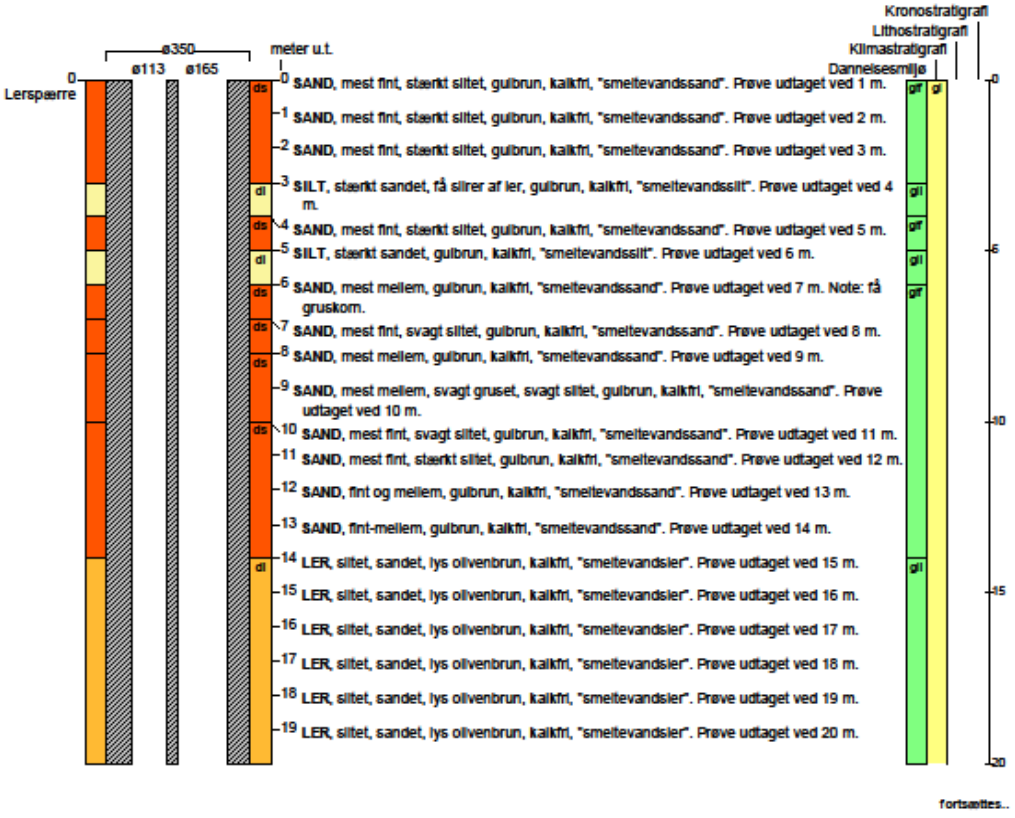


Figure 6. Borehole log from DGU no. 10.934. The log covers four pages. Upper 117 m of the 235 m deep borehole. Legend: dl: meltwater clay and silt, ds: meltwater sand and gravel, ql: Interglacial clay, qs: Interglacial sand.

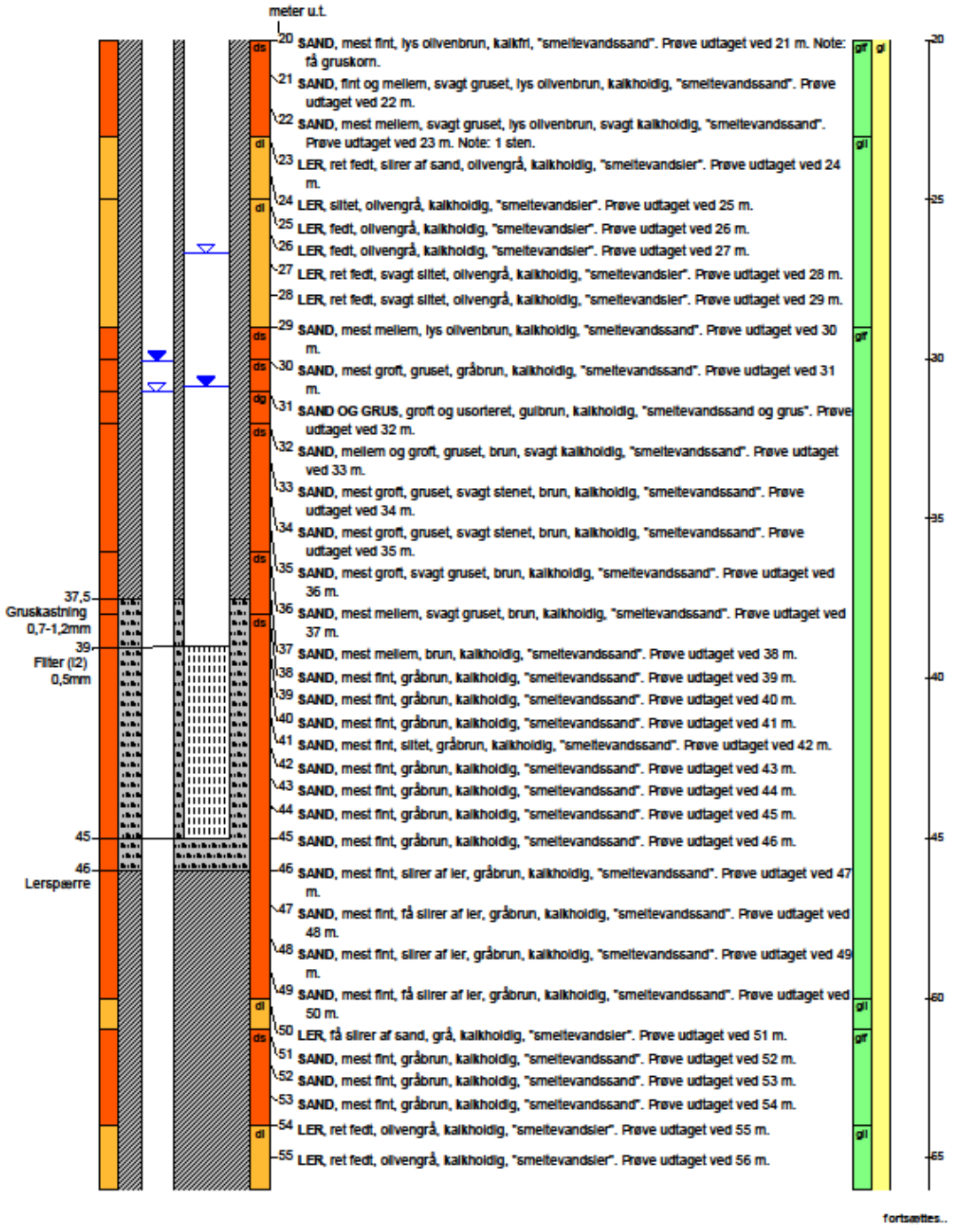


Figure 6. Continued.

BORERAPPORT **DGU arkivnr: 10. 934**

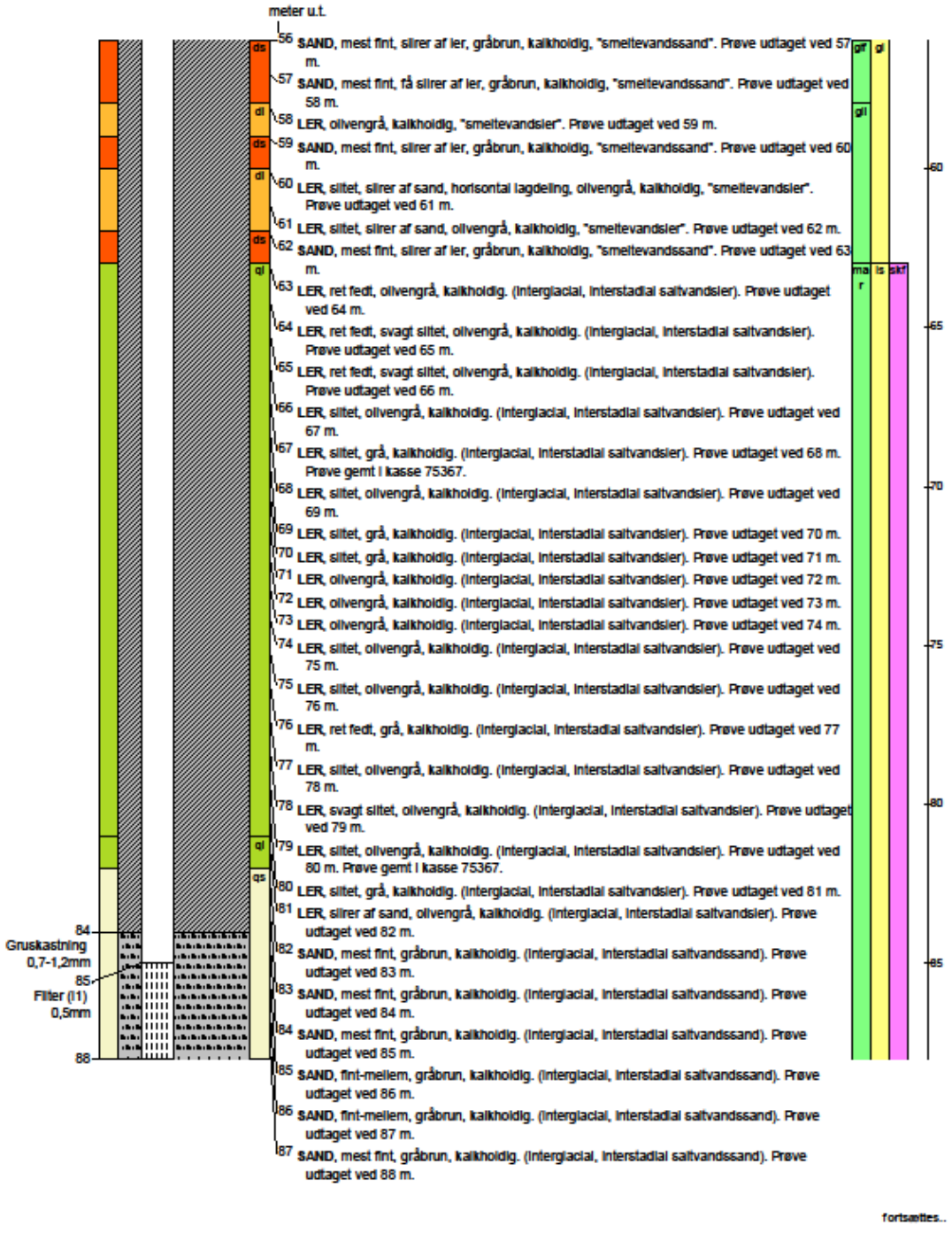


Figure 6. Continued.

BORERAPPORT **DGU arkivnr: 10. 934**

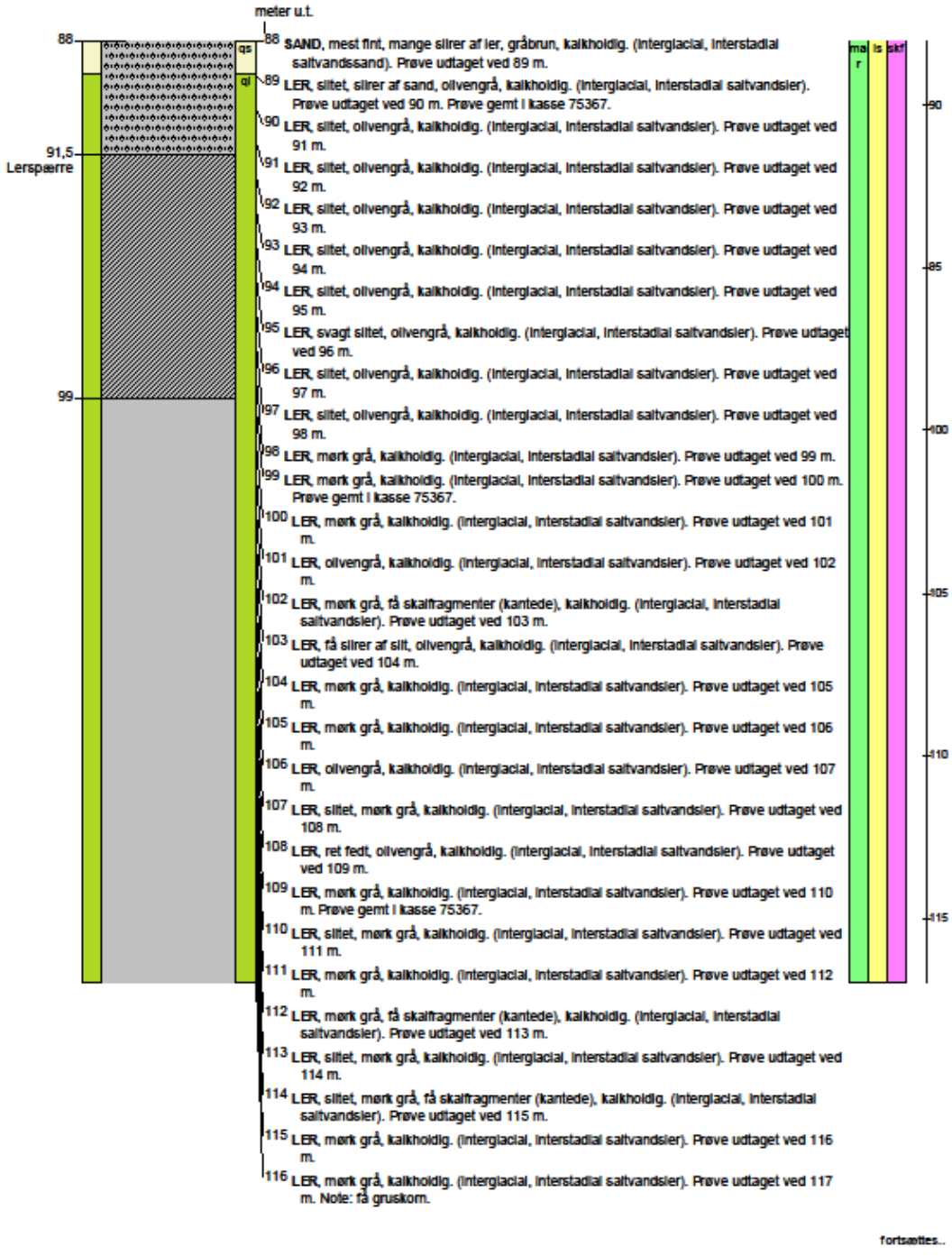


Figure 6. Continued.

5.5 Sediment and rock characteristics, mineralogy and chemistry

5.5.1 Pre-Quaternary deposits

The distribution of the pre-Quaternary deposits can be seen in fig. 7.

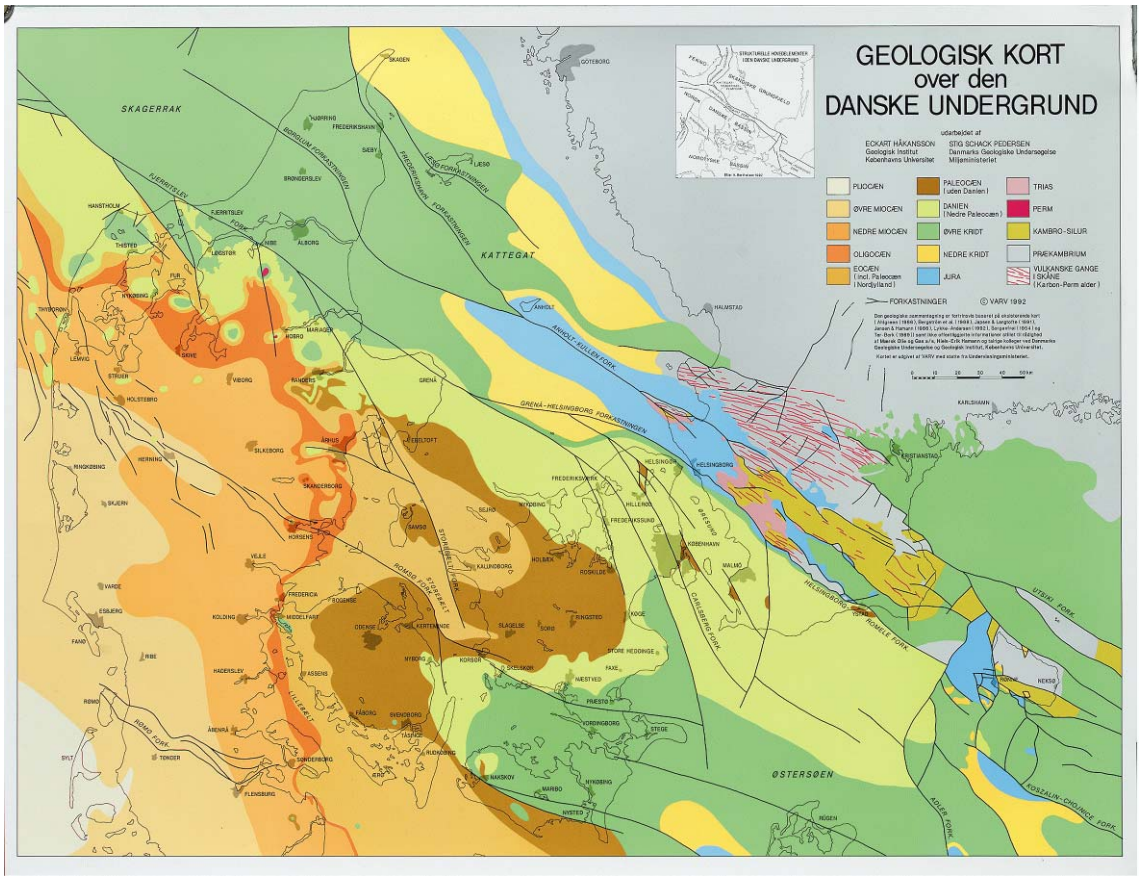


Figure 7. Map of the pre-Quaternary surface: Time units. Original scale: 1:50.000. Legend: Red lines: Precambrian intrusions; Grey: Precambrian; Olive: Cambrian-Silurian; Red: Permian; Light red: Triassic; Blue: Jurassic; Yellow: Lower Cretaceous; Green: Upper Cretaceous; Light green: Danian; Brown: Paleocene; Yellow olive: Eocene; Red brown: Oligocene; Light yellow brown: Lower Miocene; Very light yellow brown: Upper Miocene; White: Pliocene (Håkansson & Pedersen, 1992).

It is expected that the sediments on the pre-Quaternary surface are from the Maastrictian but only few boreholes reach the pre-Quaternary deposits as the Quaternary deposits are thick in Nordjylland/Vendsyssel (Fig. 8).

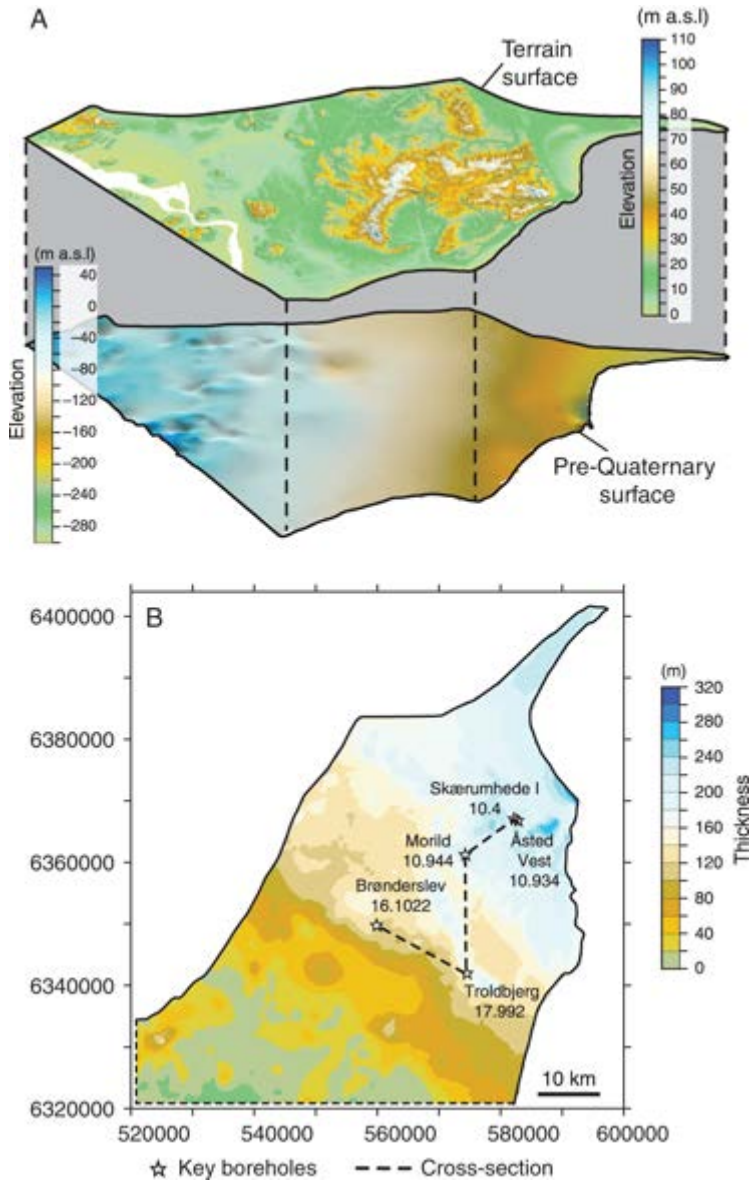


Figure 8. Vendsyssel A. Bloc diagram showing the elevation of the present surface and the pre-Quaternary surface. B. Map of the thickness of the pre-Quaternary deposits (From Larsen et al., 2009a).

5.5.2 Quaternary deposits

The distribution of the Quaternary sediments is seen in figs. 3 and 9.

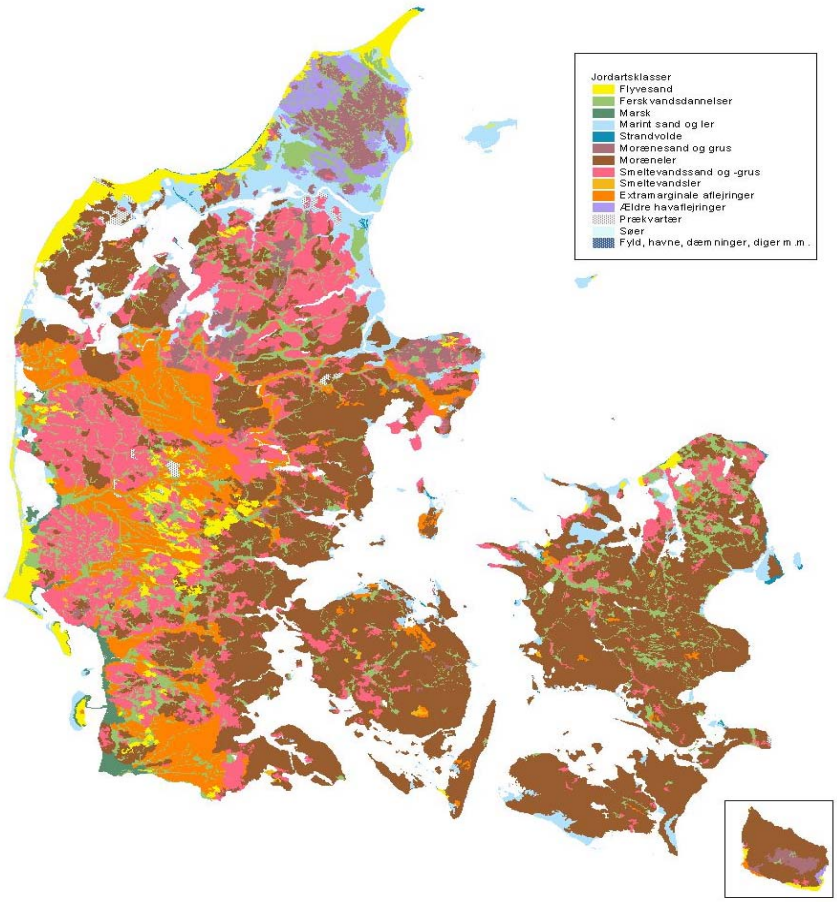
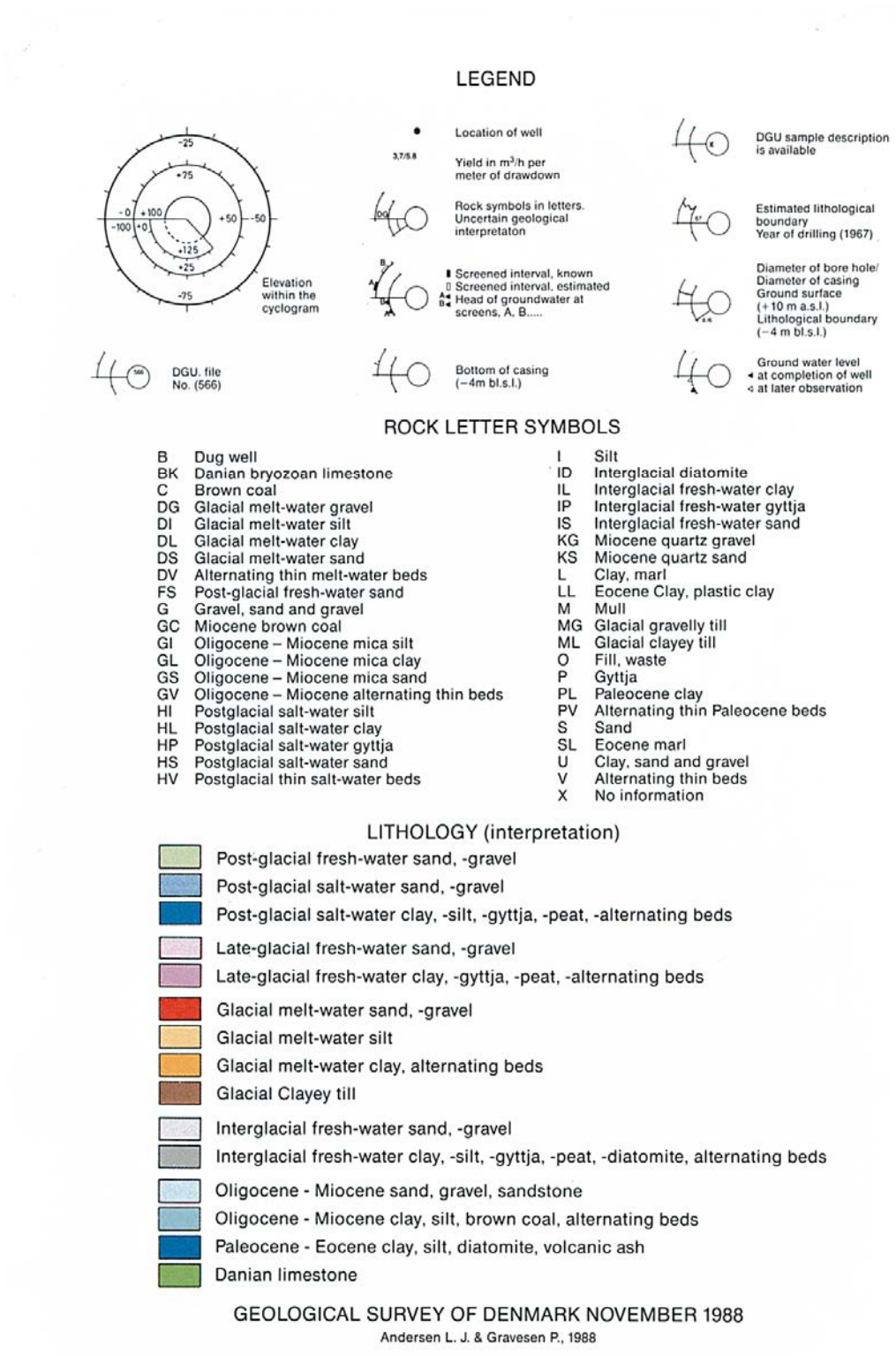
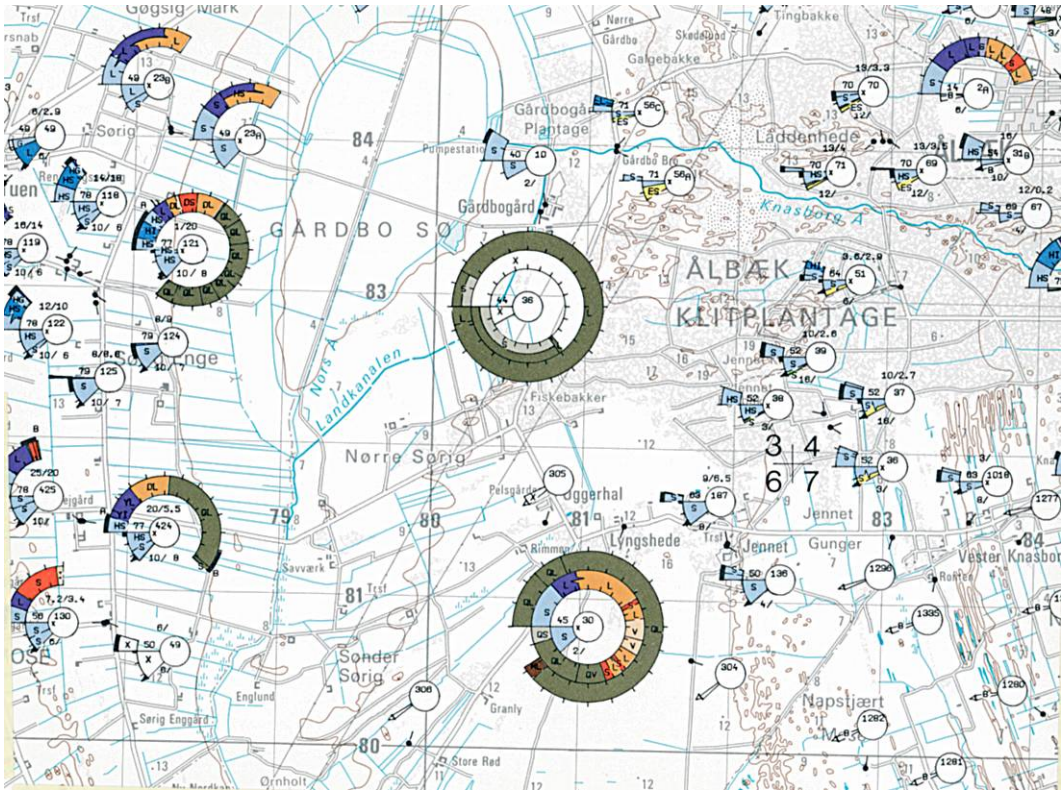


Figure 9. Map of the Quaternary surface deposits. Original scale: 1:200.000. Legend: Brown: Clayey till; Light brown: Sandy till; Red: Meltwater sand and gravel; Orange: Sandur sand and gravel; Purple: Late glacial marine deposits; Light blue: Holocene marine deposits; Green: Holocene freshwater deposits; Yellow: Aeolian sand (From Pedersen, 1989).

The Geological Basic Data maps of the area and the surroundings demonstrate the thick Quaternary sequence of the area (Fig. 10). The deposits are at least 200 m thick.


LEGEND
-25
+75
+100
+50
-50
-100
+0
+125
+25
-75
Elevation within the cyclogram
Location of well
3,7/5,8
Yield in m³/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
Estimated lithological boundary
Year of drilling (1967)
Diameter of bore hole/
Diameter of casing
Ground surface
(+10 m a.s.l.)
Lithological boundary
(−4 m bl.s.l.)
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
BK Danian bryozoan limestone
C Brown coal
DG Glacial melt-water gravel
DI Glacial melt-water silt
DL Glacial melt-water clay
DS Glacial melt-water sand
DV Alternating thin melt-water beds
FS Post-glacial fresh-water sand
G Gravel, sand and gravel
GC Miocene brown coal
GI Oligocene – Miocene mica silt
GL Oligocene – Miocene mica clay
GS Oligocene – Miocene mica sand
GV Oligocene – Miocene alternating thin beds
HI Postglacial salt-water silt
HL Postglacial salt-water clay
HP Postglacial salt-water gyttja
HS Postglacial salt-water sand
HV Postglacial thin salt-water beds
I Silt
ID Interglacial diatomite
IL Interglacial fresh-water clay
IP Interglacial fresh-water gyttja
IS Interglacial fresh-water sand
KG Miocene quartz gravel
KS Miocene quartz sand
L Clay, marl
LL Eocene Clay, plastic clay
M Mull
MG Glacial gravelly till
ML Glacial clayey till
O Fill, waste
P Gyttja
PL Paleocene clay
PV Alternating thin Paleocene beds
S Sand
SL Eocene marl
U Clay, sand and gravel
V Alternating thin beds
X No information
LITHOLOGY (interpretation)
Post-glacial fresh-water sand, -gravel
Post-glacial salt-water sand, -gravel
Post-glacial salt-water clay, -silt, -gyttja, -peat, -alternating beds
Late-glacial fresh-water sand, -gravel
Late-glacial fresh-water clay, -gyttja, -peat, -alternating beds
Glacial melt-water sand, -gravel
Glacial melt-water silt
Glacial melt-water clay, alternating beds
Glacial Clayey till
Interglacial fresh-water sand, -gravel
Interglacial fresh-water clay, -silt, -gyttja, -peat, -diatomite, alternating beds
Oligocene - Miocene sand, gravel, sandstone
Oligocene - Miocene clay, silt, brown coal, alternating beds
Paleocene - Eocene clay, silt, diatomite, volcanic ash
Danian limestone
GEOLOGICAL SURVEY OF DENMARK NOVEMBER 1988
Andersen L. J. & Gravesen P., 1988

a.



b.

Figure 10. Geological Basic Data map. a. Legend to the map (From Andersen & Gravesen, 1989), b. Part of Geological Basic Data Map 1318 I Skagen + 1318 II Frederikshavn. Original scale 1:50.000 (From Fredericia, 1982).

A stratigraphical scheme of the Quaternary deposits in Vendsyssel is found in fig. 11.

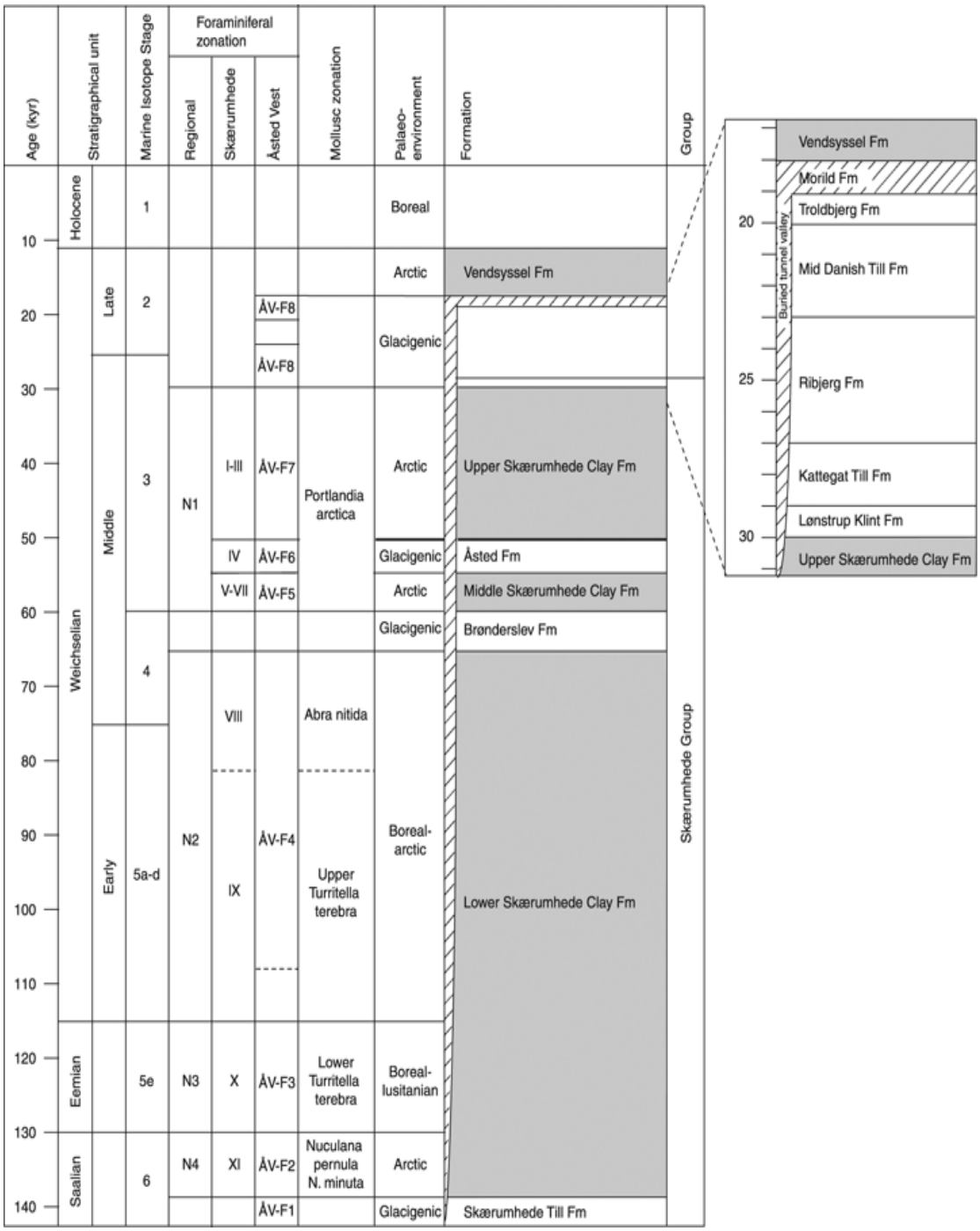


Figure 11. Stratigraphic scheme of the Vendsyssel Quaternary deposits (From Larsen et al., 2009a).

Based on investigation of lithology and fossils of the sediment samples and gamma logs from many of the boreholes combined with structural surveys of coastal cliffs, it has been possible to establish a detailed stratigraphy for the Quaternary deposits down to the Maastrictian chalk for the Vendsyssel area. The up to 250 m thick deposits comprise successions from the Saalian, Eemian, Weichselian and Holocene.

The units are as follows:

Skærumhede Till Formation: Grey clayey till with few pebbles and boulders. Between 2-12 m thick. Late Saalian, Warthe.

Lower Skærumhede Clay Formation: Marine silty clay with thin laminae of fine-grained sand. Thickness 45-80 m. Late Saalian, Eemian, Early Weichselian to Middle Weichselian.

Brønderslev Formation: Subdivided: Brønderslev Till Member: Grey brown sandy till, up to 37 m thick. Brønderslev Clay Member: 5-15 m fine-medium grained sand is found in the bottom and towards the top is up to 75 m glaciolacustrine olive brown silty clay. Middle Weichselian.

Middle Skærumhede Clay Formation: Dark grey marine clay with thin laminae of silt and fine-grained sand and dropstones. 5-15 m thick. Middle Weichselian.

Åsted Formation: Dark grey fine-grained clayey diamict (till) and silty clay with sand and gravel. Thickness 7-17 m. Middle Weichselian.

Upper Skærumhede Clay Formation (Stortorn Formation, informal name: Older Yoldia Clay): Dark grey to black structureless marine clay with a small content of gravel (Fig. 12). Up to 14 m thick. Middle Weichselian.

Figure 12. Marine dark grey to black clay with shells from the Stortorn Formation (Older Yoldia Clay). Marine Weichselian 32,000 years BP (From Pedersen, 2005).

Lønstrup Klint Formation: Glaciolacustrine blue grey laminated silty clay with ice-dropped gravel and stones and fine-grained sand. Between 15 and 35 m thick. Middle Weichselian (Figs. 13 and 14).

Four Late Weichselian formations are present in the area.

Ribjerg Formation: Glaciolacustrine fine-medium grained sand and grey laminated silt and clay. Between 7 and 55 m thick. Covers most of Vendsyssel.

Figure 13. Meltwater clay formed in a glaciolaustrine environment form the Lønstup Klint Formation. The clays are part of thrust fault imbrications, Lønstrup Klint (Pedersen, 2005).

Figure 14. Lønstrup Klint Formation. Meltwater Clay. Lønstrup Klint.

Troldbjerg Formation: Glaciolacustrine medium to coarse-grained sand with pebbles. 2 - 30 m thick.

Morild Formation: Two members: First member consists of 1 - 5 m thick silty clay and sand. Second member consists of up to 70 m thick fine to coarse-grained sand or silty clay. The sediments are filled into tunnel valleys.

Vendsyssel Formation: The formation consists of Late Weichselian sandy sediments including the marine sand and clay layers of Lower Saxicava sand, the Yoldia clay, the Upper Saxicava sand and the Zirphaea beds. The Vendsyssel Formation covers large areas of Vendsyssel.

Holocene cover: Towards the north, the Skagen Odde spit has developed during the last 8000 years and it is still growing. The dominant surface cover sediment of the area is Holocene marine sand, Holocene freshwater deposits and Holocene aeolian sand which in the low areas covers all the older deposits (Figs. 3 and 9). The aeolian sand forms dunes from 5 to 15 m thick.

Within the Area 22, the borehole DGU no. 6.30 demonstrates the following units: Skærumhede Till Formation, Lower and Middle Skærumhede Formations, Lønstrup Klint Formation, Vendsyssel Formation and Holocene deposits (Fig. 15, see also fig. 19)

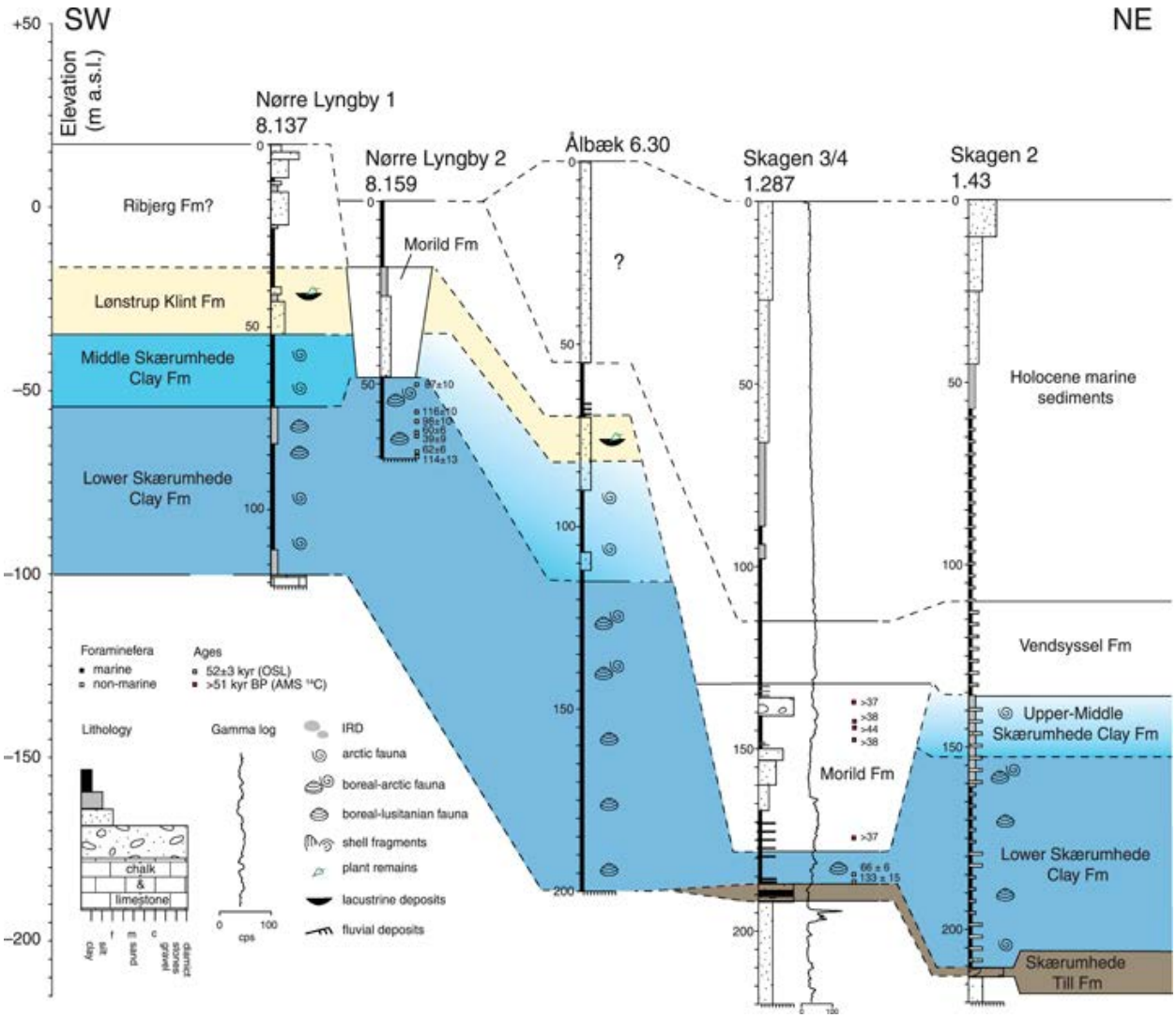


Figure 15. Geological cross section with lithostratigraphical subdivision from Nørre Lyngby (south-west) to Skagen (north-east). The section crosses the area at DGU no. 6.30 (From Larsen et al. 2009b).

Methane gas

The Quaternary deposits contain methane-rich gas in variable amounts. From 1932 to the period between the two World Wars, the gas was exploited in the Frederikshavn area. The exploitation was mainly based on investigations performed some years before. The most important areas were situated north of Frederikshavn up to Strandby, the Ravnshøj area east of Knivsholt and an area north of the Ravnshøj area (Fig. 16). These areas were mapped in relation to the gas source based on more than 1150 boreholes of which at least

450 boreholes contained gas. Boreholes outside these areas could also contain gas as in the well known Skærumhede I and II boreholes. The origin of the gas has been much debated but it is most likely generated by degradation of organic material within the marine Quaternary deposits. The gas is found in restricted sand and gravel layers in the clays just below or above the salt/freshwater boundary and mainly in two zones (level -160 m to -180 m and level -70 m to -120 m). The lower zone consisting of coastal deposits, situated between Frederikshavn and Strandby, is found 0 - 20 m below the glacial landscape from the Saalian. The upper zone is an erosion rest from uplifted parts of the Skærumhede Series. Therefore, the gas is present where tectonic movements have occurred.

Area 22 is situated north of the main gas prone area but as the deposits and formations have the same composition as the deposits in the Frederikshavn area, gas in the deposits cannot be excluded.

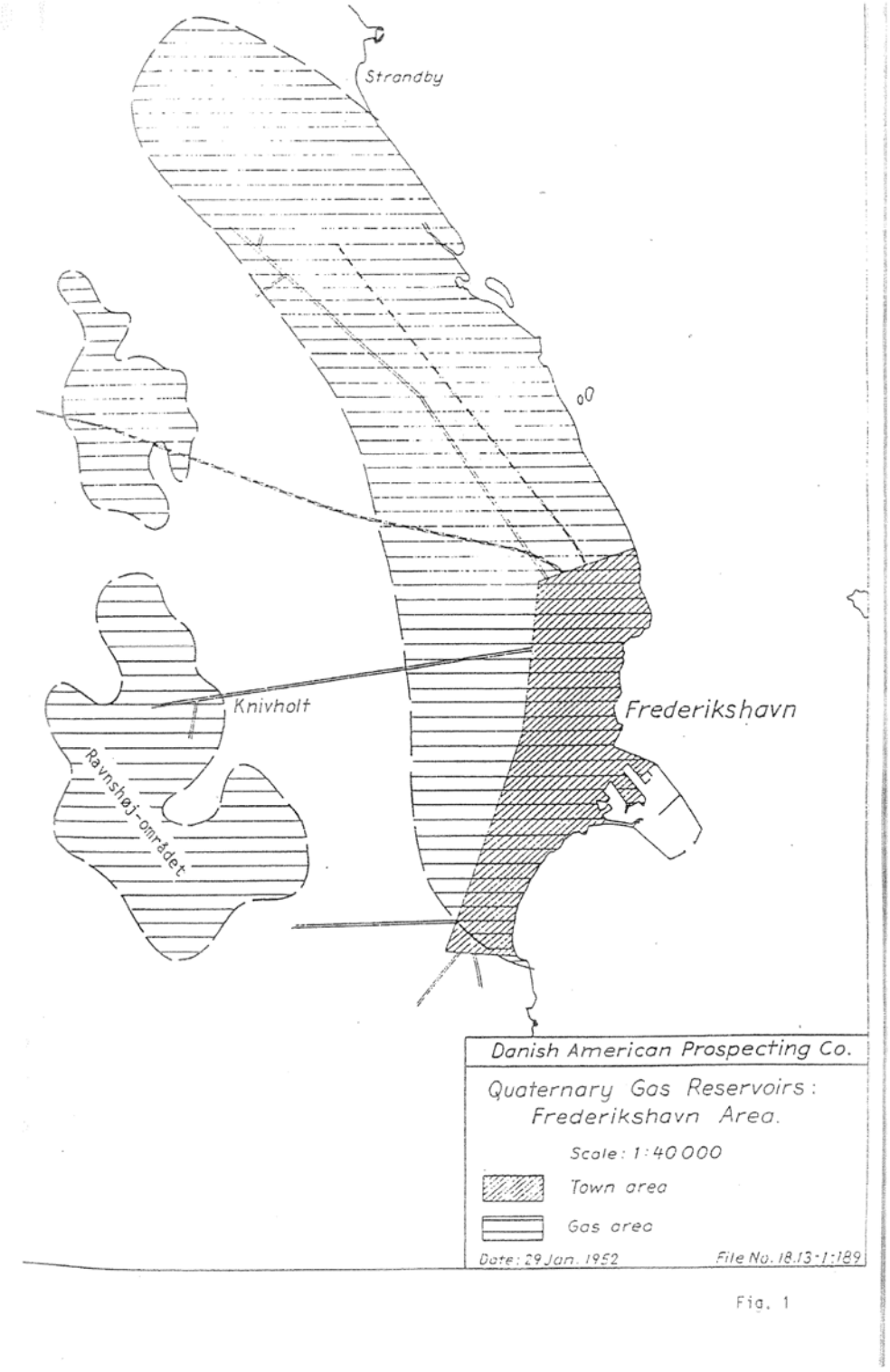


Figure 16. Map of the gas occurrences in the Quaternary deposits at the Frederikshavn-Strandby areas (From Dapco, 1952).

5.6 Tectonics, structures and seismic activity

5.6.1 Major tectonic structures

According to the map (Fig. 7), the deep laying pre-Quaternary surface in the area is cut by at least two major fault zones: the south-westernmost Børglum Fault and the north-easternmost Frederikshavn Fault. At the northernmost tip of Skagen, a third fault zone is present. The three faults are a part of the Sorgenfrei-Tornquest zone fault system. Some indications points to tectonic movements (earthquakes) in the fault zones.

The occurrence of gas in the deposits has been interpreted as caused by tectonic features. The Quaternary deposits seem in many areas to be disturbed by glaciotectonic movements and deformations as indicated by structures in coastal cliffs and by the borehole data. Dislocations have been identified in the Tuen area.

A geological section from south of the area can be seen in fig. 17. The two sections in fig. 15 and 17 show the difference in the level of the Maastrichtian chalk with more than 100 m in difference, probably caused by fault activities and severe erosion.

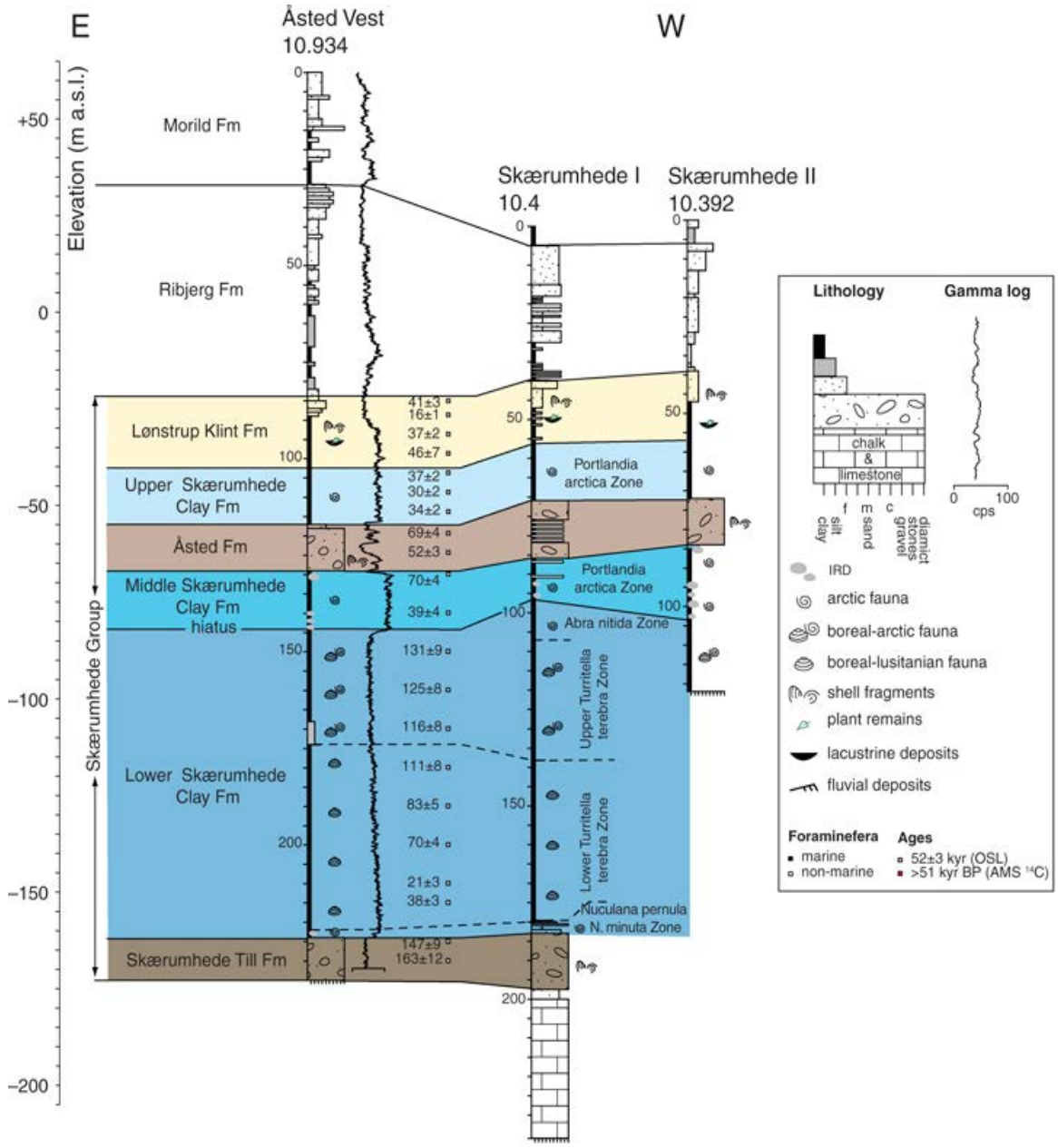


Figure 17. Geological cross section with lithostratigraphical subdivision from Åsted (east) to Skærumhede (west). (From Larsen et al, 2009a).

Geophysical surveys and borehole data have demonstrated a network of buried tunnel valleys formed in the Late Weichselian during fast melting at minor re-advances in the overall recession of the ice sheet. Four generations of N-S valleys and five generations of E-W valleys are mapped. The valleys mainly seem to be located outside the Area 22 but some influence of the valley systems may be important for the southern part of the area (Fig. 18).

A deep valley has also been demonstrated north of the area, cut down by rivers into the marine deposits during the Late Weichselian (Fig. 15).

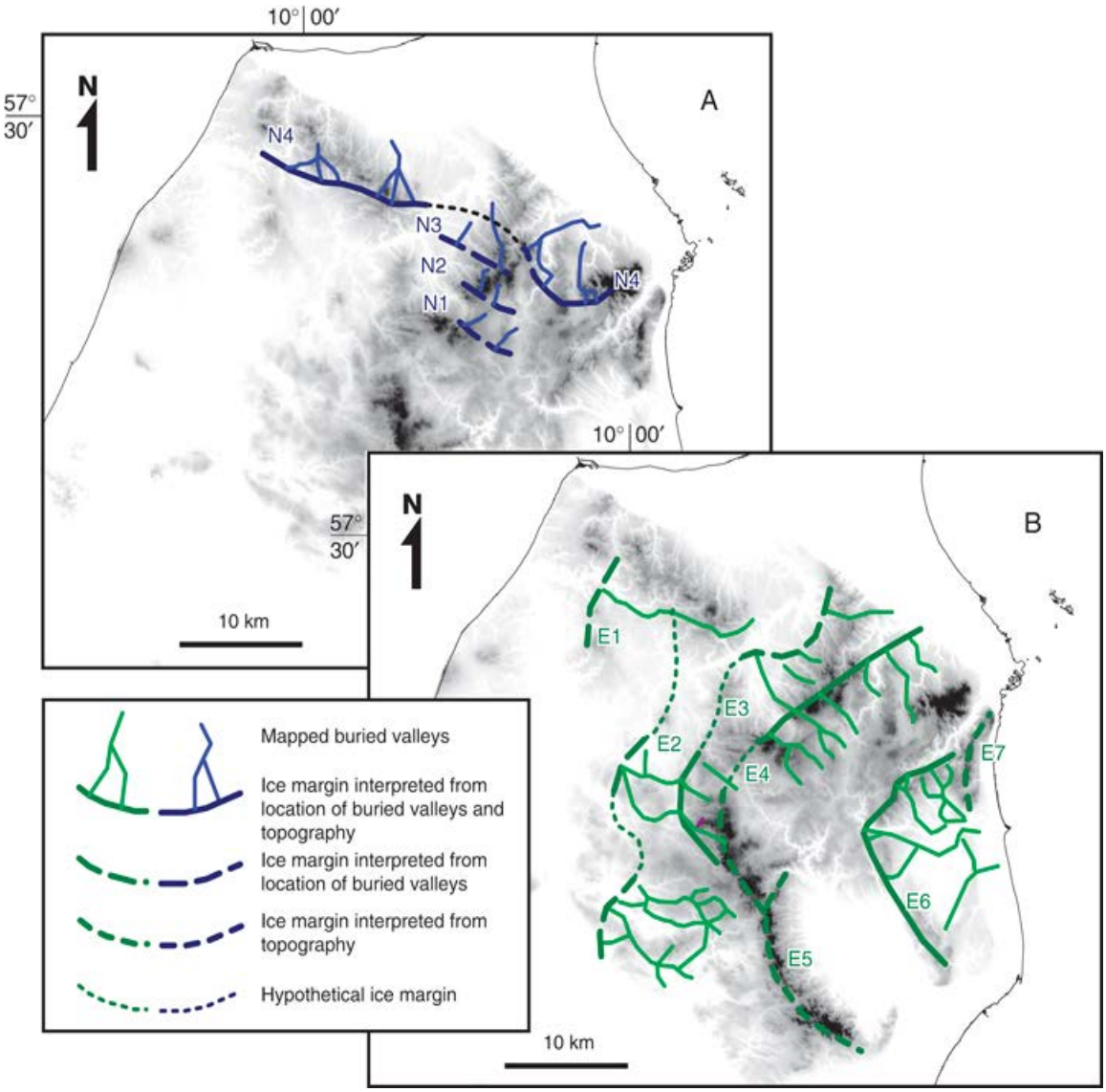


Figure 18. Buried tunnel valleys in Vendsyssel (From Sandersen et al., 2009).

Towards the south, the raised shorelines from Late Weichselian (level + 65 m) and Holocene (level + 15 m) are a result of the isostatic rebound after melting of the Weichselian glaciers. The Area 22, situated north of these, is part of a basin where changing isostatic and eustatic activities have caused an accumulation of thick sequences of sediments.

5.6.2 Fractures

There is no information from the boreholes. From the cliff sections, many fractures in the clayey tills and fine-grained meltwater and marine clays have been recognized (see figs. 12 and 13).

5.6.3 Geological model

The geological model of the area is rather simple concerning lithology and structural conditions.

Model of the area is as follows (Fig. 19):

A. Holocene marine, freshwater and aeolian deposits up to 50 m thick

B. Late Weichselian marine sand and clay from Vendsyssel Formation. Approx. 15 m thick.

C. Middle Weichselian, Lønstrup Klint Formation: Meltwater clay, silt, sand and gravel. Up to 15 m thick.

D. Middle Weichselian, Upper to Middle Skærumhede Clay Formation: Marine clays and tills. Up to 40 m thick.

E. Late Saalian to Middle Weichselian Lower Skærumhede Clay Formation: Marine clays. Up to 80 m thick.

F. Late Saalian Skærumhede Till Formation: Clayey till. Thin.

G. Maastrichtian chalk

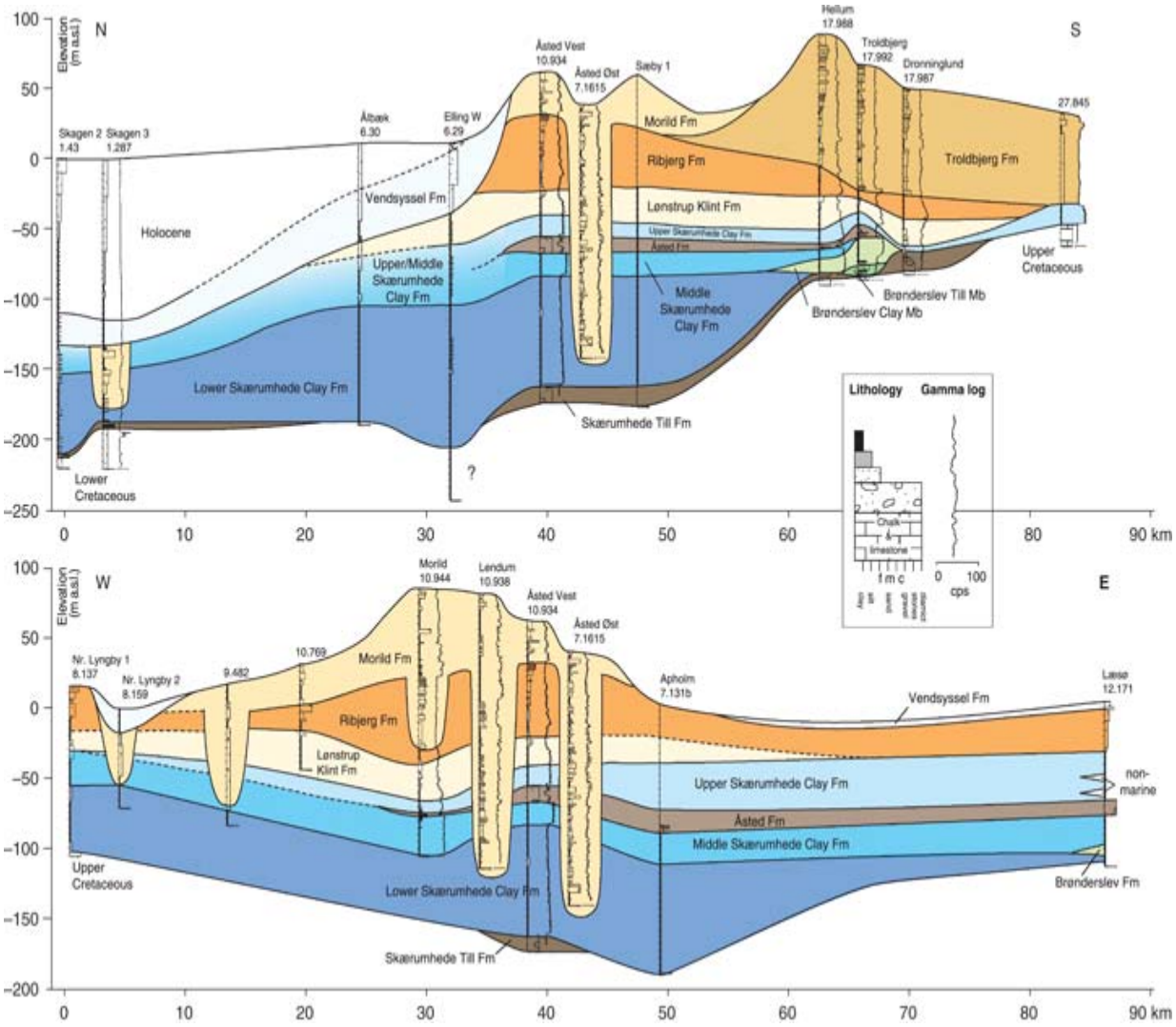


Figure 19. Geological cross sections with lithostratigraphical subdivision. The upper cross section from Skagen (north) to Dronninglund (south) is crossing the area at Ålbæk-Elling-Åsted. (From Knudsen et al., 2009).

5.6.4 Earthquake activity

The seismic station net in Denmark is runned 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 earth quake activity is measured with respect to location, time and size. The activity in Denmark is very low compared to many other countries during the period 1929-2003.

The seismic activity in the Nordjylland area is relatively low (Fig. 20). Some seismic activity has been registered near the Area 22 and at Frederikshavn and Skagen. Abundant activity is known from Kattegat and Skagerrak, mainly within the Fenno-Scandian Border Zone.

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

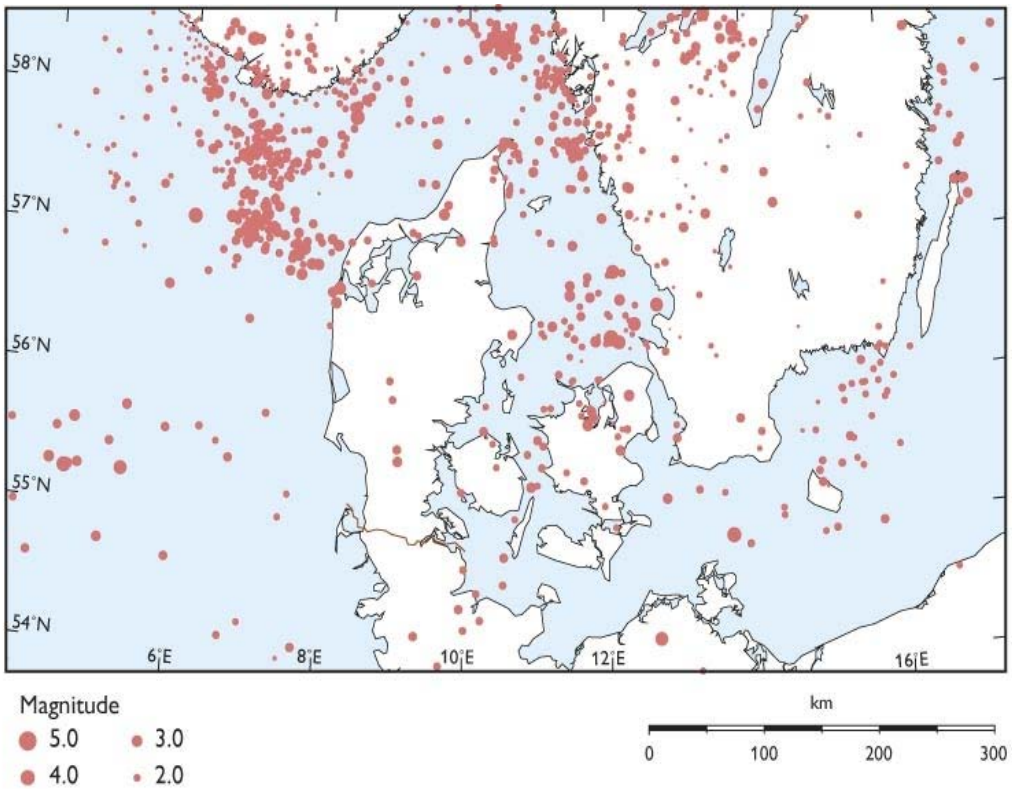


Figure 20. Map of the earthquake epicentres in Denmark and surrounding areas. A red dot shows the location and size in the Richter scale (From Larsen et al., 2008).

5.7 Ground stability

The stability of the area is considered as very good. The methane gas can cause instability e.g. in relation to fire accidents.

5.8 Groundwater hydrogeology

5.8.1 Groundwater characteristics

The Ålbæk area is located as shown in figs. 2 and 21. Area 22 is characterized by presence of more shallow groundwater bodies (GWB) directly within area 22 (DK1.1.1.2) or nearby area 22 (DK1.1.1.1; DK1.1.1.5) (Fig. 22). South of Area 22, regional (DK 1.1.2.1) and deep (DK1.1.3.2) groundwater bodies (Fig. 23 and 24) are situated. The relevant shal-

low groundwater bodies all consist of meltwater sand deposits. The subdivision into groundwater aquifers/bodies are thoroughly described in the basisanalysis (Basisanalysis Part 1, 2004) in by the former Nordjylland county. In addition, the Limfjorden catchment management plan (Hovedvandopland 1.1 Nordlige Kattegat and Skagerak) 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 GWB (all good). (See Section 5.9).

Figure 21. Location of the Ålbæk area (Area 22).

Figure 22. Ålbæk – shallow groundwater bodies (After Ministry of Environment, 2010).

Figure 23. Ålbæk – nearby regional groundwater bodies (After Ministry of Environment, 2010).

Figure 24. Ålbæk – Nearby deep groundwater body (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 present and future pollution.

As part of the Danish Government´s efforts to protect groundwater, the Environmental Centres have designated areas of major groundwater aquifers, so-called OSD-areas. OSD stands for "Areas of special drinking water interests" (Fig. 25).

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.

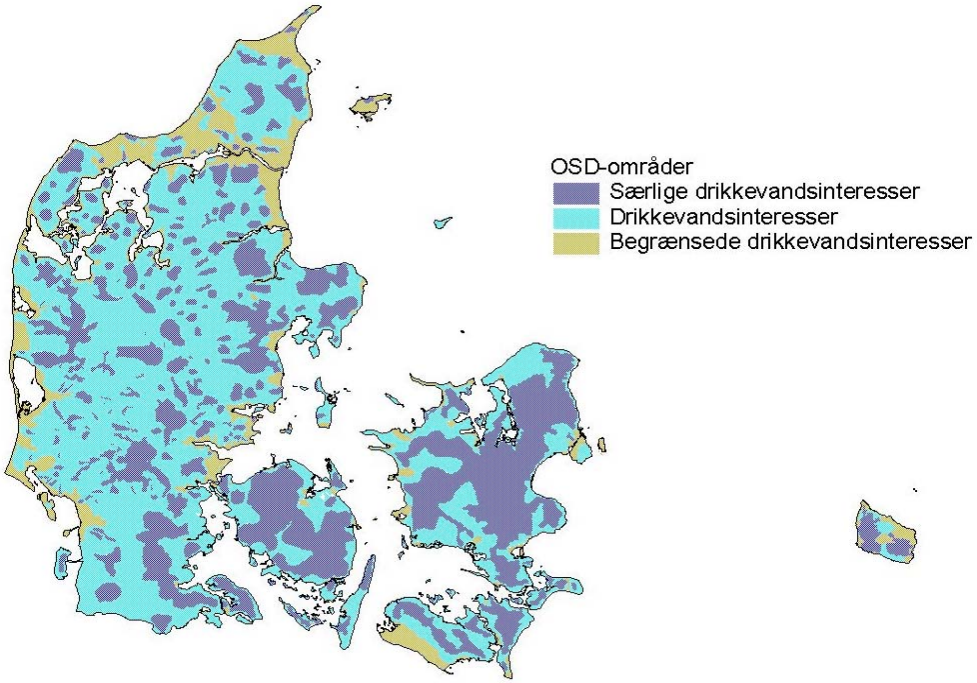


Figure 25. Areas of special drinking water interests (OSD): Dark blue and areas of drikning water interest (OD): Light blue. Areas of limited or no drinking water interests: olive.

The geographical distribution of the drinking water areas in the northern part of Nordjylland is given in figs. 26 and 27. The Ålbæk area is within an area with limited or no groundwater interests. There is a relatively high number of irrigation wells located in Area 22, and in the eastern part of Area 22, a well field for drinking water abstraction to the Ålbæk water work

is situated. Chloride has been detected in the range of 45 – 65 mg Cl/L in the Ålbæk water work wells.

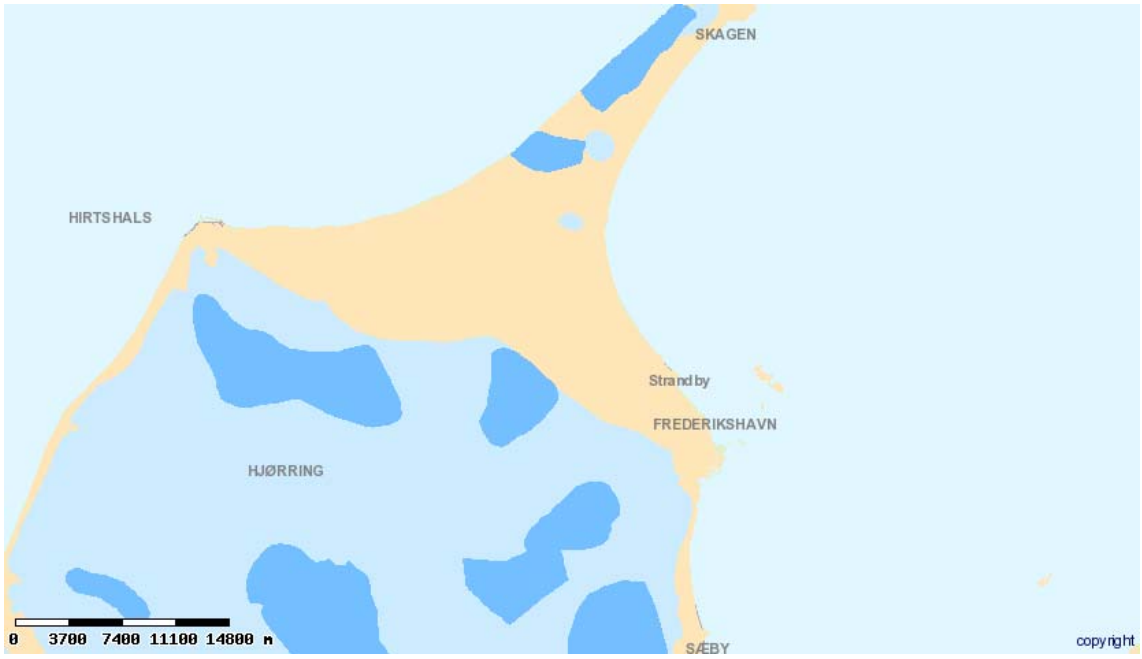


Figure 26. Map of the drinking areas in Area 22. Legend: see fig. 25. (http://kort.arealinfo.dk/).

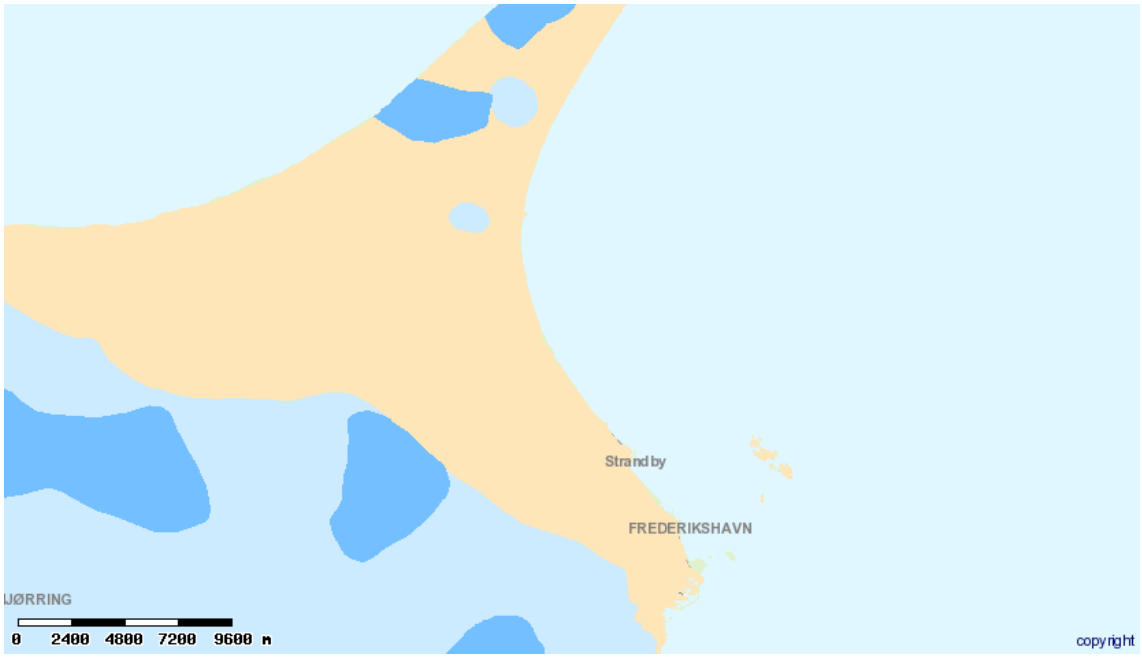


Figure 27. Distribution of the drinking water areas in the Ålbæk-Åsted area (Area 22). Dark Blue: Areas of special drinking water interests (OSD); Light blue: Areas of some drinking water interests (OD); Yellow: Areas with limited or none drinking water interests. (http://kort.arealinfo.dk/)

5.9 Groundwater chemistry

The overall groundwater quality aiming for drinking water purpose has been assessed by the Environmental Centre Aalborg in the catchment management plan “Hovedvandopland 1.1 Nordlige Skagerak og Kattegat“. The shallow groundwater bodies have water quality problems caused by impact from nutrients (nitrate). No saltwater intrusion problems have been reported in relation to the relevant groundwater bodies in Area 22. Chloride has been detected in the range of 45 - 65 mg Cl/L in the Ålbæk water work wells. The terrain surface range between 5 m and more than 15 m above present sea level within Area 22, thus no significant changes in the fresh/saltwater interface is expected to happen due to future sea level rise (climate change).

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 the predicted climate changes, including sea level rise, will cause any problems to the area during this century.

5.11 Restrictions and limitations

There are no NATURA 2000 habitat areas directly located within Area 22 (Fig. 28). However, just south of the area, a classified NATURA 2000 area is situated. In addition, other protected areas in accordance to the Naturbeskyttelseslov (law for nature protection) (Chapter 6) are located both south and north of Area 22.

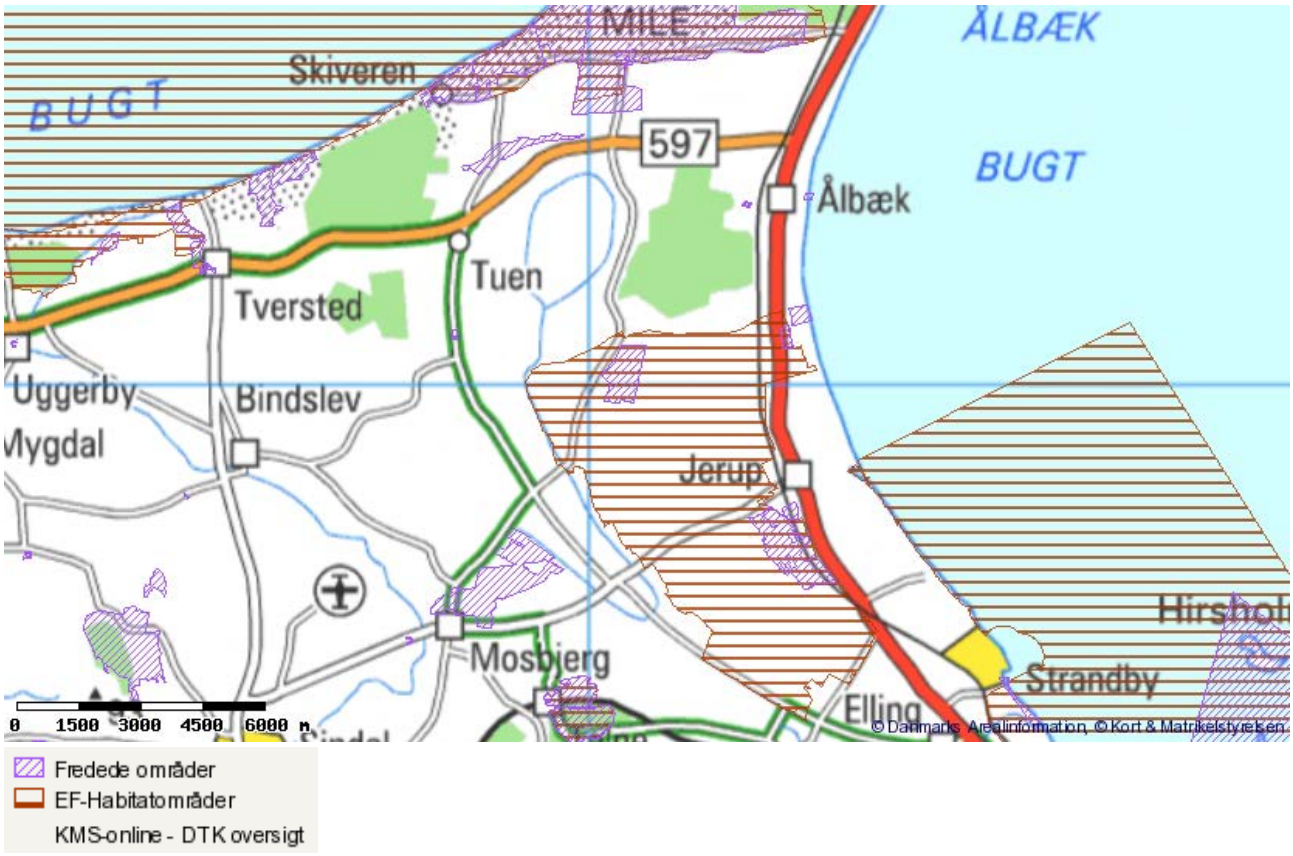


Figure 28. Ålbæk area – NATURA2000 habitat areas and other protected areas in accordance to Naturbeskyttelsesloven (Chapter 6).

Some areas of clay, sand and gravel of raw material interest may occur.

5.12 Summary of the area conditions

Amount of data:
Large amount of borehole data in Vendsyssel but few in Area 22. Some geophysical surveys exist.

Homogeneous conditions and isolation of the waste by low, permeability layers:
Perhaps perfect on depth below 40 - 50 m but the framework of fractures below these depths 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
Some seismic activity in the area but no tectonic movements are registered in the Quaterney.

Groundwater conditions

The groundwater flow conditions in clays should be positive but the variation in 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 (east).

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 and OD areas are located in the area as the Area 22 is situated in an area of limited or no drinking water interests. Minor local supplies are present.

Groundwater chemistry, non- aggressive components
The groundwater contains methane gas which apparently can give problems.

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.

5.13 Final Remarks

The thick and relatively homogeneous sequences of clay and silt could be an appropriate host for the disposal although sand and gravel layers are intercalated. The occurrence of methane gas in the groundwater and sediments will probably be the largest problem.

6. 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.

7. References/Literature

Andersen, L.J. & Gravesen, P., 1989: Cyclogram Maps in the Interpretation of Pumping Test. Recent Advances in Hydrology. American Institute of Hydrology, 598-604.

Andersen, S.A., 1941: Naturgassen ved Frederikshavn. Naturhistorisk Tidende 1941, 70-74.

Andersen, S.A., 1948: Naturgassen ved Frederikshavn. Erhvervsliv 1941 nr. 3, 475-477.

Andersen, S.A., 1961: Geologisk fører over Vendsyssel. Historisk Samfund for Hjørring Amt. Populært Videnskabeligt forlag, 207 pages.

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

Bahnson, H., Petersen, K.S., Konradi, P.B. & Knudsen, K.L., 1974: Stratigraphy of the Quaternary deposits in the Skærumhede II boring: Lithology, mollucs and foraminifera. Danm. Geol. Unders. Årbog 1973, 27-62.

Binzer, K. & Stockmarr, J., 1994: Geologisk kort over Danmark 1:500.000. Kvartæroverfladens højdeforhold. Danm. Geol. Unders. Kortserie Nr. 44, 3-10 + map.

Bonnesen, E., Larsen, F., Sonnenborg, T.O., Klitten, K. & Stemmerik, L., 2009: Deep saltwater in Chalk of North-West Europe: Origin, interface characteristics and development over geological time. Hydrogeology Journal 17, 1643-1663.

Brettmann, K.L., Jensen, K.H. & Jakobsen, R., 1993: Tracer Test in Fractured Chalk 2. Numerical Analysis. Nordic Hydrology 24, 275-296.

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

Dapco, Danish American Prospecting Company Co., 1952: Quaternary Gas Reservoirs: Frederikshavn area.

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

Dreyer-Jørgensen, K.,1945: Frederikshavn-Strandby Gasområdets Geologi. Naturens Verden, 11-32.

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

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

Fredericia, J.,1982: Geologisk basisdatakort 1318 I Skagen + 1318 II Frederikshavn. Nordjyllands amtskommue, Danm. Geol. Unders.

Fredericia, J., 1984: Geologisk basisdatakort 1317 I + IV Brønderslev. Nordjyllands amtskommune. Danm. Geol. Unders.

Fredericia, J. 1988: Den Hydrogeologiske kortlægning af Nordjyllands Amt. Geologisk rapport. Forvaltningen for teknik og miljø. Miljøkontoret, feb, 1989, 231 pages + appendices.

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

Fredericia, J. & Grambo-Rasmussen, A., 1985: Kortlægning af kvartære gasfund I Vendsyssel, Fase 2, Bind 1 og Bind 2, 126 pages.

Frykman, P., 2001: Spatial variability in petrophysical properties in Upper Maastrichtian chalk outcrops at Stevns Klint, Denmark. Marine and Petroleum Geology 18, 1041-1062.

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

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

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

Hancock, J.M., 1975: The petrology of the Chalk. Proc. Geol. Assoc. 86, 499-535.

Hansen, J.M. & Håkansson, E., 1980: Thistedstrukturens geologi – et "neotektonisk" skoleeksempel. – Dansk geologisk Forening, Årsskrift for 1979, 1-9.

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

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

Houimark- Nielsen, M., 1989: The Last Interglacial-Glacial cycle in Denmark. Quaternary International Vols. 3/4, 31-39.

Houmark-Nielsen, M. & Kjær, K.H., 2003: Southwest Scandinavia, 40-15 kyr BP: palaeogeography and environmental change. J. of Quaternary Science, Vol. 18, 769-786.

Håkansson, E., Bromley, R. & Perch-Nielsen, K., 1974: Maastrichtian chalk of North-west Europe – a pelagic shelf sediment. IAS Special Publication no. 1, 211-233.

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

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

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

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

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

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

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

Jensen, J.B., 1985: Sen-Elster smeltevandsler – en mulig ledehorisont i det vestlige Jylland. Dansk Geol. Forening, Årsskrift for 1984, 21-35.

Jessen, A., 1899: Kortbladene Skagen, Hirtshals, Frederikshavn, Hjørring og Løkken. Danm. Geol. Unders., Series I no. 3, 368 pages.

Jessen, A., 1918: Vendsyssels Geologi. Danm. Geol. Unders., Series V, no. 2, 260 pages.

Jessen, A., 1936: Vensyssels Geologi. 2 Udgave. Danm.Geol. Undrs. Series V, no. 2, 195 pages.

Jessen, A., Milthers, V., Nordmann, V., Hartz, N. & Hesselbo, A.: 1910: En boring gennem de kvartære lag ved Skærumhede. Danm. Geol. Unders. Series II, no.25, 175 pages.

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

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

Jørgensen, N.O., Laier, T., Buchardt, B. & Cederberg, T., 1990: Shallow hydrocarbon gas in the northern Jutland-Kattegat region, Denmark. Bull. Geol. Soc. Denm. Vol. 38, 69-76.

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

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

Knudsen, K.L., 1984: Foraminiferal stratigraphy in the marine Eemian-Weichselian sequence at Apholm, North Jutland, Bull, Geol. Soc. Denmark, Vol. 32, 169-180.

Knudsen, K.L., 1985: Correlation of Saalian, Eemian and Weichselian foraminiferal zones in North Jutland, Bull. Geol. Soc. Denmark, Vol. 33, 325-339.

Knudsen, K.L. & Lykke-Andersen, A.-L., 1982: Foraminifera in Late Saalian, Eemian, Early and Middle Weichselian of the Skærumhede I boring. Bull. Geol. Soc. Denmark, Vol. 33, 97-109.

Knudsen, K.L., Kristensen, P. & Larsen, N.K., 2009: Marine glacial and interglacial stratigraphy in Vendsyssel, northern Denmark: foraminifera and stable isotopes. Boreas Vol. 38, 787-810.

Kristensen, P., Knudsen, K.L., Lykke-Andersen, H., Nørmark, E., Peacock, J.D. & Sinnott, A., 1998: Interglacial and Glacial oscillations in a marine shelf sequence from northern Denmark – a multidisciplinary study. Quaternary Science Review, Vol. 17, page 813-837

Krohn, C.F., Larsen, N.K., Kronborg, C., Nielsen, O.B. & Knudsen, K.L., 2009: Litho- and chronostratigraphy of the Late Weichselian in Vendsyssel, northern Denmark, with special emphasis on tunnel-valley infill in relation to a receding ice margin. Boreas Vo. 38, 811-833.

Larsen, N.K., Knudsen, K.L., Krohn, C.F., Kronborg, C., Murray, A.S. & Nielsen, O.B., 2009a: Late Quaternary ice sheet, lake and sea history of southwest Scandinavia – a synthesis. Boreas Vol. 38, 732-761.

Larsen, N.K., Krohn, C.F., Kronborg, C. Nielsen, O.B. & Knudsen, K.L., 2009b: Lithostratigraphy of the Late Saalian to Middle Weichselian Skærumhede Group in Vendsyssel, northern Denmark. Boreas Vol. 38, 762-786.

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

Larsen, T.B., Gregersen, S., Voss, P.H. & Orozova-Bekkevold, V., 2008: The earthquake that shook central Sjælland, Denmark, November 6, 2001. Bull. Geol. Soc. Denm. Vol. 56, 27-37.

Lykke-Andersen, A.-L., 1990: Marine aflejringer fra Sen Elster på Sjælland. Dansk Geologisk Forening, Årsskrift for 1987-89, 77-80.

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

Lykke-Andersen, H., Knudsen, K.L. & Christiansen, C., 1993: The Quaternary of Kattegat area, Scandinavia: a review. Boreas Vol. 22, 269-281.

Lykke-Andersen, H. & Surlyk, F., 2004: The Cretaceous-Palaeogene boundary at Stevns Klint, Denmark: inversion tectonics or seafloor topography? Journal of the Geological Society, London, 161, 343-352.

Mertz, E.L., 1924: Oversigt over De sen- og postglaciale Niveauforandringer i Danmark.- Danmarks geologiske Undersøgelse II Række , Nr. 41, 49 pages.

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

Miljøministeriet (2010). Forslag til Vandplan 2010-15. Hovedvandopland 1.1Nordlige Kattegat og Skagerak. By- og Landskabsstyrelsen, Miljøministeriet. Hearing version, October 2010 http://www.naturstyrelsen.dk/NR/rdonlyres/A01CEB30-7CE6-4B0A-952C-D179B21BCA1E/114418/11NordligekattegatogSkagerrak_4_oktober_2010.pdf

Ministry of Environment, 2010:http://www.miljoegis.mim.dk

Nielsen, L.H. & Johannesen, P.N., 2001: Accretionary, forced regressive shoreface sands of the Holocene-Recent Skagen Odde spit complex, Denmark – a possible outcrop analogue to fault-attached shoreface sandstone reservoirs. In: Martinsen, O. & Dreyer, T. (eds.). Sedimentary Environments Offshore Norwey – Palaeozoic to Recent. NPF Special Publication 10, page 457-472.

Nordjylland amt (2004). EUs vandrammedirektiv i Nordjylland (Vanddistrikt 80) Basisanalyse, december 2004. http://www.vandognatur.dk/NR/rdonlyres/A53CE1AE-1D24-4824-A529-4F3FC7432D14/0/VD80NordjyllandDel1.pdf

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

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

Pedersen, S.A.S., 2005: Structural analysis of the Rubjerg Knude Glaciotectonic Complex, Vendsyssel, northern Denmark. Bull. Geol. Surv. Denm. Greenl, 8, 192 pages + appendices.

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

Pedersen, P. Chr.,1937: Fiskeeksportør Rasmus Clausen, Strandbygassens pioner. Forlaget Vendsyssel, 64 pages.

Petersen, K.S., 1991: Holocene coastal and faunal development of the Skagen Odde, Northern Jutland, Denmark.- Quaternary International 9, 53-60.

Rasmussen, L.Aa., Bahnson, H., Mikkelsen, N., Nielsen, A.V. & Petersen, K.S., 1979: Om den geologiske kortlægning af Fjendsområdet i 1978. Danm. Geol. Unders. Årbog 1978, 105-118.

Region Nordjylland, 2008: Råstofplan 2008 for Region Nordjylland, 55 pages + maps.

Rosenbom, A.E. & Jakobsen, P.R.: Kalk, sprækker og termografi. Geologi. Nyt fra GEUS nr.3 nov 2000, 2-7.

Rosenbom, A.E. & Jakobsen, P.R., 2005: Infrared Thermography and Fracture Analysis of Preferential Flow in Chalk. Vadose Zone Journal 4, 2, 271-280.

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

Sandersen, P.B. E., Jørgensen, F., Larsen, N.K., Westergaard, J.H. & Auken E., 2009: Rapid tunnel-valley formation beneath the receding Late Weichselian ice sheet in Vendsyssel, Denmark. Boreas Vol. 38, 834-851.

Seidenkrantz, M.-S., Knudsen, K.L. & Kristensen, P., 2000: Marine late Saalian to Eemian environments and climatic variability in the Danish shelf area. Geol. En Mijnb., 79, 335-343.

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

Sejrup, H.P. & Knudsen, K.L., 1999: Geochronology and palaeoenvironment of marine Quaternary deposits in Denmark: new evidence from northern Jutland. Geol. Mag. Vol. 136, page 561-578.

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

Sorgenfrei, Th., 1949: Outline of the gas wells drilled in the Frederikshavn-Strandby area, North Jutland. Internal Dapco-report nr. 62, 5 pages.

Sorgenfrei, Th., 1952: Natural gas in Denmark – Plans for further exploration. Danish American Prospecting Company, Report no. 73, 3 pages.

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

Surlyk, F. & Håkansson, E., 1999: Maastrictian and Danian strata in the southeastern part of the Danish Basin. Excursion A 3. In: IAS Field Trip Guidebook. 19th Regional European Meeting of Sedimentology, August 24-26, 29-58.

Surlyk, F., Damholt, T., Bjergager, M., 2006: Stevns Klint, Denmark: Uppermost Maastrichtian chalk, Cretaceous-Tertiary boundary, and Lower Danian bryozoan mound complex. Bull. Geol. Soc. Denmark, Vol. 54, 1-46.

Ter-Borch, N., 1990: Geologisk kort Danmark. 1:500.000. Kalkoverfladens struktur. Danm. Geol. Unders. Kortserie Nr. 5, 2 pages + map.

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

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

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

Williams, A., Bloomfield, J., Griffith, K. & Butler, A., 2006: Characterising the vertical variations in hydraulic conductivity within the Chalk aquifer, J. Hydr., 330 (1), page 53-62.

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

Ødum, H., 1933: Marint Interglacial på Sjælland. Hven, Møn og Rügen. Danm. Geol. Unders. IV Rk., 2 (10), 44 pages.

Besides the literature cited above geological maps at GEUS have been used: Maps of the geological surface deposits, geological basis data maps showing the geology in shallow wells, maps of the deep seated geology and structures, maps of the pre-Quaternary surface, transmissivity and groundwater potential maps. Also information from GEUS Jupiter database containing data on approx. 250.000 shallow wells has been included (Gravesen et al., 2010).

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