Thyborøn Area

Overview of the geological conditions in the Thyborøn model area.

GeoAtlas Live Documentation
Report 1, 2018-07-12

This report gives a brief overview of the geological setting and conceptual interpretation of the Thyborøn Model Area. The Thyborøn model was interpolated as a 25m grid cell model, in the Thyborøn Harbour area, the Quaternary layers were additionally interpolated in a 1m grid cell version in order to obtain a more detailed model version, the 1m model is described in a separate document.

The pre-Quaternary and quaternary stratigraphy and the structural setting of the area is presented by maps and profiles illustrating the complexity of the area.

The mapped layers in the Thyborøn model are briefly described by occurrence, thickness and sedimentology.

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1 Introduction

This note gives a brief overview of the geology of the Thyborøn model area (25m). All available geological datasets (drillings, geophysics, maps) have been imported into the modelling software GeoScene-3D. The lithological units present in the area were interpreted and correlated on a regional scale based on the depositional history and urban development.

The sedimentary units interpreted in the conceptual geology were setup in the modelling software. The surfaces were interpolated with a 25m cell size in the regional model area. The extend of the model area is illustrated in Figure 1

Figure 1. Extend of the Thyborøn Model Area (25m) extending from Agger in the north to Lemvig in the south and the Thyborøn Harbor model (1m) covering the eastern part of build -up area of Thyborøn and the harbor area.

2 Geological setting and history

2.1 Pre-Quaternary structural geology and deposits

Structurally, the model area is positioned in the Danish Basin along the margin of the Ringkøbing-Fyn High (RFH). The RFH is a structural ridge orientated NV-SE consisting of elevated crystalline bedrock. The margin of this high is marked by a system of subparallel fault lines trending NV-SE that runs straight through the Thyborøn area.

Along this structural system, migration of deep-seated Permian evaporates is triggered by along the fault lines, the evaporates (rock salt) is less dense than the sedimentary strata above and will migrate upwards along the weak zones along the fault lines, migrating close to the surface at Thyborøn.

During the upward migration, the evaporates have transected and up-folded the sedimentary strata superposing it, the salt-tectonic processes in combination with the fault lines transecting the area, have given the elevation of the pre-quaternary sediments in the area, very undulating surface, see Figure 2.

At Thyborøn the only remaining part of up folded strata above the evaporates is a thin cover rock consisting of Cretaceous limestone, that forms the pre-quaternary surface at Thyborøn and Harboøre. In the surrounding area, the pre-quaternary deposits consist of clay and sand deposits of Miocene age.

The deposits forming the pre-quaternary surface in the area are shown in Figure 2.

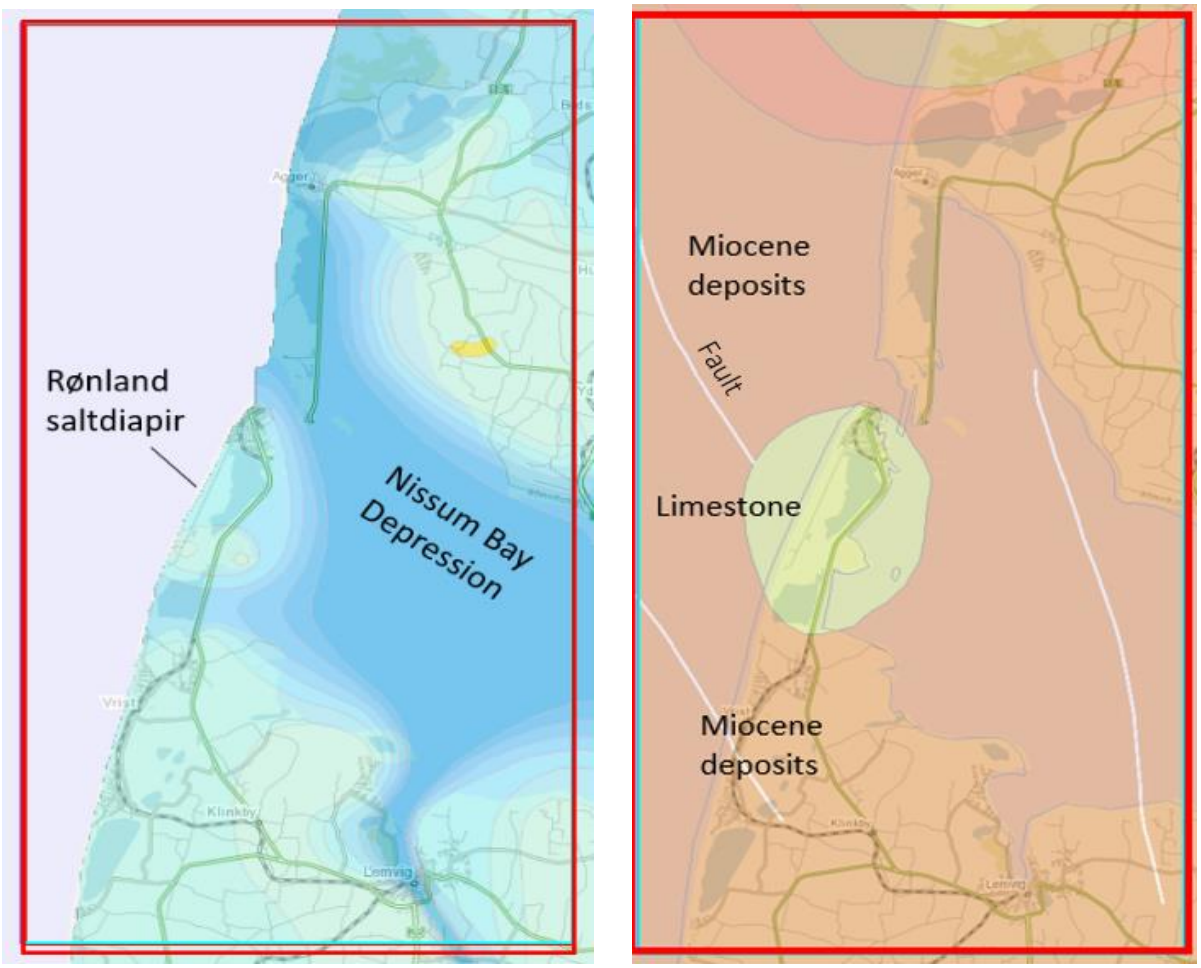

Figure 2. A) Elevation of the pre-Quaternary surface at Thyborøn and surrounding area, blue colors denotes low elevation, green and yellow colors denotes high elevation. Note the Nissum Bay depression and the elevated pre-Quaternary surface at Rønland/Thyborøn. B) Distribution of pre-Quaternary deposits at Thyborøn and surrounding area. The area is dominated by deposits of Miocene age (orange color) but in a circular area in the Thyborøn-Rønland area, the pre-Quaternary subsurface consists of Cretaceous limestone marking the extent of the salt dome. Note the white lines representing fault lines in the area. From /1/

2.2 Permian deposits

The Permian deposits in the area consists of rock-salt (halite) anhydrite, clay and minor sand layers that were deposited in shallow marine basins in an arid, subtropical climate. The evaporation from the basins lead to deposition of salt on the seabed, that to some degree have been interbedded with clay and sand layers.

In the Danish Basin, the evaporates have been buried by younger sediments of EG. Cretaceous and Miocene age. The salt is less dense than the overlying deposits and have been mobilized by later tectonic activity at fault zones, enabling it to migrate upwards creating dome-structures.

2.3 Cretaceous deposits

The Cretaceous Chalk was deposited as skeletal carbonate mud in a marine environment. The Cretaceous Chalk consists of fine-grained skeletons or skeletal fragments of algal coccolithophores with minor silt sized components E.G. bryozoans or marine invertebrates. The chalk is regularly bedded with only minor flint beds.

2.4 Miocene deposits

In the surrounding area, the pre-quaternary geology consists of mica rich clay –and sand deposits of Miocene age. The Miocene deposits represents a period of alternating marine and deltaic/fluvial deposition in the Danish Basin due to tectonic and climatic variation, the clay deposits representing marine sedimentation in a fully marine or near shore environment.

The sand deposits represent deltaic or fluvial deposits prograding into the Danish Basin from the north. Two major deltaic formations are represented in the model area, the Billund -and the Bastrup Formations, the lowermost part of the Miocene deposits is represented by the clay-dominated Vejle Fjord Formation, that makes up the pre-quaternary surface to the north in the model area.

The Miocene deposits are tilted towards the SW due to the general structure of the Danish Basin, in the model area however, the Miocene deposits are influenced by the salt tectonics at Rønland and the deposits have subsided along the margins of the salt structure.

2.5 Quaternary deposits

The Quaternary deposits are represented by two clay tills and four layers of meltwater sand, however additional (minor) Till layers may be present along the margin of the salt diaper.

The two Till layers are interpreted to represent two major glaciations during the Weichelian period, namely from the north (lower Till) and from the northeast (upper Till). The glacial deposits form major ice marginal ridges to the south in the Lemvig area and to the north at Vestervig. The extend of the glacial ice sheets during the Weichelian glaciation is shown in Figure 3

The glacial deposits are thin above the salt diaper at Thyborøn but increase in dramatically magnitude in a circular area around the diaper (circular depression) indicating that major salt-tectonic movements took place at the diaper during this period.

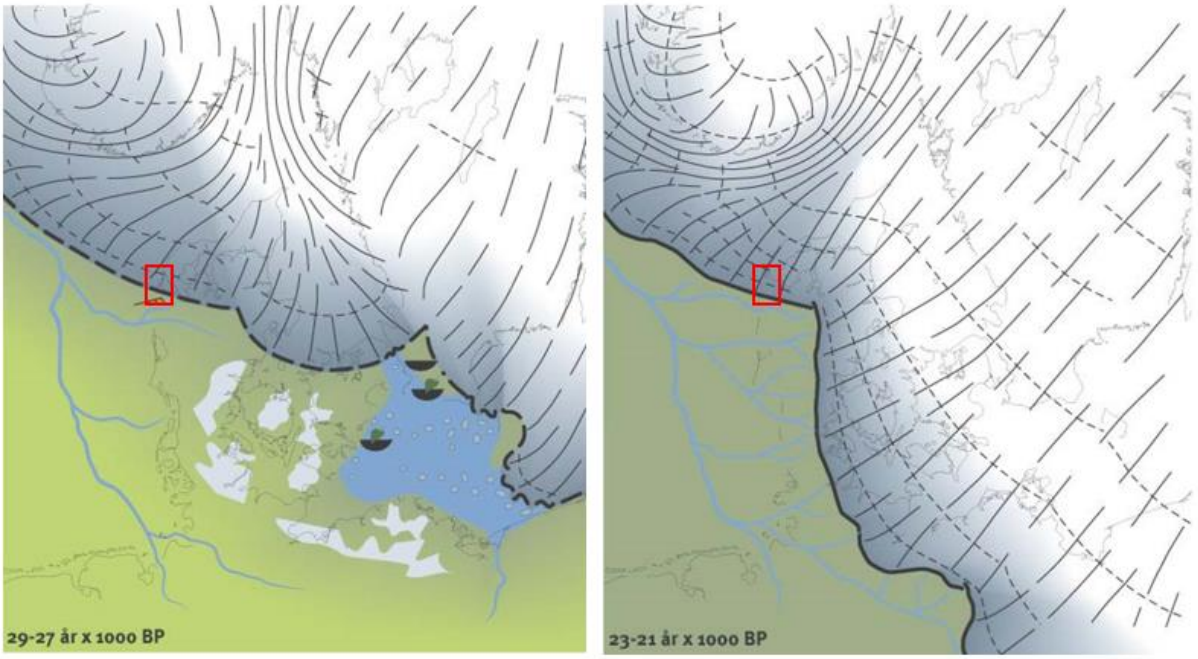

Figure 3. Extend of glacial ice sheets during A) Ice sheet expanding from a northern direction, associated with the lower Till, B) Ice sheet expanding from a NE-direction, associated with the upper Till. From /2/.

2.6 Postglacial and Recent deposits

The postglacial sediments consist of marine clay (Agger ler), marine sand, organic deposits (gyttja) and Aeolian sand. The postglacial development has been elaborately described by Elkær., (1985).

The marine clay is deposited during the postglacial marine transgression in the area, the clay is quite thin above the salt diaper but in accordance with the glacial sediments, the magnitude increases dramatically in the circular depression around the diaper indicating continued salt- tectonic movements in the area during the Postglacial.

The marine sand is deposited during the buildup of the barrier system that forms the present day land areas at Thyborøn (Harboøre and Agger Tange). The system is believed to have been deposited from the Postglacial to historic time and is thus a quite recent deposit (Holocene). The sand deposits show only little influence from salt tectonics.

Along the coastline Aeolian sand is deposited at present day, fill deposits at Thyborøn consists primarily from sand pumped up from the Limfjorden area or from glacial sand deposits at Jyske Banke in the North Sea.
The distribution of the postglacial deposits is shown in Figure 4.

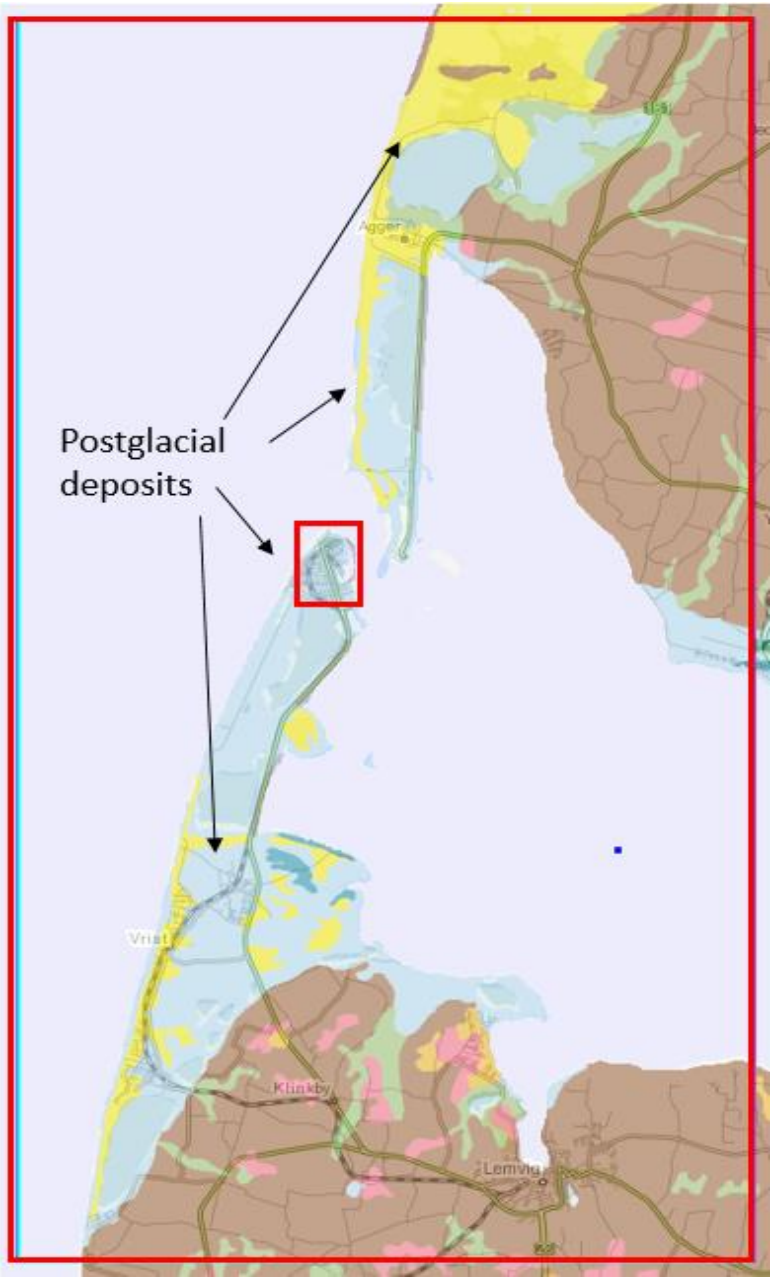

Figure 4. Distribution of Postglacial deposits, primarily marine clay and sand deposits (blue colors) and Aeolian sand (yellow color). Older glacial deposits are shown with brown colors. From /1/.

3 Conceptual geology

The stratigraphy of the Thyborøn area is divided into a pre-Quaternary sequence, a glacial Quaternary sequence and a postglacial sequence. The resulting interpretation resulted in an 18. layer model consisting of 7 pre-Quaternary layers, 5 Quaternary layers and 6. Postglacial layers.

An overview of the stratigraphy is given in Table 1.

Table 1. Overview of the stratigraphy in the Thyborøn Model Area. The stratigraphy includes Permian, Cretaceous, Miocene, glacial and postglacial Quaternary sediments including recent fill and Aeolian sands.

No.	Name	Lithology code (DK)	Age	Description	Occurrence in model area
1	Aeolian sand	ES,S	Recent	Sand, fine-medium	In costal dunes
2	Fill	O,S,L	Recent	Sand, medium, sl. gravelly	Probably mainly marine sand from Limfjorden
3	Upper Marine sand	HS,DS, S	Recent	Sand, medium, w. gyttja and clay	Local occurrence in "Limfjord Barriers" area
4	Gyttja/organic dep.	HP.P, HL, L	Postglacial	Gyttja and Peat	As lenses at Thyborøn, as minor layers at barriers
5	Marine sand	HS,DS, S	Postglacial	Sand, medium	Regionally distr., silt, gyttja in upper part
6	Marine clay	HL,DL, L	Postglacial	Clay, fat ('Agger-clay')	Regionally distr., silt and sand lenses in upper part
7	Upper meltwater sand	DS, S	Glacial	Sand, fine-medium	Only local distribution
8	Upper clay Till	ML, L	Glacial	Clay Till, gravelly, sandy	Regional distribution
9	Intermediate meltwater sand	DS, S	Glacial	Sand, medium-coarse, gravelly	Regional distribution, occurs as lenses in ice marginal ridges
10	Lower clay Till	ML, DL, QL, L	Glacial	Clay, fat-sandy	Regional distribution, upper part is sandy clay
11	Lower meltwater sand	DS, GS,S	Glacial	Sand, medium-coarse, gravelly	Regional distribution, locally contains mica-sand
12	Arnum Clay Fm.	GL,L	Miocene	Clay, very silty	Contains minor layers of mica-sand
13	Bastrup Sand Fm.	GS, KS,S	Miocene	Sand, fine-medium	Contains minor layers of mica-clay
14	Klintinghoved Clay Fm.	GL,L	Miocene	Clay, fat, slightly silty	Regionally distributed
15	Billund Sand Fm.	GS, KS,S	Miocene	Sand, fine, silty	Regionally distributed, contains minor layers of mica-clay
16	Vejle Fjord Clay Fm.	GL,L	Miocene	Clay, fat	Regionally distributed.
17	Cretaceous Limestone	SK, K, L	Cretaceous	Limestone	Occurs only above salt structure
18	Evaporates	W, L, S	Permian	Rock salt with layers of clay and anhydrite	In local salt structure at Rønland

The conceptual interpretation is illustrated in a conceptual profile orientated SW-NE showing the general geological settings and structures of the Thyborøn Model (25m), Figure 5.

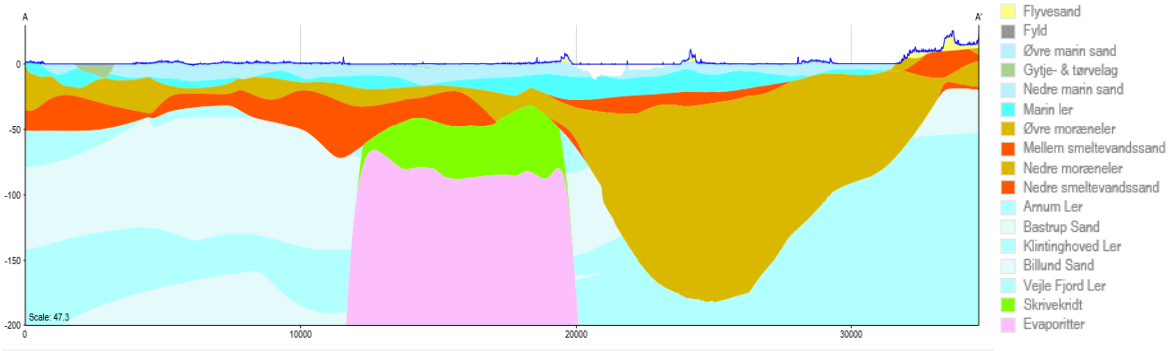

Figure 5. Conceptual profile SW-NE transecting the regional geological model (25m) for the Thyborøn Area. Note the Rønland saltdiapir covered by limestone deposits and clay infill in the Nissum Bay depression to the north.

4 Description of the Pre-Quaternary sediments

The pre-Quaternary deposits consists of Permian evaporates and Cretaceous Chalk (Skrivekridt) in small area at Thyborøn and Harboøre due to salt tectonics along fault systems transecting the area. The surrounding area is dominated by clay- and sand layers of Miocene age that are tilted towards the SW due to the regional tectonics, the Miocene deposits wedge out to the north.

4.1 Arnum Fm

The Arnum Fm. was deposited deposited in a nearshore marine environment. The Arnum Fm. consists of clay, silty to very silty clay with minor sand layers or lenses. The layer occurs primarily in the southern and southwestern part of the model area due to the tilting of the pre-quaternary strata, the thickness is generally

between 10 -30m, but the layer may pinch out in some areas. The formation also occurs locally in in the synclinal around the saltdiapir with thicknesses about 10-15m.

4.2 Bastrup Fm.

The Bastrup Fm. was deposited in deltaic and/or fluvial sedimentary environments. The Bastrup Fm. consists of fine- medium size sand rich in mica; it may contain minor layers or lenses of clay. The layer occurs in major parts of the model area except from the easternmost parts, the Nissum Bay area and above the saltdiapir. The thickness is generally between 20-50m in thickness, but may exceed 100m in the southwestern part. The formation also occurs locally in synclinal around the saltdiapir at Thyborøn with thicknesses about 10-20m.

4.3 Klintinghoved Fm.

The Klintinghoved Fm. was deposited in a nearshore marine environment. The formation consists of fat to slightly silty clay. The layer occurs in most of the model area except for the northernmost area, the Nissum Bay area and above the saltdiapir at Thyborøn. The thickness varies between 20-30m but locally reach 40m. The formation also occur in the synclinal around the saltdiapir at Thyborøn.

4.4 Billund Fm.

The Billund Fm. was deposited in a deltaic and/or fluvial environment. The formation consists of fine- medium size sand rich in mica, it may contain minor layers or lenses of clay. The layer occurs in the southern part of the model area, south of the saltdiapir, but it also occurs in the synclinal around the saltdiapir except from the northern part. The layer is missing in the southeastern part of the model area. The thickness increases from about 10-20m in the synclinal around the saltdiapir, to between 40-80m in the southern area in general.

4.5 Vejle Fj. Fm.

The Vejle Fj. Fm was deposited in a marine environment. The formation consists of fat clay with local sand layers. The layer occurs in most of the model area except from above the saltdiapir at Thyborøn and in the Nissum Bay area where it may be missing or very thin. The thickness increases in general from the north towards the south, with thicknesses between 20-80m in the northern part to between 100-150m m in the southern part.

4.6 Cretaceous Chalk

The Cretaceous Chalk was deposited as skeletal carbonate mud in a marine environment.
The Cretaceous Chalk consists of fine-grained skeletons or skeletal fragments of algal coccolithophores with minor silt sized components E.G. bryozoans or marine invertebrates. The chalk is regularly bedded with minor flint beds. The limestone occurs in a circular area above the salt diaper only extending from Thyborøn in the north to Harboøre in the south. The thickness varies between 20-40m, but at two peaks below Thyborøn and Harboøre respectively, the thickness reaches 50-60m.

4.7 Permian evaporates

The Permian evaporates were deposited shallow marine basins in arid, subtropical climate. The evaporates consist of rock salt (halite) with layers of clay and anhydrite. The rock salt occurs in a circular area between Thyborøn and Harboøre only, where it constitutes a horst structure that transects the Miocene layers. The precise thickness of the evaporates is unknown, but is believed to be about 1 km.

5 Description of the Quaternary sediments

The Quaternary stratigraphy of the Thyborøn model area consist of a glacial and a post- glacial sequence. The glacial sequence comprises three layers of meltwater deposits of mainly sand and gravel interbedded with two layers of glacial till, the glacial sequence rests mainly on top of Miocene deposits, but in the Thyborøn-Harboøre area, it rests on Cretaceous Chalk.

The glacial deposits are in the coastal /isthmus areas superseded by postglacial marine clay (Agger ler) and marine sand that in the rim along the Nissum Bay may be covered by organic deposits or by Aeolian sands along the coastal strip bordering the North Sea. Locally, in the build-up areas and at infrastructure (roads, harbors) recent fill deposits are present.

5.1 Aeolian sediments

The Aeolian deposits are presently being deposited along the coastline of Jutland due to the strong influence of westerly winds and re-deposition of marine sand.

The Aeolian deposits consists of medium- to fine sand with local layers of peat. The layer occurs along the coastline in elongate dunes, generally 4-8m high. Furthest to the north in the northwestern part of the model area, north of Flade Sø, the Aeolian deposits cover areas of former marine surfaces.

5.2 Fill deposits

The fill consists primarily of marine sand extracted from the seabed or glacial sand extracted from Jyske Rev, the fill thus consists sand, fine medium, locally slightly gravelly.

The fill occurs in the build-up areas of Thyborøn and Lemvig, at the chemical plant at Cheminova/Rønland and in the adjacent costal dunes to the west and at the roads and harbor constructions in the “tangen” area.

The thickness of the fill is about 1-2m at roads and other infrastructure in the “tangen” area, in Lemvig the thickness may locally reach 5m. In Thyborøn, the fill forms a wedge-form with fill thicknesses in the harbor area to the east reaching 6-8m, thinning towards the west to 3-5 m in the town and 1-2m along the dunes.

5.3 Postglacial organic deposits

The Postglacial organic deposits includes both terrestrial and marine deposits of peat, gyttja or organic clay. The terrestrial deposits are distributed locally along the coastline, at places interbedded with marine sand.

Layers or discontinuous layers are found at Thyborøn and Cheminova stretching from the coastline in the west into the lagoon area towards the east, At Thyborøn the organic layer is about 0,2-0,3m in thickness in the town area, locally reaching 1m in the harbor area. At Cheminova a similar layer stretches from the coastline to the central part of Rønland, the layer varies between 0, 2-1m in thickness.

In Nissum Bay, the layer is found in the deeper parts of the bay towards the east and along the northern coastline of the bay. The marine organic sediments vary between 1-5m in thickness.

5.4 Postglacial marine sand

The postglacial marine sand was deposited in a high-energy marine environment during a phase of marine transgression in the area; the upper part of the layer may represent recently deposited or re-deposited sediments. The layer consists of medium sand that in the upper part may be interbedded with organic sediments.

The layer occurs in the entire isthmus area ("tangen") extending further to the south and north along the coastline. The layer is also present in the adjacent marine areas to the east. The layer is missing in the Thyborøn Channel and in the eastern part of the Nissum Bay area. To the west, the layer is present in parts of the western parts of the marine area (the North Sea).

The thickness is about 5-15m in the isthmus and costal area gradually thinning towards the east into the bay area. In the North Sea, the thickness is between 10-20m.

5.5 Postglacial clay ("Agger ler")

The postglacial clay was deposited in low-energy marine environment with clay sedimentation in protected bay-areas. The layer consists of fat clay that may be interbedded with sand layers in the upper part.

The clay occurs in the whole Nissum Bay Area, along the isthmus and further along the coastline towards Agger and Flade Sø to the north and towards Ferring Sø to the south. In the North Sea, it occurs along the western margin of the model area.

In the Nissum Bay Area the thickness reaches about 50m, in the isthmus area the thickness reaches 20m in the northern part of Thyborøn, but is generally about 10-15m, locally it may be absent. In the North Sea, the thickness is about 5-10m.

5.6 Upper meltwater sand

The upper meltwater unit is interpreted to have been deposited during the late glacial period when the glacial ice in the area was melting. The layer consists of medium- to fine sand.

The meltwaters and occurs locally in valleys, depressions in the northeastern part of the model-area in Thy, along the northern shore of the Nissum Bay and in the tunnel valley at Lemvig. The thickness varies between 1-5m, locally 5-10m

5.7 Upper clay Till

The upper till unit is interpreted to have been deposited during an ice-advance from the NE during the mid Weischselian and is associated with ice marginal complexes along the southern shore of the Nissum Bay at Lemvig and Klinkby. The layer consists of sandy- gravelly clay till and is widely distributed in the glacial landscape but is not found in the postglacial landscape along the west coast and the isthmus at Thyborøn and Agger.

The thickness generally varies between 5-15m but in the ice marginal complexes, the thickness varies between 30-50m, locally reaching 70m at the ice marginal complex at Lemvig.

5.8 Intermediate meltwater sand

The intermediate meltwaters and unit is interpreted to have been deposited by the NE-ice. The layer consists of medium-coarse or gravelly sand and is widely distributed in the glacial landscape, in the isthmus area between Thyborøn and Agger and to the north of Flade Sø. The layer typically forms the core or a deformed core of the ice marginal hills both to the north and to the south of the Nissum Bay.

The thickness generally varies between 10-20m but locally at Lemvig, thickness reaches 30-40m.

5.9 Lower clay Till

The unit is interpreted to have been deposited by an ice-advance from the north, but it may contain deposits from older glaciations. The layer consists of fat-sandy clay till and is distributed in the most part of the model-area, especially in the Nissum Bay depression.

Outside the Nissum Bay depression, the thickness of the layer varies between 10-40m, locally at Harboøre and in the central part of Thy, the thickness may reach 90m.

In the Nissum Bay depression, the layer fills out the depression to the pre-quaternary surface and in this area, the thickness reaches 160m, stretching from Lemvig towards Thyborøn and along the west coast towards Agger.

5.10 Lower meltwater sand

The lower meltwater sand is interpreted to have been deposited sub-glacially by the NE-ice sheet. The layer consists of medium-coarse sand or gravelly sand, and is distributed in the glacial landscape north- and south of the Nissum Bay and in the isthmus area south of Thyborøn. To the south, the layer is present in the ice marginal complexes stretching from Lemvig to Klinkby with a thickness between 10-80m, to the north, the layer is associated with several buried valley systems to the west of Hurup stretching N-S, and the thickness in the valley systems reaches 120-130m.

6 References

/1/ GEUS, map service.

/2/ Houmark-Nielsen, M. et al., 2005: De seneste 150.000 år I Danmark, istidslandskabet og naturens udvikling. Geoviden, GEUS.