Chapter 1

Soil and Rocks

1.1 Soil and rock types as a result of processes

In geotechnical standards the terms "soil" and "rock" are used for all natural deposits and formations from the ground (terrain) and below. Soil is used for the loose material and rock for the solid material /1.1/. Further comments on the use of the words "soil types" and "rock types" is found in Chapter 13, Glossary.

Each soil and rock type is composed of one or more minerals (see Figure 1.1). A mineral is a natural chemical compound, that has formed a solid. Each mineral is characterized by a specific chemical composition and a certain internal structure of atoms. More on minerals in Section 1.2.

Rock and soil can be subdivided into two main types:

- Sediments (formed as loose deposits at the earth's surface).
- Bedrock (formed at high pressure and/or high temperature).

Bedrock can again be divided into *metamorphic* rocks and *igneous* rocks, as shown in Figure 1.1. The metamorphic are formed by adaptation to high pressure and/or temperature deep down in the ground. The igneous rocks are formed by the solidification of a molten rock mass.

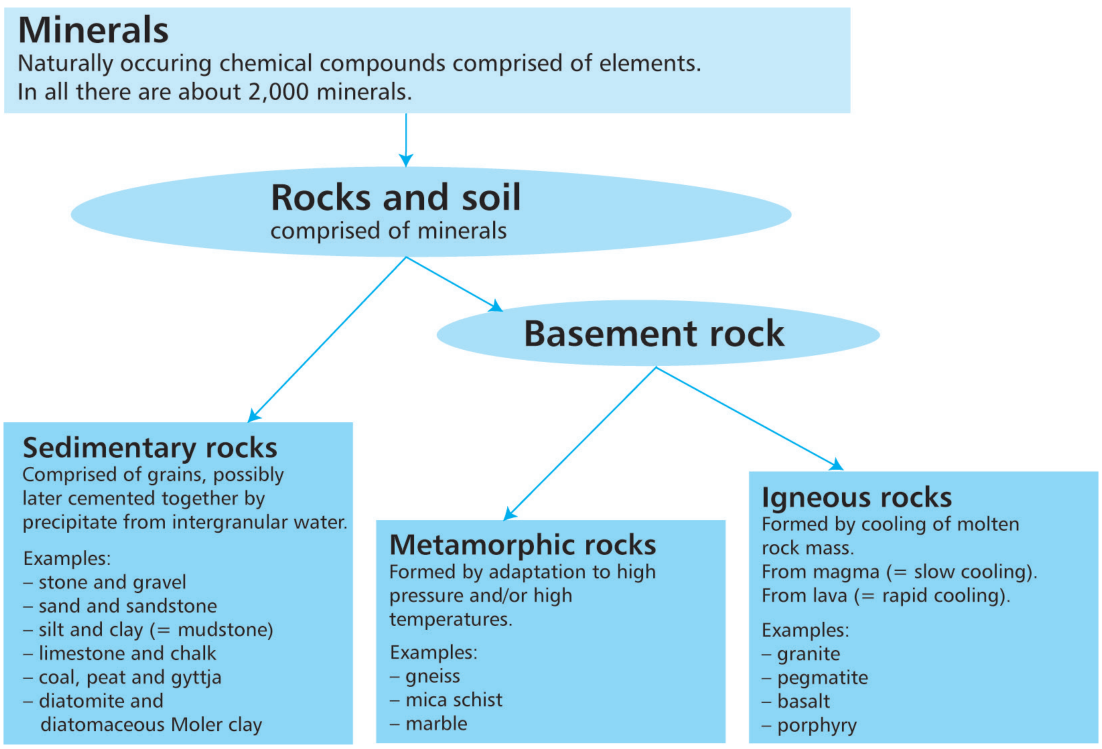

Figure 1.1. Types of rock.

When solidification of the molten rock mass occurs relatively fast (at the earth's surface), we get fine-grained crystalline rock, called lava rocks (e.g. basalt). If solidification on the other hand occurs relatively deeper down in the earth, the result is coarse crystalline rock, known as magma (e.g. granite).

Solidification of the molten rock mass may also initiate deep down and finish at the surface due to a sudden uplift and volcanic eruption. This gives the rock a porphyric structure with large mineral grains in a fine-grained crystalline matrix (e.g. rhomb porphyry).

In Denmark, the surface everywhere consists of loose deposits, i.e. of sedimentary rocks that cover the bedrock. In some places the sediment cover is only a few metres thick. This is the case on the island Bornholm. In the rest of Denmark, the sedimentary cover above the bedrock is typically several kilometres thick.

Rocks are largely recycled as seen in Figure 1.2. The source material for the sedimentary rocks is often bedrock exposed at surface level. Here there is a crumbling and weathering that, among other things, cause the bedrock's minerals to be transformed into clay minerals. Sediments of clay, sand and limestone sink slowly down into the earth's crust, where they face increasing pressure and temperature and become metamorphic rock. Later, the metamorphic rocks may melt and become magmatic or volcanic rock (igneous rock), as seen in the rock cycle, Figure 1.2.

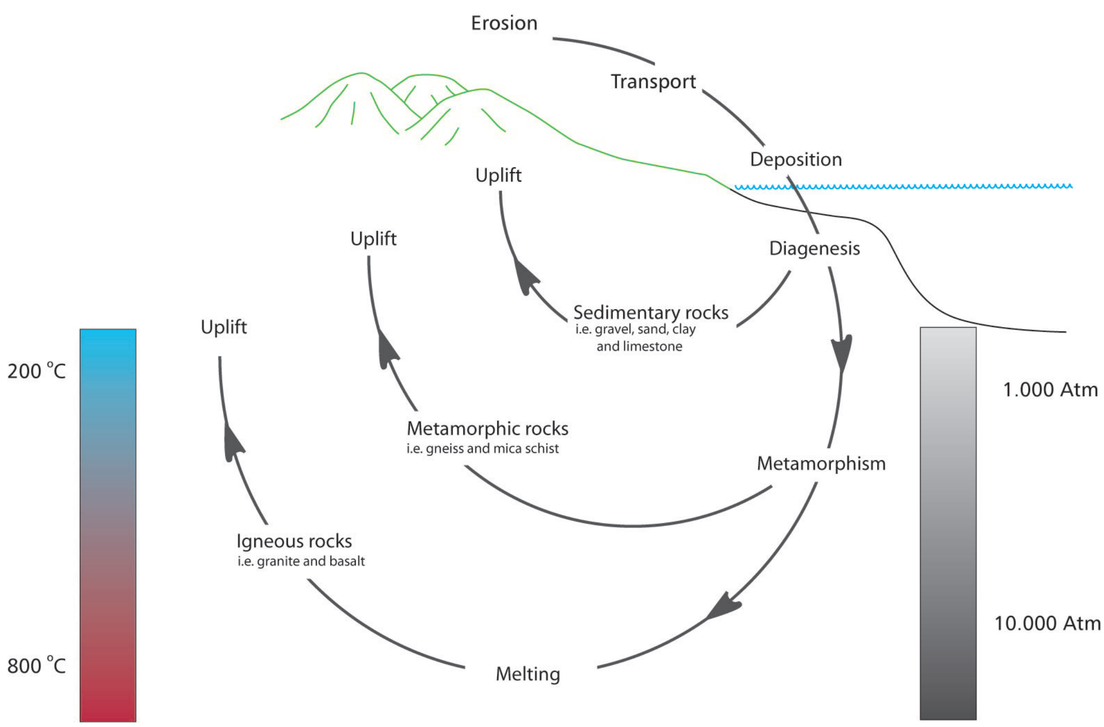

Figure 1.2. The rock cycle. The reuse of rock materials spans over millions of years.

The sediments in Denmark´s upper beds are mostly formed as loose particles transported by water, wind or ice and deposited as clay, silt, sand, gravel, cobbles and boulders. Only on the island Bornholm part of the upper beds consist of bedrock formed deep down in the earth.

Soil and rock types in Denmark can, because of the way they have been formed, be subdivided into the seven groups that are briefly described below. The purpose of this brief description is to provide a general understanding of how rock and soil are formed. Later, in Section 1.3, is given a more detailed characterization of the individual soil and rock types and their variations. See also Section 11.9 on assessment of sedimentary environments for soil samples (Chapter 11).

The 7 different formation processes, which are summarized here, are:

1) Sediments deposited in water (e.g. gravel, sand and uniform clay)
2) Sediments deposited after transport by wind (e.g. fine sand)
3) Sediments deposited by glaciers (e.g. moraine clay)
4) Accumulation of shells from small animals (e.g. chalk)
5) Accumulation of organic matter (e.g. peat and mud)
6) Chemical precipitations (e.g. salt from sea water or lime from a spring of fresh water)
7) Bedrock formation (e.g. marble and granite)

Sediments transported to their final deposition by water, wind or ice are named *clastic* sediments – (formation process 1), 2) and 3) from the above list).

Re 1) Sediments deposited in water.

The water-deposited sediments are formed by the settlement of materials in *meltwater*, *seawater* or *freshwater*. Common to all water deposited sediments is that they are graded, and their grain size is determined by the speed and turbulence that has been in the water at the time of deposition. In rapid flowing water, only stones and gravel are deposited, while in calm and still water, only clay is deposited.

Re 2) Sediments deposited after transport by wind

Wind deposits typically consist of very well sorted fine sand, normally known as *aeolic sand*. The grain size of wind deposits may also be in the silt fraction, and this soil type is known as *loess*. Silt is a material with a grain size somewhere between clay and sand, see Figure 1.5.

Re 3) Sediments deposited by glaciers

A glacier is a gradual advancing mass of ice. Normally, glaciers absorb materials from the base when sliding forward. In contrast to materials transported by water and wind, there will be no sorting during transportation by a glacier.

Glacier deposits are, therefore, characterized by soil completely unsorted, i.e. in the same soil sample, you will typically find occurrences of clay, sand, gravel as well as cobbles and boulders. Glacier deposits are called moraine (or till), and depending on the main components, distinction is made between moraine clay, moraine silt, moraine sand and moraine gravel. For these groups, moraine clay is by far the most common.

Re 4) Accumulation of shells of small animals

Materials deposited on ocean seabeds may be completely dominated by microscopic shells from plankton organisms. After their death, the organisms sink down to the seabed where the shells are preserved while the organic parts decay.

The material that the shells are made of consists either of limestone ($CaCO_3$) or silicia (SiO_2). Shells of limestone are much more frequently in Danish soil and rock than sediments made of silicia shells.

Typically, shells of limestone and silicia are very small and of the same size as the particles in silt and clay. Therefore, the biological forms and characteristics of the shells can only be seen in high magnification microscopes.

The small organisms that provide silicia shells are called diatoms, and clusters of these silicious shells are called diatomite. The diatomite occurring in the Limfjord region is known as "*moler*" (diatomite).

The vast majority of clusters of shell material occur in the marine environment, but they may also occur in fresh water. Beds with limestone-shells are called calcareous-gyttja and those with silicia shells are called diatomite.

Re 5) Accumulation of organic matter

All plants and animals contain molecules of carbon atoms, which is collectively called *organic substance*. When dead plants and animals are decaying, carbon atoms and oxygen are converted to carbon dioxide and water. If there is a *lack* of oxygen, there will be an accumulation of excess organic matter in the sediment. Lack of oxygen happens typically in locations with still water - e.g., in lakes and marshes, or salt lakes and lagoons along the coasts. In these environments, organic substance is typically deposited in the form of peat (comprises visible plant residues), or as gyttja (fine particles of organic material without any visible plant residues and other biological structures).

Organic substance can also occur as dispersed dark particles in sand, or finely divided sub-components in clay giving the sediments a dark or even totally black colour. Topsoil (humus) is also partly organic substance. However, it remains in constant transformation because of the many microorganisms that live in the topsoil.

Re 6) Chemical precipitations

Soils, which consist of chemical precipitation, are formed from dissolved substances in the soils pore-water. The chemical precipitation might happen when pore-water passes from a low permeable bed to beds of high permeability, or when soft clay deposits are slowly compressed. Chemical precipitation is not very common in Denmark, and occur mainly as sub-components in other soil and rock. Salt from sea water is also a chemical precipitation.

Re 7) Bedrock formation

Bedrock (also called "rock") can occur due to the sinking of sediment several kilometres down into the earth´s crust, thus changing the sediment as pressure and temperature rises. In this way marble and slate arise from, respectively, limestone and clay.

If the subsidence continues, the materials melt completely and become magma. If this magma subsequently cools (because it is slowly uplifted to the surface), solidification takes place to form e.g. granite. This cycle is outlined in Figure 1.2.

Bedrock in Denmark is present in the upper beds on the island Bornholm while in the rest of the country, the solid bedrock is deeply buried below loose sediments. Loose materials of bedrock are, however, found in Denmark as cobbles and boulders eroded from the bedrock of Norway and Sweden and transported by the ice age glaciers.

1.2 Minerals in Danish soil

All soil types are built up of minerals, no matter how the soil has been formed. A mineral consists of a solid inorganic chemical compound that is formed by chemical processes in and on the earth's crust. In most cases, minerals are composed of several native elements, but they may also consist of only one element.

There are more than 3,500 different minerals, but only approx. 20 of these are common in Denmark. Summary table, Figure 1.3 (2 pages), shows the names, formulas and a few characteristics of the typical minerals present in Danish soil. The table (Figure 1.3) is from a textbook about water supply /1.2/, and that is why column 3 has information about mineral weathering and significance for groundwater quality.

MINERAL NAME and chemical formula	**APPEARANCE AND OCCURRENCE**	**WEATHERING** and significance for the groundwater
QUARTZ SiO_2 (with crystalline structure).	Mainly light, translucent or white. Common in nearly all types of sand. Quartz sand consists virtually 100% of quartz grains.	Very stable – does not weather. Great mechanical hardness and chemical resistance.
FLINT SiO_2 (like quartz, but flint is amorphous, i.e. it lacks a crystal structure).	Black, grey or light, often with a coating of calcite and found together with chalk. Nodules and layers in chalk and limestone. Also as finely distributed cement. Common constituent of beds from the glacial periods.	Stable – does not weather.
FELDSPAR **K-feldspar** $KAlSi_3O_8$ **Plagioclase** $(Ca,Na)AlSi_3O_8$. **Albite** is the name for a pure sodium plagioclase $NaAlSi_3O_8$	Reddish skin-coloured (K-feldspar). Light, grey or brown (plagioclase feldspar). Feldspar occurs as a constituent of basement rock and as angular grains in meltwater sand.	Feldspar crumbles out of basement rock. Gradually weathers to clay minerals and can thereby release K^+, Na^+ and Ca^{2+} ions to the groundwater.
DARK MINERALS Silicates with formulas very like those of the clay minerals, but containing less water.	Typically hard in the fresh state. Common as constituents of basement rock and as sand grains in very young sand, i.e. immature sand.	Easily weather to clay minerals while concomitantly taking up water. This allows the release of small amounts of Na^+, K^+, Ca^{2+}, Mg^{2+} and Fe^{2+} ions. Released Fe^{2+} can act as a reducing agent in groundwater.
MICA **White mica** (muscovite) $KAl_2(AlSi_3O_{10})(F,OH)_2$ **Black mica** (biotite) $K(Mg, Fe)_3AlSi_3O_{10}(F,OH)_2$	Glittering appearance. Sheets or flakes. Common constituent of basement rock. White mica is found in all fine-grained deposits from the Late Tertiary Period (mica sand, mica silt and mica clay).	White mica is relatively stable. Black mica weathers easily to clay minerals. The iron released in the process can act as a reducing agent in the groundwater.
CLAY MINERALS 4 groups – all contain Si ions, Al ions and OH ions arranged in a sheet structure **Additional constituents**: **Illite**: K and Mg, Fe **Chlorite**: Mg, Fe, Ni, Fe **Kaolinite**: No other ions **Smectite**: Ca, Na, Mg, Fe	Grain size less than 0.002 mm. Plastic (pliable) when wet. Smectite has a great ability to swell when wet and form fractures when it dries out. Early Tertiary clay consists virtually 100 % of clay minerals. Moraine clay only contains about 14–20 % of clay minerals by weight.	Clay minerals are a weathering product of silicate minerals such as feldspar, mica and dark minerals. Clay containing Fe^{2+} becomes oxidised and hence acts as a reducing agent in groundwater. Oxidation of clay causes a colour shift from blue-gray to yellow or reddish, the latter when the clay is free of calcite. Smectite, Na clay, can act as an ion exchanger in groundwater.

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GLAUCONITE $K(Fe,Mg,Al)_2Si_4O_{10}(OH)_2$	Olive green to dark green. Often occurs as small rounded grains. **Only occurs in marine deposits.** Often occurs together with apatite.	Glauconite can weather to rust-like grains. Due to its Fe^{2+} content it can act as a reducing agent in groundwater.
CALCITE $CaCO_3$ = calcium carbonate	Always effervesces when in contact with diluted hydrochloric acid. Can resemble quartz, but quartz is harder. Constitutes the Pre-Quaternary chalk and limestone beds. Occurs finely distributed in unweathered beds from the glacial periods.	Readily soluble under acidic conditions, and calcite therefore eventually disappears from the upper beds. Feeds the groundwater with Ca^{2+} and HCO_3^- and thereby affects groundwater hardness.
APATITE $Ca_5(PO_4)_3(OH,F,Cl)$ Mixture of the phosphate minerals hydroxylapatite, fluorapatite and chlorapatite.	Aggregates of phosphorite, the impure massive form of apatite, are often found in bottom layers when new marine deposits replace older eroded deposits. Apatite is also found finely distributed in basement rock.	Apatite can release fluoride into the groundwater as F^- in the mineral can be exchanged with Cl^- and OH^-.
PYRITE FeS_2	Pyrite is also called fool's gold. The crystals are typically cuboid or have the form of small needles. Pyrite shines like gold. It is very common in deposits containing organic matter.	Pyrite is easily oxidised, thereby forming sulphuric acid and ochre or rust. Pyrite acts as a reducing agent in groundwater.
SIDERITE $FeCO_3$	Siderite, or spathic iron ore. Often mixed with clay and then called clay ironstone. Common as aggregates in Tertiary clay, often as "fossilised worm burrows". It is often found in meltwater gravel (eroded out of Tertiary clay).	In the weathered state it is often observed as aggregates of rust with a concentric structure. Some of the iron can have been replaced by manganese. Acts as a reducing agent.
LIMONITE $Fe(OH)_3$ or Fe_2O_3, H_2O	In loose form it is called ochre, and in hardened form it is called bog ore. Rust red or light brown or yellow. Very common as a precipitate from oxidised groundwater in the form of a coating on sand grains. Often contains manganese precipitates (blue-black).	Limonite is a weathering product of minerals containing iron in the form of Fe^{2+} (e.g. pyrite, apatite and glauconite). Some of the iron can have been replaced by manganese.
GIBBSITE $Al(OH)_3$	Clay-like – difficult to distinguish with the naked eye. Formed by the weathering of silicates.	Weathering of silicates to gibbsite occurs when percolating acidic water cannot be neutralised by calcite. Gibbsite can release Al^{3+} to the groundwater.
GYPSUM $CaSO_4 \cdot 2H_2O$	Low hardness. Is translucent or white. Occurs as a cover layer over salt domes. Also occurs as small crystals in dunes with black mica.	The mineral anhydrite ($CaSO_4$) is converted to gypsum in a process involving the uptake of water. Occurs when a uplifted salt dome meets groundwater. Gypsum can also be a weathering product of pyrite.
SALT NaCl (KCl can be present)	Tastes salty. Is translucent or white. Can occur in deep well samples from areas with salt domes.	Readily soluble in water, which can render the groundwater salty. Salty mineral water is groundwater affected by Pre-Quaternary salt domes.

Figure 1.3. Common minerals in Danish soil.

1.3 Main types and variations of soil types and rocks

The naturally occurring soils and rocks in Denmark's upper beds are by their nature grouped as shown in the first column of the table in Figure 1.4. Within each main group, it is possible to distinguish a number of variations of the group dependent on its environmental deposition and geological age; see column 2 in table Figure 1.4.

The variation does not include the older rocks on the island Bornholm.

It is always possible to determine which main group a given soil sample belongs to, but to determine the variation of the type in question, it is usually necessary to know the soil sample´s geographic location as well as the actual position in the borehole - i.e. which depth the sample is from, and what lies above and below the sample in question.

The following section details the individual soil types in terms of appearance and technical characteristics. Occurrences and distribution, as well as geological affinity of the soils, is only sporadically discussed, as reference is made to the systematic description of the geological periodes in the other chapters of this compendium.

Main Component	Variations of the main component after the formation and geological age
Cobbles and boulders (grain larger than 6 cm) **Gravel** (grain between 2 and 60 mm)	Glaciofluvatile gravel and cobbles
	Moraine gravel
	Marine cobbles and gravel (marine materiel)
	Quartz Gravel
Sand (grain between 0.06 mm and 2 mm)	Glaciofluvial sand
	Moraine sand
	Aeolian Sand
	Marine sand (beach sand)
	Hillslope downwash sand
	Quartz sand
	Mica sand
	Greensand (glauconitic sand)
Silt (grain between 0.002 mm and 0.06 mm) **Clay** (grain below 0.002 mm) Silt and clay can, in a wet state, be rolled to a sausage. Only silt is able to "gimpe" (to be squeezed and stretched)	Glaciolacustrine silt and clay
	Moraine silt and clay
	Hillslope downwash silt and clay
	Soil creeps
	Late glacial marine silt and clay
	Postglacial / Interglacial clay and silt
	Mica silt and clay from Upper Tertiary
	Plastic clay from Lower Tertiary Period
Organic Topsoil	Topsoil
Gyttja (organic mud)	Freshwater gyttja
	Saltwater gyttja
Peat (organic with visible old plant residues)	Freshwater Peat
	Saltwater Peat
Coal	Brown coal

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Limestone including Chalk Material from animals (mostly microscopic) with shells composed of calcium carbonate.	Micritic limestone (Chalk = White Chalk)
	Sandy limestone and silty limestone
	Bryozoan Limestone and Coral Limestone
	Saltholm Limestone and Copenhagen Limestone
	Glauconitic Limestone
	"Oland Limestone"
Diatomite Materials from microscopic animals with shells composed of silicia	"Moler" from Lower Tertiary
	Kielselguhr (freshwater sediment)
Chemical Deposition	Flint
	Travertine and other calcarenous precipitations
	Bog ores and other ferrous precipitations
	Salt (evaporation from saltwater)
Bedrock (= rock) (Only as boulders outside Bornholm)	Granite (magma rock type - slow solidification)
	Gneiss (metamorphic rock)
	Basalt (magma rock type - rapid solidification)

Figure 1.4. Danish soil types and rocks subdivided according to main components and typical variations. Characteristics of each variation are listed in tables in the text.

Gravel, cobbles and boulders

These components are described together because in nature, they very often occur together. They are defined by their particle size, gravel being larger than 2 mm and less than 63 mm, cobbles are between 63 and 200 mm and boulder larger than 200 mm, see Figure 1.5.

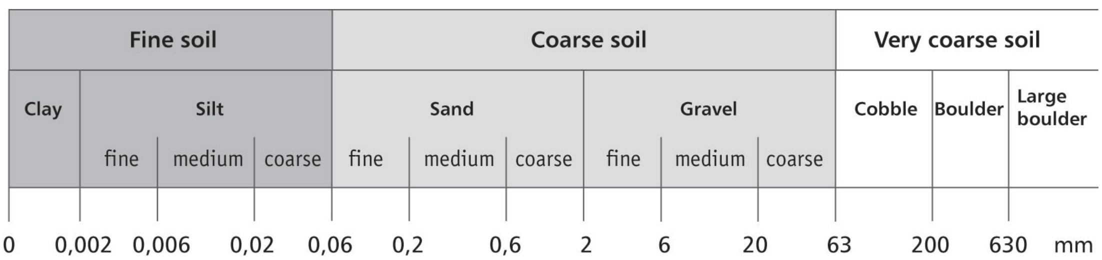

Figure 1.5. Scale in millimetres for the classification of clastic sediments. According to DS/EN ISO standard 14688-1 from 2004, /1.1/.

Generally speaking, gravel, cobbles and boulders in Denmark are composed of a rather mixed material, that ice and meltwater have eroded out from bedrock in Scandinavia as well as in Denmarks own substrata. All flint components are thus a result of the glacial erosion process in the solid Danish limestone substratum.

The mixed material of gravel and boulders may comprise some local "rotten" rock component and other relatively unstable elements. For construction purposes, these rotten rock components are undesirable and, therefore, efforts are made to sort them out when producing sand and gravel material for the building industry. The marine materials, however, extracted from the seabed comprise only a few unstable elements.

Variations of gravel, cobbles. and boulders	*Typical characteristics.*
Glaciofluvial gravel and cobbles	Sorted, many different rock type components.
Moraine gravel	Unsorted, always containing clay and sand.
Marine cobbles and gravel (marine materials)	Always well sorted and well rounded.
Quartz gravel	Colour is white to light, only quartz components, well sorted and very well rounded.

Sand

Grain size of sand is between 0.06 mm and 2 mm, and even the smallest grains can be seen with the naked eye. Grains often consist of many different minerals as, for example, in the case of glaciofluvial sand. The sand grains can also be very uniform and consist of a single mineral, as in the case of quartz sand.

More specially, sand can also consist of limestone grains, which along with green glauconite grains comprise the soil type “green sand” known from the island Sjælland in Denmark.

The volcanic ash layers from the Limfjord area’s “Moler” is also technically defined as “sand”, because the individual grains in the ash lie in the sand fraction.

In moist state, sand has a weak ability to be shaped by the hand but it cannot be rolled into a sausage - as in the case of clay and silt. In the dry state, sand completely lacks cohesion and is quite loose.

In addition to the variations of sand, which are listed in the table Figure 1.4, there is also a variety of sand called heavy mineral sand. This sand can be found as very thin layers of beach sand, where it appears as dark or reddish bands in a beach profile. It is typically concentrated during storms where strong wave motion “centrifuges” the heavier mineral grains from the beach sand and deposits them in dark, thin layers, resembling oil. Among the heavy minerals is magnetite, which is easy to recognize because it is strongly magnetic.

Finally, it should be mentioned that Bornholm has old sandstone, i.e. that the sand here is quite solid and hard - e.g. red Nexø sandstone, bright Balka quartzite and Rispebjerg sandstone, which is bright with redbrown spots.

Variations of sand.	*Typical characteristics.*
Glaciofluvial sand	Sorted, comprises many different components of rock types. Typically layered structure with coarser and finer layers.
Moraine sand	Unsorted and always with clay and boulders.
Aeolian sand	Always very well sorted and always fine-grained.
Marine sand (beach sand)	Very well sorted and rounded, often with shell remains. Sometimes thin layers of heavy mineral sand.
Hillslope downwash sand	A little organic content (dark), possibly with plant residues. Clay is a typical sub-component.
Quartz sand	Colour is white to light, only components of quartz. Well sorted and very rounded.
Mica sand	Fine-grained quartzsand, bright colour (can be dark), always very well sorted and always bright mica flakes.
Greensand (glauconitic sand)	Green grains of glauconite.

Clay and silt

Clay and silt are defined by their grain sizes, as shown by the scale in Figure 1.5. Despite the difference in grain size, clay and silt have a number of common features that make it natural to treat them as one group for engineering purposes.

The common characteristics of clay and silt are:

- Individual grains of clay and silt cannot be seen with the naked eye.
- Silt and clay can be shaped and is sticky in wet conditions - you can "roll a sausage" from them.
- Silt, and particularly clay, are both firm and hard when dry.

Clay and silt have poor permeability (i.e. very restricted ability to transmit water) but great capillarity (i.e. ability to "suck up" water in the pore spaces). The great capillarity means that the pore spaces of clay and silt will always be completely filled with water except for any desiccation zone (drying out zones) at the very top near the ground surface. This zone of desiccation is in Denmark maximum approx. 1 m deep.

The characteristic differences in clay and silt are the following:

- Only silt can "gimpe"(able to be squeezed and stretched like a harmonica, see Figure 1.6). Clay is not able to "gimpe".
- Silt can usually be dusted away by hand when dry, whereas clay is so finegrained that it goes down into the pores of the palm, so water has to be used to remove it.
- Silt has a mat surface, when cut with a knife, whereas clay has a shiny cut-surface, the more plastic the clay, the more shiny is the cut-surface.
- Silt has a larger capillarity than clay - i.e., it moistens faster.

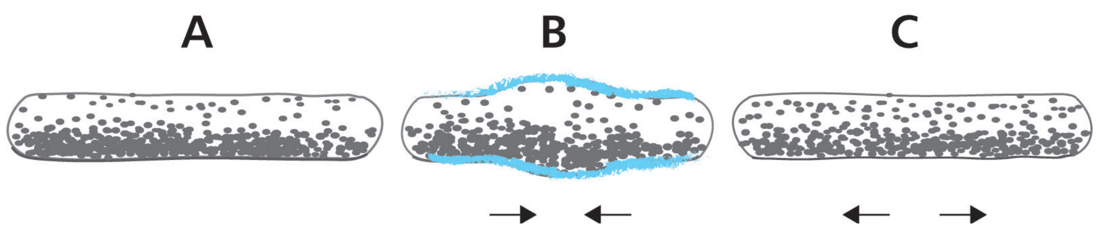

Figure 1.6. The "gimpe-test" is for identification of silt. A rolled sausage of silt (A) will regain its shape when you make small accordion movements with it (B and C) - a clay sausage is "dead" and will not revert back to the sausage shape.

When making a quick assessment of a soil, the ability to shape the soil in wet state is an important criterion. The ability to be shaped is also present even though a sample only comprises 15 to 20 percent of clay. This means that a sample can be described as clay even though up to 80 % of the sample in fact consists of silt and sand.

Clay and silt with high lime content (more than 15 %) is called marl. Previously in Denmark, a lot of marl was dug for ground improvement related to cultivation of moorlands.

The "plasticity" of clay is a property related to the proportion of grain in the clay fraction, i.e. grains with diameters less than 0.002 mm. What decides clay's plasticity is the proportion of smectite minerals in the clay sample. Smectite is one of the four groups of clay minerals; as shown in the table Figure 1.3.

Plastic clays swell and contract depending on the soil´s water content. Therefore, it is problematic to found constructions in fat clay as the water uptake may uplift the constructions. Also plastic clay on a slope will cause slipping - even on very low slopes.

While drying out the soil shrinks, and a dry summer can thus cause substantial damage due to subsidence for houses founded on plastic clay.

Variations of silt and clay.	*Typical characteristics.*
Glaciolacustrine silt and clay	Gray and calcareous below upper weathering zone. Often finely layered with varve structure.
Moraine silt and clay	Always unsorted and with sand, gravel, cobbles and boulders.
Hillslope downwash silt and clay	Often a small organic content and sometimes plant residues. Typical sandy.
Soil creeps	Unsorted, may comprise a small organic content.
Late Glacial marine silt and clay	Uniform and well sorted, sometimes with shells.
Postglacial / Interglacial clay and silt	Organic content, dark colour. Often with shell remains (in marine beds) or plant residues (in freshwater and brackish beds).
Mica silt and clay from Upper Tertiary	Always with bright mica flakes. Dark brown or black due to organic content. Shell remains may be present in marine beds, brown coal may be present in freshwater and brackish beds.
Plastic clay from Lower Tertiary	High plasticity clay, often with pastel colours. Does not scrunch when bitten with your teeth.

Topsoil

Topsoil is a subsoil formation, which naturally develops when the climate is favourable. There is always living microorganisms in natural topsoil, and there is always a turnover of the organic substances found in the topsoil. Topsoil is easily identifiable by the dark colour and the loose crumbly structure.

Topsoil is not divided into different types. Variations are always coupled to any subcomponents found in it - for example, clay-topsoil and sandy-topsoil.

Gyttja

Gyttja consists entirely of fine-grained organic matter where it is no longer possible to recognize the plants or animals that originally supplied the organic substance. Gyttja is deposited in quiet water. Therefore, the presence of a gyttja layer always indicates that the site was originally a lake or a fjord – however, on condition that the gyttja layer has not been moved after its deposition.

Gyttja may resemble clay and silt, but it can be identified by the following characteristics:

- Gyttja has a lower density than clay and silt.
- Gyttja has a characteristic, slightly elastic or spongy texture a little like yeast.
- Fresh gyttja has a faint odour of sewage.
- The colour can vary, but is usually dark.

In all construction work it is very important to identify gyttja, because load can compress gyttja and cause vertical subsidence, i.e. this soil type has a poor load-bearing capacity.

Variations of gyttja	*Typical characteristics*
Freshwater gyttja	Yeast-like, low density in dry state, high natural water content, weak odour. Sometimes plant residues.
Marine gyttja	Yeast-like, low density in dry state, high natural water content, weak odour. Often shells.

Peat

Peat consists, just like gyttja, of organic matter, but unlike gyttja peat has visible wood or plant residues. There is a gradual transition between peat and gyttja, and sometimes it may be difficult to determine if peat or gyttja constitutes the main component in a given soil sample. Typically, you will find peat on top of gyttja, indicating that a lake with free and open water surface has gradually developed into a “forest” of rushes and reeds. One characteristic of peat is that by wringing a peat sample by hand, it is possible to squeeze water out of it.

Variations in peat	*Typical characteristics.*
Freshwater peat	Visible plant residues and sometimes pieces of wood.
Saltwater peat	Visible plant residues and sometimes shells.

Coal

With increasing pressure and temperature, peat and gyttja can be solidified to form coal. In Denmark, lignite (brown coal) is found in Central Jutland and Bornholm. The Central Jutland lignite is from the Upper Tertiary period, while Bornholm´s lignite is from the much older Jurassic period.

The individual coal beds are typically less than 1 m thick and surrounded by layers of mica silt, fine sand and quartz sand.

Lignite (brown coal) can be distinguished by the tree structure - and whole pieces of logs can be found in brown coal. Moreover, coal is known for its hardness - it cannot be squeezed like peat. In previous times, and especially during World War 2, large quantities of lignite were dug for fuel in Central Jutland. This production continued up till the mid-1960s.

Limestone and chalk

Soil types of limestone and chalk can always be recognised because of their effervescence when dilute hydrochloric acid is added. The effervescence is due to production of the gas CO_2 when hydrochloric acid (HCl) reacts with limestone ($CaCO_3$).

Chalk is an old term for a white limestone that is so soft, that it rubs off when touched.

A hard limestone can be quite cracked and fractured and therefore able to transmit water very easy. For that reason it can be difficult to lower the groundwater table when excavation for construction is carried out in hard limestone. Inflow of water may be so strong that it requires a very powerful pumping system to keep excavation in hard limestone free of inflowing water.

In Denmark, firm limestone outcrops are known in a belt from Hanstholm, Thisted, Ålborg over northern Djursland to Copenhagen and down to Fakse, Stevns and Møn (see Figure 4.5 in Chapter 4).

Limestone occurs in a number of variations, which is linked in particular to the hardness, grain size and structure of the limestone.

Variations of lime	*Typical characteristics.*
Chalk (White Chalk)	White, soft and smudgy due to the softness and the finegrained occurrence. The term "micritic limestone" is used for this kind of limestone.
Sandy limestone and silty limestone	Hard, greyish to white, often a gritty structure
Bryozoan Limestone and Coral Limestone	Clear traces of reef building organisms such as bryozoans and corals.
Saltholm Limestone and Copenhagen Limestone	Very hard, gray, perhaps ringing sound.
"Greensand limestone"	Green grains of the mineral glauconite and white grey grains of limestone.
"Öland Lime"	Very hard, dark gray also reddish or greenish.

Diatomite

The soil type diatomite is quite rare as an upper soil layer in Denmark. A key characteristic is its low density, which occurs because diatomite consists of air-filled shell material. In the Limfjord region of Denmark, there is a considerable excavation for diatomite (Moler clay). The material is used for diatomite bricks, which are lightweight and insulating. The greatest use of diatomite is, however, in the form of dried granules for cat litter.

Outside the Limfjord region, there are scattered locations with diatomite representing former freshwater lakes from the warmer periods between the ice ages. Earlier, there have been excavations in several of these deposits, but the exploitation of these pits is now at an end.

Variations of diatomite	*Typical characteristics.*
"Moler" from Lower Tertiary (marine sediment)	Very light in the dry state, perhaps fine layer separation
Diatomite from Quaternary period (freshwater sediment)	Similar to limestone, but diatomite does not effervesce with hydrochloric acid. Also very low density in dry state.

Chemical precipitations

Despites the fact that chemical precipitations very rarely constitute the main components of soils, they nevertheless are included in the list of Danish soils and rocks, since they can be very dominant locally. Thus, flint can occur as a coherent layer in limestone and also be a cementing agent in this rock.

Where meltwater or seawater has eroded large quantities of limestone, rolled flint cobbles and boulders may be concentrated as the main component after all limestone has been eroded and washed away. This is, for example, the case at Glatved in Djursland.

Limestone precipitations in glaciofluvial sand and gravel may cause loose sand and gravel to appear as a hard rock, with all the grains cemented together. Because of this, natural soil can look very much like concrete, as is seen for example on a hillside near Hadsund, East Jutland. Another example of precipitation is the so-called "cementstone" in the Limfjord area. In this sediment volcanic ash layer and moler (diatomite) is cemented together to a characteristic streaky hard rock.

Iron and manganese precipitations (in the form of clay ironstone) are common as large and small nodules and tubers in the plastic clay from Lower Tertiary. These nodules and tubers are often seen in weathered state as "rusty" rocks in glaciofluvial cobbles and gravel. Precipitation of iron and manganese may also appear as hard bands in gravelly sand beds - especially where the sand is adjacent to a clay layer. Finally, iron precipitations is also present in the form of local hardgrounds (named "*al*" in Danish) - a subsoil horizon developed on sandy soil with relatively high rainfall.

Variations of chemical precipitations	*Typical characteristics*
Flint	Very hard and dense, conchoidal fracture, a lot of different shapes are seen.
Travertine (tufa) and other calcium carbonate precipitations	Effervesces always with hydrochloric acid. Mostly porous structure.
Bog iron and other ferrous depositions	Rust red colour, mostly high density.
Salt (from evaporation of seawater)	Bright, often translucent. Salty taste.

Bedrock

In Denmark, solid bedrock in upper layers is only found on Bornholm. However, bedrock is dominant in the rest of Scandinavia, Greenland and the Faroe Islands, and therefore construction work in bedrock is not unknown to Danish contractors. Characteristic of the bedrock is its high degree of hardness, and therefore blasting is often used to excavate bedrock.

Bedrock occurs in many variations - but it is outside the scope of this compendium to deal with them. Only 3 examples are mentioned - namely granite and gneiss known from Bornholm, and basalt, which is prevalent in the upper layers in Iceland and the Faroe Islands.

Examples of bedrock.	*Typical characteristics.*
Granite	Grained mosaic of minerals, dense and hard.
Gneiss	Striped structure – otherwise as granite.
Basalt	Fine-grained and close structure. Often dark.

1.4 Geochemical weathering and alterations

Minerals and soils may disintegrate, i.e. they degrade and crumble to smaller units and may eventually be completely dissolved. This can be due to both physical processes (e.g. rupturing due to frost) and/or purely chemical processes (e.g. dissolution and oxidation).

In engineering geology in Denmark two particularly examples of chemical processes are seen. This is *oxidation* and *dissolution of calcium carbonate*, which will be briefly summarised below.

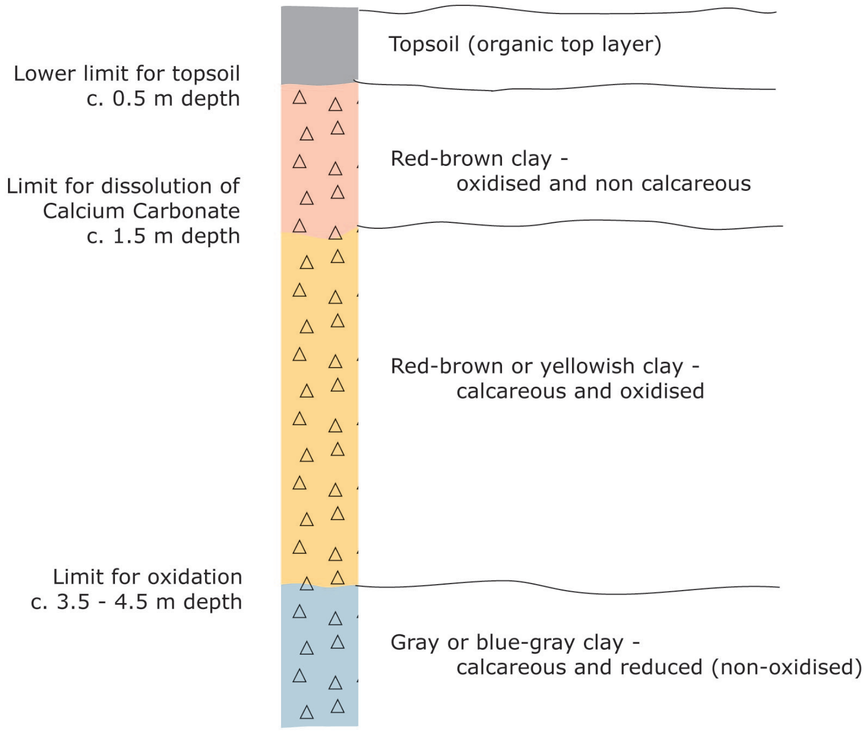

Figure 1.7. Dissolution of calcium carbonate and oxidation in undisturbed moraine clay or glaciolacustrine clay in e.g. East Jutland. The depth of the zones depends on how calcareous the clay is as well as the clay's plasticity (related to grain size).

Soil becomes oxidised when there are air-filled pores between the soil particles. Thereby can minerals with divalent iron be oxidised to trivalent iron (Fe^{++} becomes Fe^{+++}) causing the colour of the sediment to change from reddish (or yellowish) into grey shades sometimes with a faint blue or green look.

Dissolution of calcium carbonate (present as small limestone particles in the sediment) occurs because slightly acid water (from precipitation) percolates from above. This is due to the fact, that when precipitation percolates down through the organic topsoil, the water will become slightly acid because the CO_2 from decaying organic matter combines with water as follows:

$$H_2O + CO_2 \rightarrow H^+ + HCO_3^-$$

Dissolution of the limestone particles in sediment will neutralise the slightly acidic groundwater, thereby rising the pH. In this process the limestone particles gradually become consumed. The border zone between sediment with and without limestone particles is termed *the acid front*.

The processes manifest themselves in a natural colour-zoning in the upper layers. When oxidation occurs, there is typically a colour change from dark gray or blue-green shades to rust-like colours - or yellowish shades if there is limestone in the oxidised soil; see Figure 1.7. The figure shows the natural zoning that occurs in soil due to oxidation and dissolution of limestone in the upper layer.

The figure applies to clay from the younger Ice Age landforms. In the older Ice Age landforms in western Jutland, dissolution of limestone is far more advanced, i.e. the acid front between calcareous/non-calcareous sediments is here somewhat deeper in the ground.

The zoning, which is shown in Figure 1.7, can help to determine whether a given excavation is done in in-fill soil or virgin soil, which has not previously been excavated. In pristine/virgin soil, the natural zoning is thus preserved, while in the in-filled soil the zoning will always be disturbed so that the colours and calcareousness vary randomly.

Oxidation normally has no impact on the soil's construction or foundation characteristics. Dissolution of calcium carbonate – on the other hand – will cause a lower strength in the soil compared to a soil where the calcium carbonate is preserved. Efforts to compensate for this in new road construction projects may be achieved by adding a little powdered limestone to increase the strength of the upper non-calcareous moraine clay.

In organic soil, it matters whether air (oxygen) is able to come into contact with the soil. This is because the organic substance may be oxidized away, so that the soil subsides (to be recognized as one of the long-term effects of drainage). Another effect of oxidation is weathering of the mineral pyrite.

The mineral pyrite (ferrous sulphide, see Figure 1.3) is typically found together with dark, organic sediments. When pyrite is exposed to oxygen and water, a chemical reaction will take place, releasing sulphuric acid. This acid can cause corrosion of, for example, concrete and reinforcement bars and sheet piling of steel. Sulphuric acid also leads to the dissolution of iron, which can then precipitate as ochre - a well-known product in connection with the drainage of muddy and peaty deposits.

The formation of sulphuric acid can be prevented by the shielding of the pyrite-containing soil, so that no oxygen gets into it - e.g. by covering the soil with clay or with another tight membrane.

To conclude this section on weathering and geochemical processes in soils, we should remember that there is never anything that is lost in nature. The chemical degradation products from one rock will always form the basis for the formation of other minerals and soils, which are better adapted to the current geochemical and physical conditions at the specific site. A good example is the clay minerals that occur at the earth's surface from, for example, the components released by the weathering of the dark minerals in granite. All soil types in nature participate in this global recycling scheme, which is outlined in Figure 1.2.

References

/1.1/ DS/EN ISO 14688-1. Nov. 2004. *Geotechnical investigation and testing - Identification and classification of soil - Part 2: Principles for a classification.*

/1.2/ Sørensen, I.; (2009): *Water Supply Textbook Chapter 3, Geology*. (to be published by Ny Teknisk Forlag in 2010).

Review questions to Chapter 1

1) In excavations in clay - e.g. eastern Danish moraine clay – the colour changes typically from the surface to the bottom. At the top is reddish clay – further down, more yellow clay, and the lowest part is gray clay. How can this colour change be explained ?

2) Gyttja is a soil that is often present in many low-lying areas in the present landscape. What does gyttja consists of and how is it formed ?

3) Where in the cycle, see Figure 1.2, are clay minerals formed - is it deep below, in the middle depths, or at the ground surface ?

4) What characteristics have the soil type silt ? (How can you identify silt - for example in an excavation or during a description of a soil sample ?)

5) In the text you can read that silt has a large capillarity - what does that mean in practice ?

6) What is ”diatomite “, and how can we distinguish it from ordinary clay ?

7) What difference is there between peat and gyttja, and what have the two sediments in common ?

8) Some Danish soil types are formed by chemical precipitation. Name at least one soil type that is formed in this way.

9) How can one determine whether a given soil sample contains calcium carbonate (limestone) ?

10) Pyrites is the name of a mineral that can occur in small amounts in a particular type of deposit – which type of deposit ?

11) Sand and gravel may be deposited in flowing water.
What difference is there between the flowing water in the two cases ? (When is sand deposited and when gravel ?)

12) What is the definition of a mineral?

13) What is the name for a soil composed of siliceous shells ?

14) Moraine clay is deposited by melting of a glacier, and glaciolacustrine clay is deposited in a meltwater lake. What is the difference in appearance and habits between the two types of clay ?

15) What is glauconite and what does it look like? In which deposition environment is it created ?

16) What is the difference (in appearance) between marine gravel and gravel deposited by meltwater ?

17) Glaciofluvial gravel almost always contains numerous flint cobbles. Where do this flint come from? (From where has the melting water eroded it out ?)

18) You have a soil sample and have to determine whether the sample should be characterized as clay or sand. Which very simple test can you perform to determine whether the sample’s main component is clay or sand ?

Chapter 2

Main Geological Development

2.1 Geological time

Previously the age of the Earth was considered to be only about 600 million years and this span of years was then divided into three periods: *Paleozoic* ("old era"), *Mesozoic* ("middle era") and *Cenozoic* ("new era"). Today, the age of the Earth is calculated to be much older, about 4,600 million years, as is shown in the spiral diagram Figure 2.1. Besides the geological periods this diagram also shows the main features of the evolution of plant and animal life, and small snowmen indicate the glacial periods.

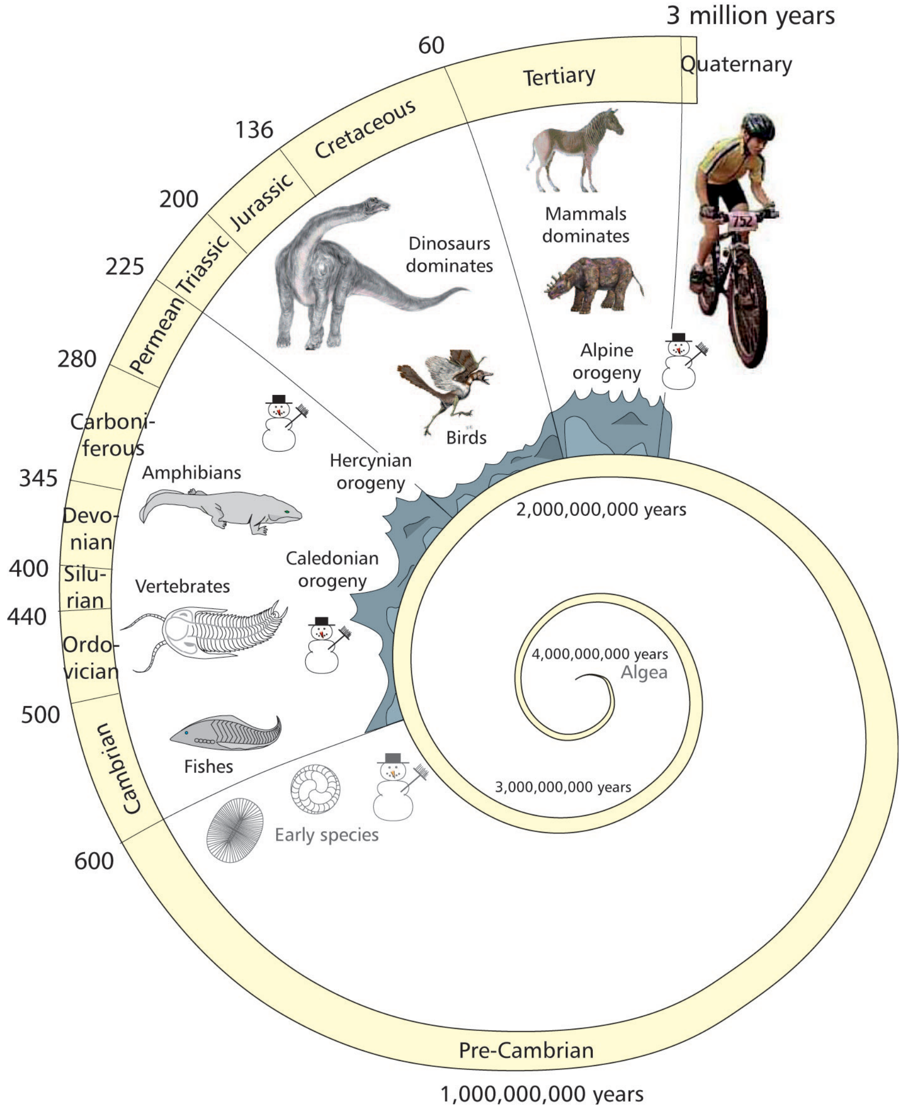

Figure 2.1. Geological timescale shown as a spiral with the oldest layers in the middle.

Each period is characterized by a series of natural processes, which together have formed the layers of soil or sediment we meet today in boreholes and excavations. Nowhere is there a complete series of beds representing all periods. In a given area, only soil and rocks from a small part of the history of the Earth is typically conserved, since natural erosive processes from time to time have removed much of the material previously deposited. When the material is removed in one area, it is just deposited somewhere else – nothing disappears. In this way, beds of one or more periods can be totally absent from an area, so that you can go directly from the very young to very old beds.

The present knowledge about geological history represents an extensive piece of detective work, where information from many different areas is pieced together to form a model of perception of the time periods. The detective work is by no means over, because although we believe we know the main features of the geological development history, we will probably never be finish with reconstructing in detail the evolution of all of Earth's different locations.

Figure 2.2 shows the topic of geological time represented by four columns, which become more and more detailed in the breakdown of time when moving from column 1 to 4. Column 1 is an overview of the Earth's total age of 4.6 billion years, with a specific mark for the past 600 million years. These 600 million years is magnified in Column 2, which shows a breakdown in the three main intervals (primeval, middle and modern times) together with the names of the individual time periods within each interval. The time periods are named after type localities – the places where people had first discovered beds from the period.

Column number 3 has zoomed into the last 100 million years, the period which is particularly relevant in Danish engineering geology. At the top of Column 3, the Quaternary Period is seen. This period, among other things, is the time when people begun to evolve independently from the apes. The oldest stone tools are between 2 and 3 million years old, / 2.1 /. Zooming in from Column 3 you enter the Quaternary Period in Column 4, with various glacial and interglacial periods. The most recent ice cover disappeared from Denmark approximately 12 thousand years ago (10,000 years BC) and the Earth then went into a Post Glacial period - also named the Holocene period.

To better understand the geological nomenclature it is quite convenient to know the translation of the three Latin words *Pre*, *Inter*, and *Post* used in connection with the prefix of the geological periods. Pre means *before*, Inter means *between* and Post means *after*. The prefixes are used, for example, in the period names Pre-Quaternary, Interglacial and Postglacial.

Within the upper few hundred metres of soil and rocks in Denmark, deposits span in age over approximately 1700 million years. Outside of the island Bornholm, Denmark has "only" the latest 100 million years represented in the upper layers corresponding to Column 3 and 4 in Figure 2.2. This present textbook is focused on processes and deposits from these latest 100 millions of years.

To conclude this section on Earth's age and geological time periods, it should be briefly mentioned that the time information in millions or thousands of years is based on different methods of age determination of soil and rock layers. These are:

- Relative age determination (older layers below the younger layers).
- Age determination by means of animal and plant residues.
- Absolute age determination from radioactive elements.

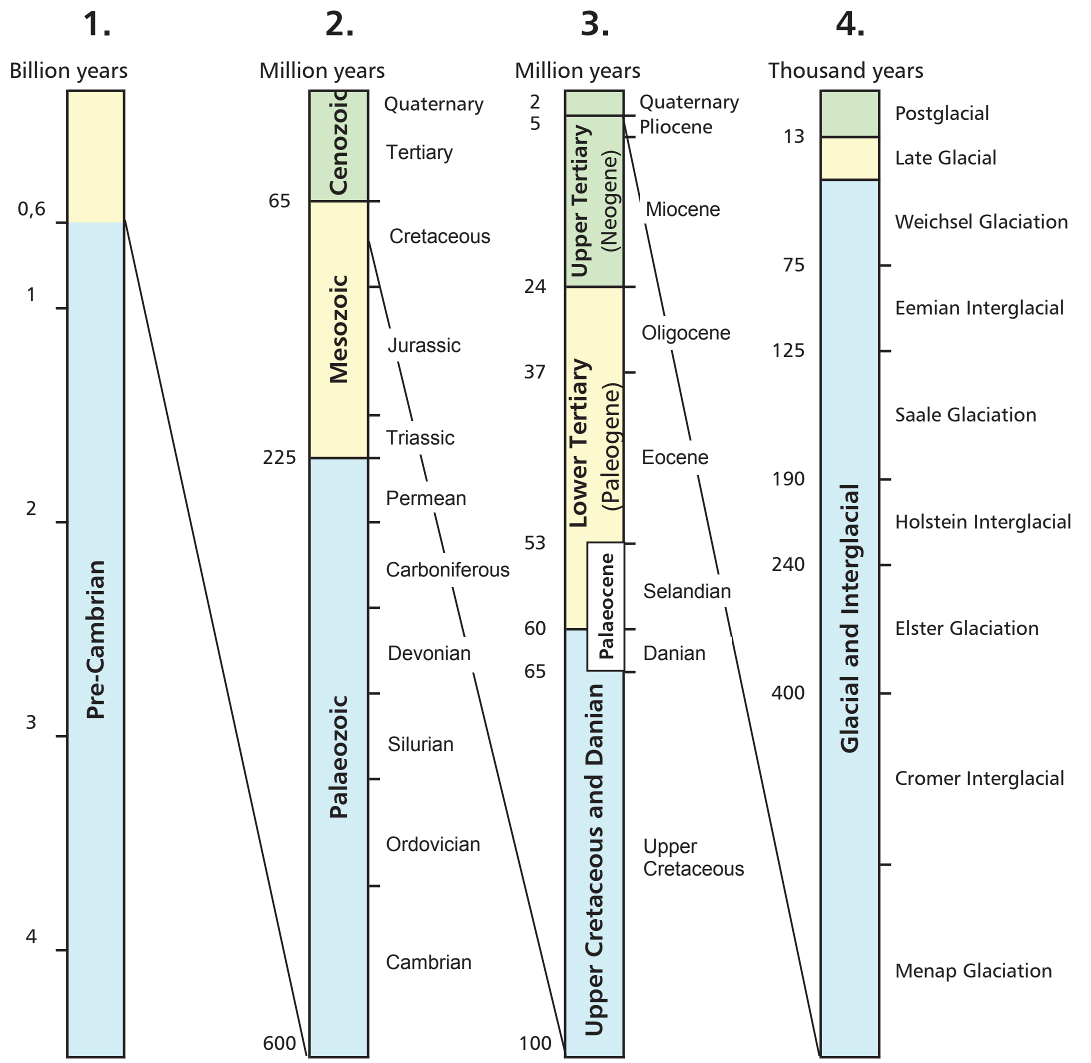

Figure 2.2. Geological time-columns, with increasing degrees of details for the youngest time segments.

2.2 Main division in 5 geological time periods

Within engineering geology, it is convenient to divide the last 100 million years in the following 5 main periods:

- Postglacial and Late Glacial (also called Holocene)
- Glacials and Interglacials (also called Pleistocene)
- Early Tertiary (also called Neogene)
- Late Tertiary (also called Paleogene)
- Danien and Late Cretaceous

The five periods are schematically shown in Figure 2.3. In the first column is a division into geological ages and how many years each time segment comprises. The column in the middle shows keywords for the deposition environment and processes in each time period. The column to the right refers to the most typical sediments and rock types from each time segment.

	Geological age	Depositional environment	Sediments and rock materials
QUATERNARY	(Present) **Postglacial**	Marine environments with various coastal settings Lakes Streams Swamps Landslips Dunes	**Freshwater sand / silt / peat / gyttja** **Marine sand clay gyttja** **Hillslope and downwash sediments** (clay/silt/sand) **Glaciofluvial sand Glaciolacustrine clay**
	Late Glacial	Marine and fresh waters Land slides and soil creeps Meltwater outwash plains	
	15,000 before present	*Denmark gradually became free of ice*	*Sea level changes*
	Glacial Periods *alternating with* **Interglacial**	Active Glaciers Meltwater streams and outwash Meltwater lakes Landslides and soil creep *During interglacials similar processes to Late Glacial and Postglacial (see above)*	*Alternating beds of* **Moraine clay –sand –gravel** **Glaciofluvial sand –gravel and –boulders** **Glaciolacustrine clay and -silt** *During interglacials similar deposits to Late Glacial and Postglacial (see above)* also Diatomite in lakes
PRE-QUATERNARY	2-7 million years	*Denmark is part of a continent exposed to erosion*	
	Upper Tertiary (comprises **Pliocene, Miocene** and Middle and Upper **Oligocene**	Marine (mostly western Jutland) Freshwater and brackish River systems and lakes Deltas at river mouths Lagoons, tidal flats and other coastal environments	*Alternating beds of* **Mica (fine)sand** **Mica silt and mica clay** **Quartz sand and –gravel Brown coal** also Glauconitic sand / sandstone Branden clay and Viborg clay (low mica content)
	c. 30 million years	*Sediment-laden rivers from Norway and Sweden deposit sediments in Denmark* *Uplift of Scandinavia (tectonic forces) and much of Denmark becomes exposed as dry land*	
	Lower Tertiary Comprises lower part of **Oligocene** **Eocene** and **Palaeocene** (without **Danian**)	Denmark is part of a sea floor, probably deep water Negligible sediment supply from adjoining land areas Volcanic eruptions in the North Atlantic region	**Plastic clay** *can be divided into* **Søvind Marl** **Lillebælt Clay Røsnæs Clay** **Ølst Clay Holmehus Clay** *Also* Volcanic ash beds Diatomite Kerteminde Marl and glauconitic calcarenites
	c. 60 million years		
	Danian **Upper Cretaceous**	Marine (inner shelf) Marine (outer shelf)	*Alternating limestones including* **Clastic limestones (silt/sand grade)** **Bryozoan** and **Coral limestone** **Micritic limestone** (= chalk) **Chalk** (very fine-grained limestone)
	c. 100 million years		

Figure 2.3. Simplified geological timescale, indicating depositional environments and typical Danish sediments and rocks from each time period.

2.3 Up and down tilting of layered deposits

Sediments are initially deposited in horizontal layers, as in a layered cake - first the one layer, then the second layer on top and again the third layer, etc. However, it is very rarely that the "cake" is allowed to lie undisturbed as times go. Typically, there are some areas that rise and other areas that subside, and at the same time, there may be sideways shifts and disturbances. It is these forces that are shown by arrows on the "global recycling system", Figure 1.2.

The reason for these movements of deposits is plate tectonic forces, which we know to be the cause of continental drift, volcanoes and earthquakes.

There are many examples of deposits that are displaced and staggered relative to each other in Denmark's subsurface. Generally speaking, there has been an uplifting towards northeast, so that older strata here are tilted upward, and the southwest of Denmark is tilted downward. When the beds tilt upward, they are exposed to erosion. The erosion will eventually wear down the uplifted parts so they will become in level with the younger layers as seen in Figure 2.4.

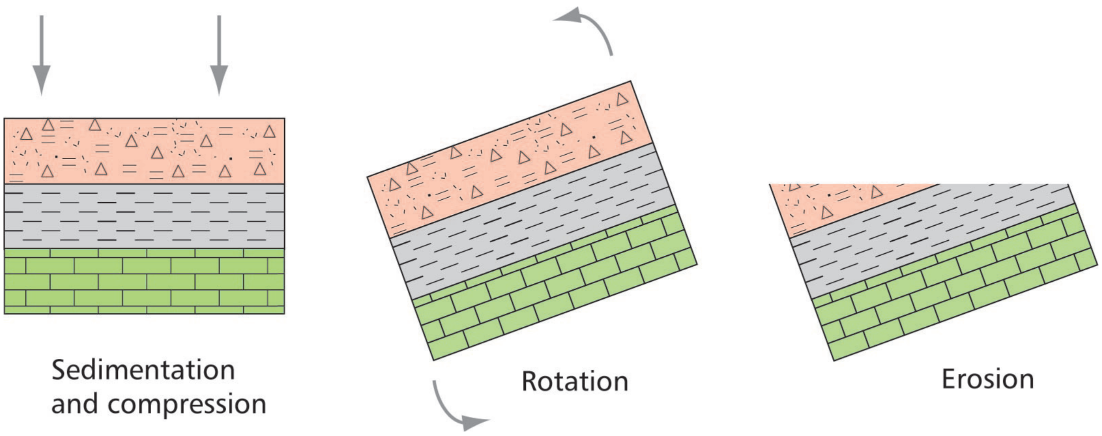

Figure 2.4. Draft showing how the substratum can tilts upward and subsequently be exposed to erosion so older layers are in level with younger layers. After /2.2/.

An example of the variation of the subsurface can be seen in the cross-section from west to east across the island of Fyn, see Figure 2.5. The general trend of uplifting in the east and lowering in the west is apparent. It is also suggested in the figure that the sediments below the Quaternary are divided into blocks that tip in relation to each other.

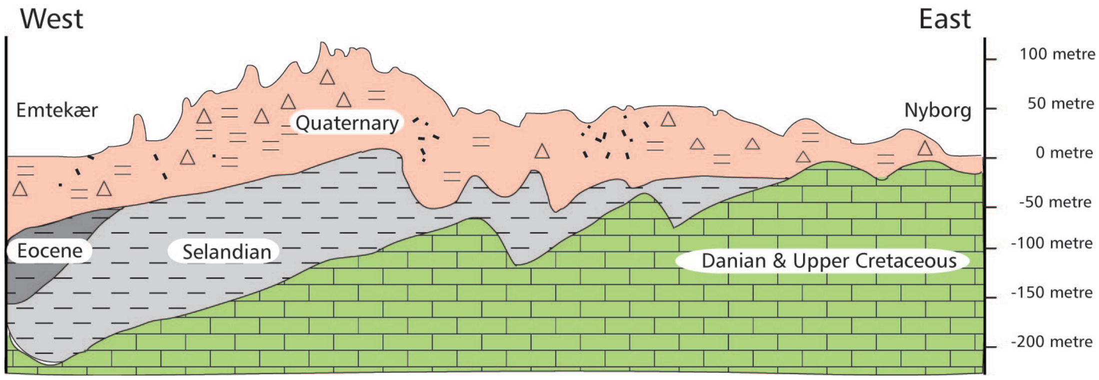

Figure 2.5. Cross-section of Fyn from west to east. Pre-Quaternary substratum consists here of layers from the time periods Eocene and Selandian as well as limestone beds from Danian and Late Cretaceous.

2.4 Pre-Quaternary surface map

Sediments from the periods before the Quaternary Period are collectively called the “subsurface”. What we usually call the ”Pre-Quaternary surface map” is a map of Denmark that shows the geological ages of the upper subsurface - i.e. the geological ages of the surface just below the upper cover of beds from the ice ages.

Figure 2.6 shows a simplified Pre-Quaternary surface map of Denmark. The figure is based on a Pre-Quaternary surface map in large format, published by VARV in 1992.

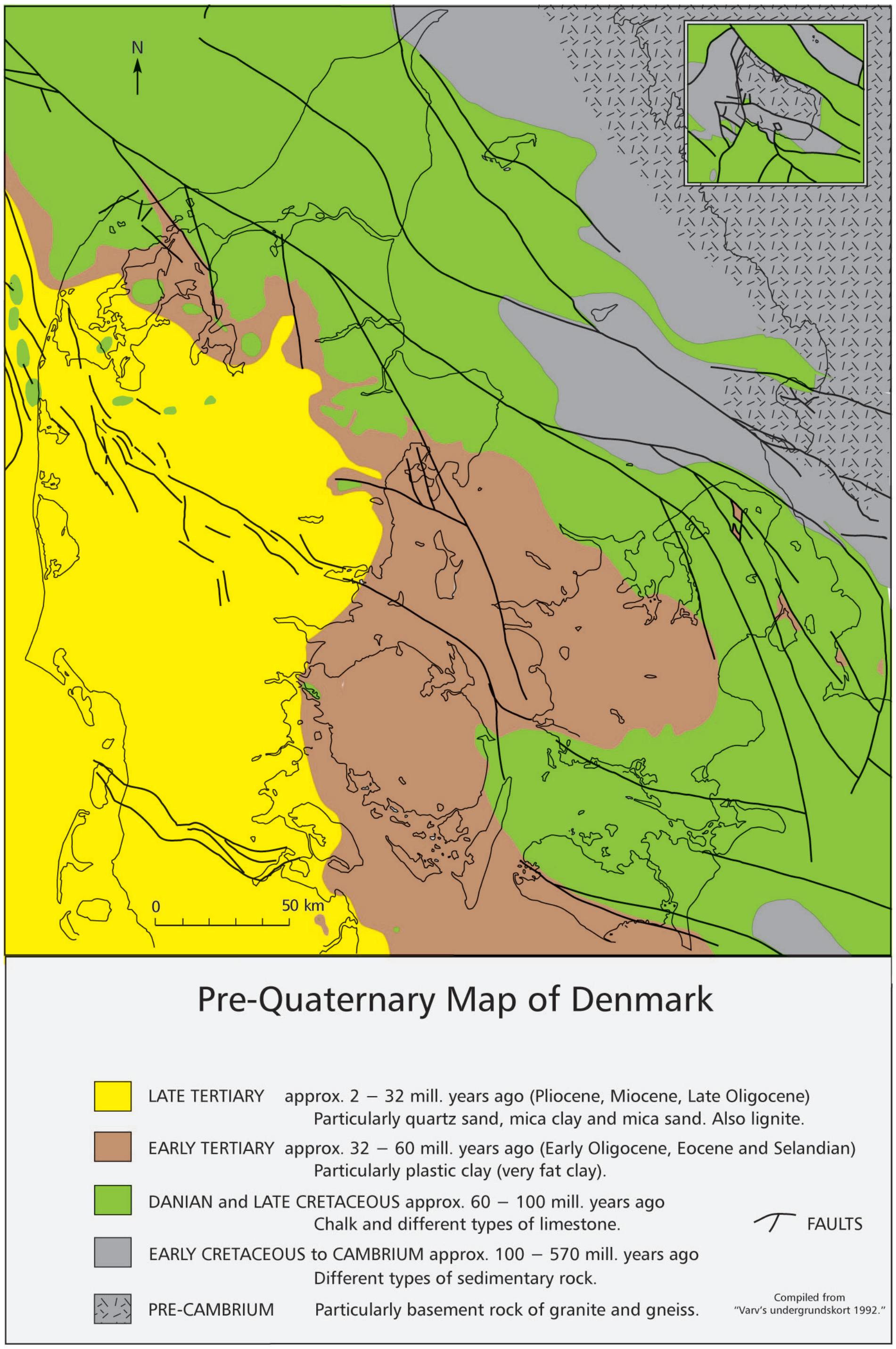

Figure 2.6. Simplified map, showing the Pre-Quaternary surface of Denmark. After /2.3/.

Apart from the tectonic forces from plate tectonics, the Pre-Quaternary surface map also reflects the movements that have occurred in the so-called *salt domes*. The salt is capable of lifting elderly beds so that they appear as knots surrounded by younger beds. Salt domes will be discussed in Section 2.5.

In summary, the Pre-Quaternary surface map (Figure 2.6) is divided into the following structural elements:

- High-lying bedrock to the northeast.
- The border zone between the high lying and deep lying bedrock. This zone is called the “Fennoscandian Border Zone” or the “Sorgenfrei-Tornquist Zone”. There are many faults along this zone, and the frequency of small earthquakes is relatively high here compared to the rest of the country.
- The Danish Basin with salt domes. Here, the deepest wells show that the bedrock is relatively deep - down to a depth of 10 km.
- The Ringkøbing-Fyn Ridge. Here, the bedrock lies only 1 to 2 kilometres down. The Pre-Quaternary surface map shows that the ridge is bounded by NV-SE-going faults, marking the transition between general subsidence in the Danish Basin and the general uplift of the bedrock ridge.
- The Southern Danish Basin in the southwest part of the map. Here is also a number of salt domes. This basin is also known as the “North German Basin” and constitutes the easternmost part of the great North Sea Basin.

Finally, it should be mentioned that the faults drawn on the Pre-Quaternary surface map are only the overall, larger faults that are recognized via seismic measurements. (Seismic measurements are measurements of artificial pressure waves´ distribution in beds). Apart from the faults shown in Figure 2.6, there are probably many other displacements that have not yet been identified and mapped.

2.5 Salt Domes

The salt domes consist of salt (mainly NaCl). The salt was deposited as precipitations from a warm sea that covered most of Denmark some 240 million years ago during the Permian and Triassic Periods (shown in Figure 2.2). In these old periods Denmark was divided into two basins separated by the spine of high bedrock called Ringkøbing-Fyn Ridge, see Figure 2.7.

Originally the beds were formed as horizontal deposits on the seabed. Later they became covered by alternating layers of clay, sand and limestone. As salt has a lower density (approx. 1.9) than the overlying clay, sand and limestone (approx. density 2.3), the salt slowly flows together and pushes itself upward through fractures and through displacement zones in the overlying beds, eventually resulting in the formation of salt domes.

Above salt domes the geological beds are raised locally leading to enhanced erosion relative to the surroundings. This may results in exposure of older Pre-Quaternary beds above the central part of a salt dome. This is why limestone quarries can be found in mid Jutland that is located far from other areas with limestone in Central Jutland.

The individual salt domes are approx. 5-10 km in diameter and the uppermost layer of rock salt is typically 300-500 m below ground surface.

Many salt domes can be recognized on the Pre-Quaternary surface map as isolated “islands” of older layers surrounded by younger layers. There are nearly 20 salt structures in Danish on-shore areas and many situated off-shore in the North Sea.

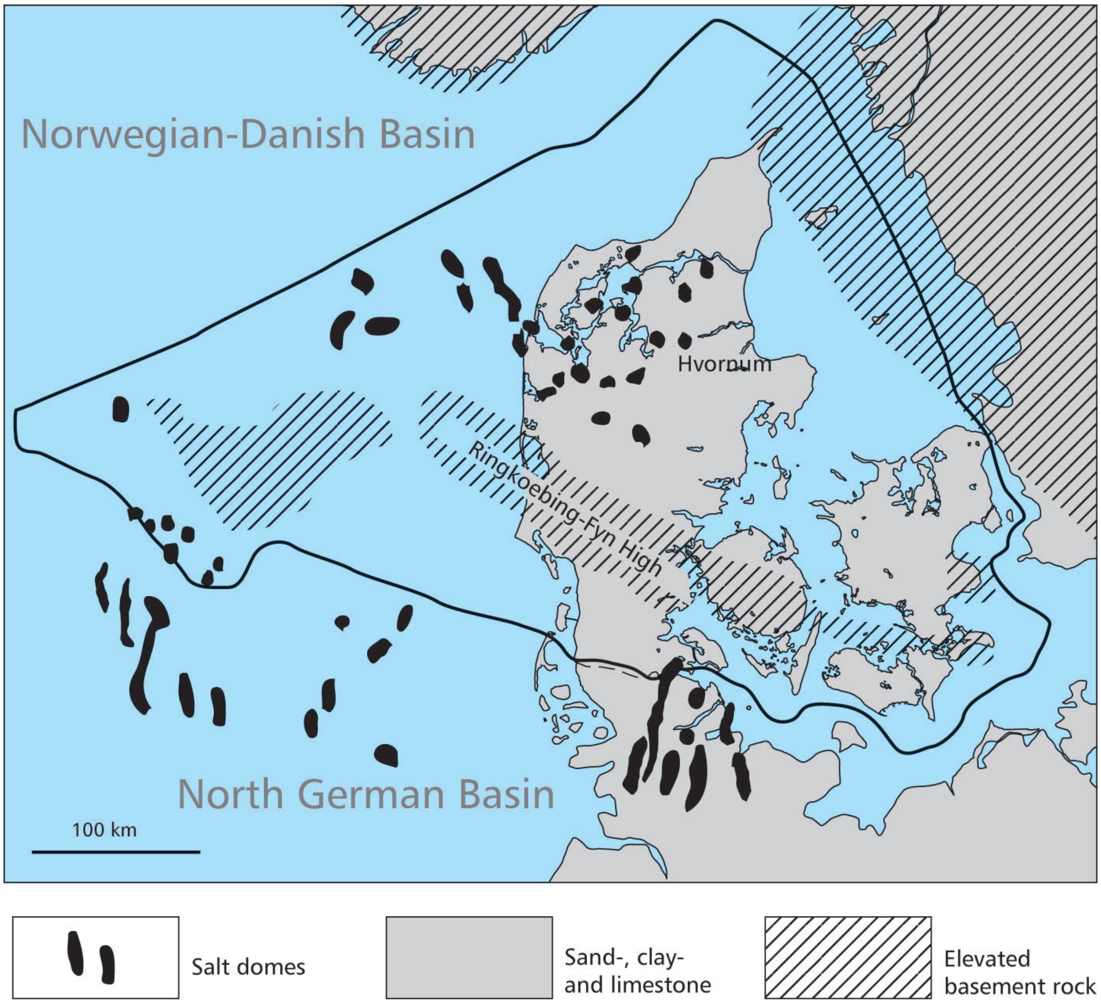

Figure 2.7. Outline of areas with salt domes and relative elevated bedrock. The black line is borderline for Danish sea-territory. From /2.4/.

2.6 Contour map of the Pre-Quaternary Surface

Pre-Quaternary beds are a collective description of all the beds, which were present prior to the Quaternary period. Pre-Quaternary is, therefore, the same as was referred to in the previous section as "subsurface".

A contour map of the Pre-Quaternary surface is a map showing the relief of this surface by contour lines and colour intervals. Contour lines and level intervals are always relative to Level 0, which is defined as sea level. On the map, Figure 2.8, the ranges go from under level -250 metres to about + 100 metres. The map is an A-4 version of a somewhat larger map in scale 1:200,000, which was published by GEUS in 1994.

The lowest levels for the Pre-Quaternary surface are found in northern Jutland and the Skagerak area, where the dark red and purple colours (Figure 2.7) shows that the surface in some of the long troughs are deeper than level -250 metres. Central Jutland is, however, characterized by a high Pre-Quaternary surface; with the yellow and brown colour indicating that the surface of the Pre-Quaternary is in the range of Level 0 to up to + 100 m.

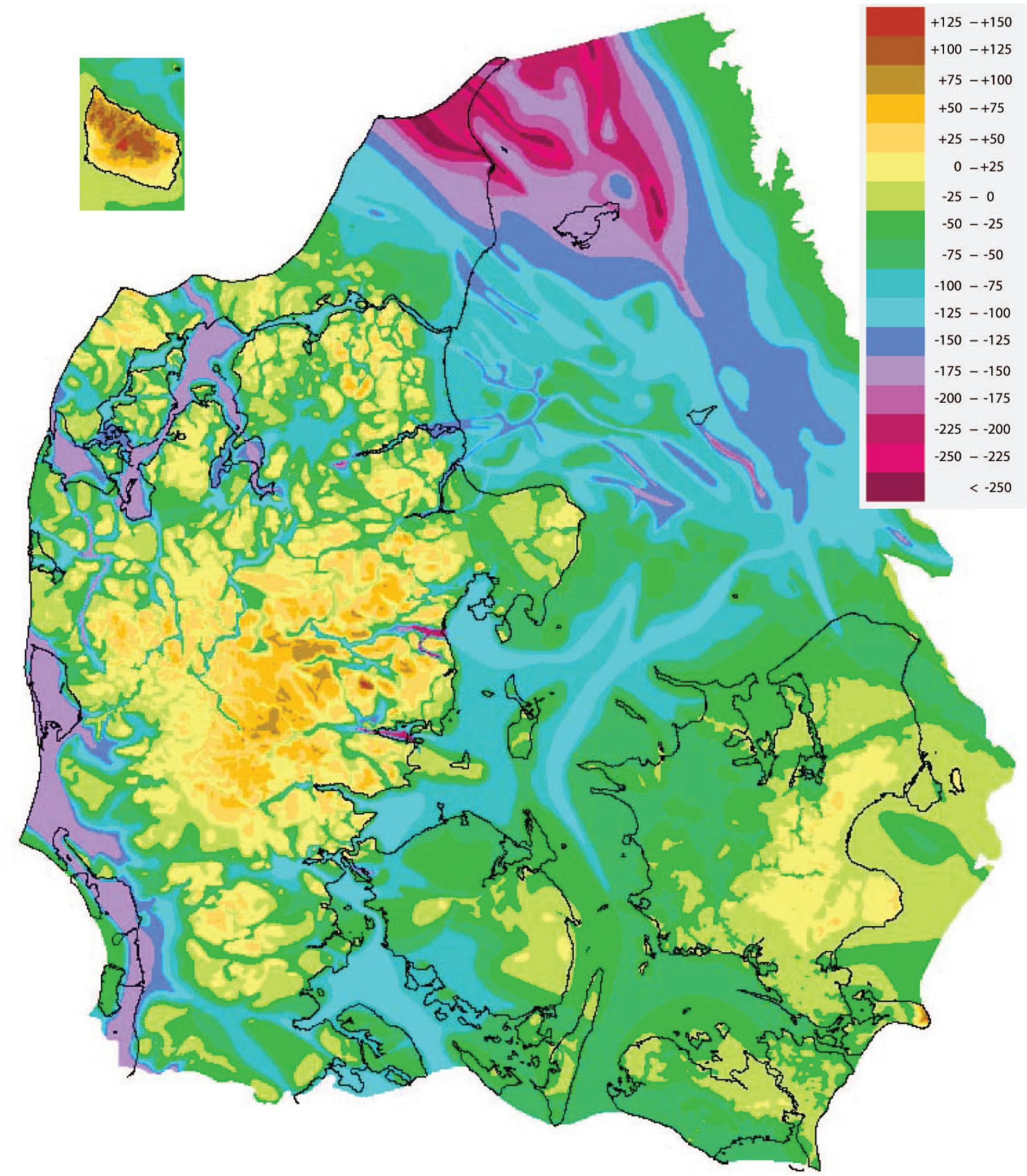

Figure 2.8. The Pre-Quaternary surface of Denmark outside Bornholm. Between each colour interval is 25 meter difference in level. After /2.5/.

The basis for outlining the Pre-Quaternary surface relief is all the boreholes, excavations and cliff exposures where subsurface beds older than Quaternary are revealed. In the areas where there are only few or no boreholes or excavations revealing these old layers, the contour lines may be quite uncertain.

Interpreted contour lines and coloured intervals of the Pre-Quaternary surface is also available as a digital vector-map that can be purchased by contacting GEUS, ref. /2.6/. The digital map of the contour lines is available for VIA-students for use in the GIS-software MapInfo.

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/2.6/ www.geus.dk. Map of the Pre-Quaternary surface mentioned under the menue: “Digital data and maps” (visited 28-03-2010).

Review questions to Chapter 2

1) Figure 2.4 in Chapter 2 shows a cross section of the island of Fyn. Explain where in the section the Pre-Quaternary surface is located (starting in the west and moving eastward, and mark the line showing the Pre-Quaternary surface).

2) What is approx. the lowest level (= deepest level) for the Pre-Quaternary surface along the section across Fyn ? And what is approximately the highest level for the Pre-Quaternary surface along the cross section ?

3) If you go outside the cross section of Fyn, and look at the whole of Denmark, what is the approx. highest and the lowest levels for the Pre-Quaternary surface ?

4) What is used as a basis to draw the contour lines of the Pre-Quaternary surface, as shown in the example of Figure 2.7 ?

5) Which kind of geological processes can cause the level of the Pre-Quaternary surface in some places to vary quite much even within short distances ? Name at least two processes.

6) By combining information from the Pre-Quaternary surface map with information from the summary table in Figure 2.2, you can find out what types of Pre-Quaternary beds you can expect to find in a given locality. Now the question is: What type of Pre-Quaternary beds can be expected when drilling through the Quaternary layers on Amager, Copenhagen ?

7) If you were to drill down through the Quaternary beds on the island of Samsoe, what type of Pre-Quaternary beds can you expect to find there ?

8) Which two sediments are most commonly found from the Quaternary period ?

9) Why do old salt deposits rise upwards, forming salt domes ?

10) Salt domes are found in a large part of Jutland, but there are none on the island of Fyn. Why are there no salt domes on Fyn?

Chapter 3

Information from boreholes

Borehole information is one of the main sources for the assessment of geological conditions, because they directly tell us something about the soil type and their order at a very specific point. Roughly speaking, a distinction between the following types of boreholes can be made:

- Boreholes for water abstraction - can go down to 2-300 metres depth.
- Geotechnical boreholes and environmental boreholes are typically less than 10 metres deep.
- Deep boreholes for investigation of oil and gas can go down to several kilometres depth.

The following describes the recording and availability of information from the three types of boreholes. Emphasis is placed on the first two groups, i.e. boreholes for the abstraction of water and geotechnical and environmental boreholes. To understand the information recorded on boreholes for water extraction, it is necessary to know a bit about water in the soil and the importance of the terms used to describe groundwater conditions and technical aspects of water extraction wells. This is explained briefly in the introductory section of the chapter (3.1 to 3.3). For a detailed explanation on the technical aspects of water, reference is made to /3.1/.

Chapter 3 includes a description of how it is possible, via the Internet, to see drilling information recorded in the Jupiter database at GEUS (*Geological Survey of Denmark and Greenland*), see /3.2/.

3.1 Subsurface water

There is always a certain amount of water present in the ground, more or less filling the voids between the soil grains and the fractures in the solid rock. If the voids and fractures contain both air and water, the zone is said to be *unsaturated*. Other names for the unsaturated zone are *vadose zone*, *soil moisture zone* or *zone of aeration*. Below the unsaturated zone lies the *saturated zone*, where the voids and fractures are completely filled with water, see Figure 3.1. The term *groundwater* is used for the exchangeable part of water in the saturated zone, i.e. the circulating part of the water. Over the years this will be replaced by precipitation infiltrating down from above.

In Denmark the thickness of the unsaturated zone does not exceed 70 - 80 metres. In areas with high mountains and dry deserts, in contrast, the unsaturated zone can be several hundred metres thick. The boundary between the saturated and unsaturated zone is called the *capillary water table*. This is always located higher than the level we call the *groundwater table*, see GWT in Figure 3.1. The groundwater table is also named the *groundwater head* and indicate the groundwater's pressure level, and this is detailed in Section 3.2.

How much the capillarity groundwater table is above the groundwater table depends on how big the *capillary effect* (= capillary force) is in the soil beds above the groundwater table.

Fine grained deposits such as clay and silt have a strong capillary effect and then the water can be raised several metres above the groundwater table - often up to the surface. In coarser sediments, such as sand and gravel, the capillary effect, in contrast, is much weaker and the capillary water table is almost coincident with the groundwater table, or only a few centimetres above it. See Figure 3.1.

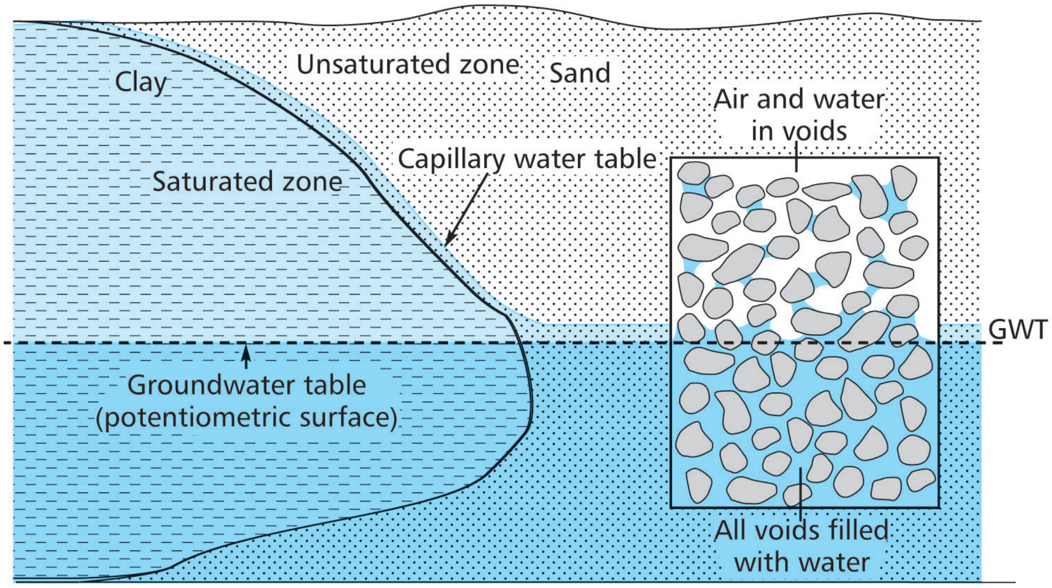

Figure 3.1. Subsurface water - saturated and unsaturated zones.

3.2 Aquifers and their groundwater heads

An aquifer can be defined as water-saturated rock, from which it is possible to abstract groundwater. The size of the aquifer is determined by the extent of the permeable rock strata. Aquifers can be isolated, i.e. surrounded by impermeable clay layers on all sides, or they can be widespread, for example as solid limestone strata or large outwash plains. Examples of both isolated and widespread aquifers are shown in Figure 3.2.

Each aquifer has a *groundwater head* (pressure level) also named a *potentiometric surface*. Another name for the potentiometric surface is *groundwater table* shown as GWT in Figure 3.2. The names are used somewhat interchangeably, but they refer all to the same, meaning the water level that can be measured in a borehole screened in the aquifer. More about screens in boreholes in section 3.3.

The location of the groundwater table relative to the upper boundary of the aquifer determines whether the aquifer is *unconfined*, *confined* or *artesian* (Figure 3.2). In an unconfined aquifer, the groundwater table lies within the permeable rock, and the voids just above the water comprise an unsaturated zone containing air. The aquifer is not completely "filled up". Figure 3.2 shows three examples of unconfined aquifers - the two small sand lenses in the clay and the right part of the primary sand aquifer.

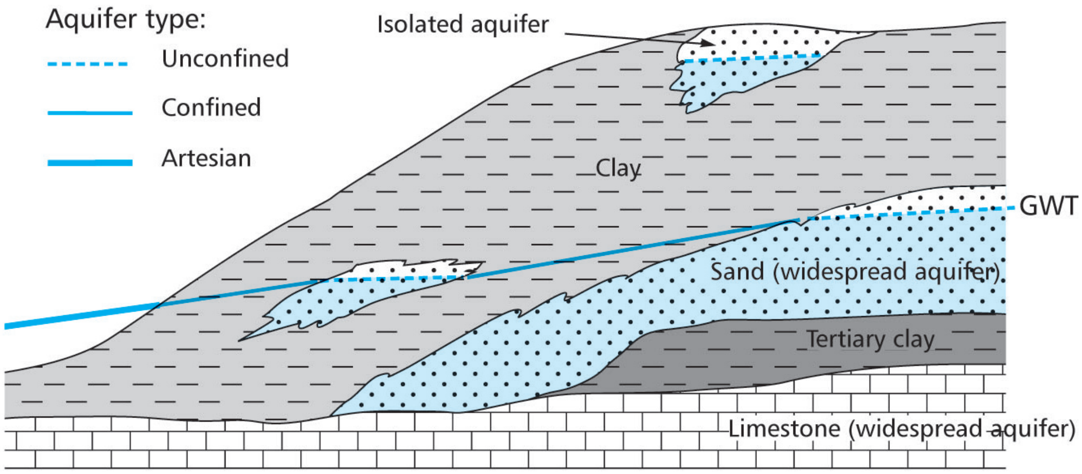

Figure 3.2. Examples of different types of aquifers. GWT is groundwater head.

In *confined aquifers* the groundwater table lies above the upper boundary of the permeable rock that constitutes the aquifer. There are no air-filled voids just above the aquifer, and the confined aquifer is thus under pressure. In Figure 3.2 there are two confined aquifers – the bottom limestone aquifer and the left part of the primary sand aquifer.

An *artesian aquifer* is a confined aquifer in which the pressure level of the groundwater lies above ground surface. This can only happen if the upper layer at ground surface is impermeable and can stand the below water pressure. In Figure 3.2, the far left part of the limestone aquifer is artesian as the pressure level lies above ground surface. When a borehole is drilled into an artesian aquifer the water will rise like a fountain, as the hinterland's potentiometric level is higher than the actual ground surface's. Artesian aquifers are often found in valleys or lowlands, where the upper rock consists of impermeable clay or organic mud.

In some places there is no aquifers. In such cases the borehole only passes through impermable beds as e.g. silt or clay. Groundwater - if present - will only seep very slowly into the well. With such boreholes it is not possible to measure a representative water level until after a long period. The borehole is said to be negative in the sense of water abstraction.

3.3 Completion of boreholes for water abstraction

Drilling work can be divided into cable tool drillings and mud circulation drillings also named rotary drilling. By cable tool drillings, the excavated material is mechanically transported to the surface with a tool fixed on the drilling rod or on a steel cable. By mud circulation drillings the material is transported to the surface suspended in a continuous fluid flow of thick mud. Both methods can be further subdivided according to the type of cable tool and to the direction of the circulating mud. A detailed description of these drilling methods can be found in /3.1/.

If water abstraction is intended from the borehole – and a suitable permeable, water-saturated soil or rock has been revealed – the borehole has to be completed for use by installing a screen and a casing (Figure 3.3). The screen is a pipe with holes or slots to be positioned at the same depth interval as the aquifer to enable groundwater to flow into the well.

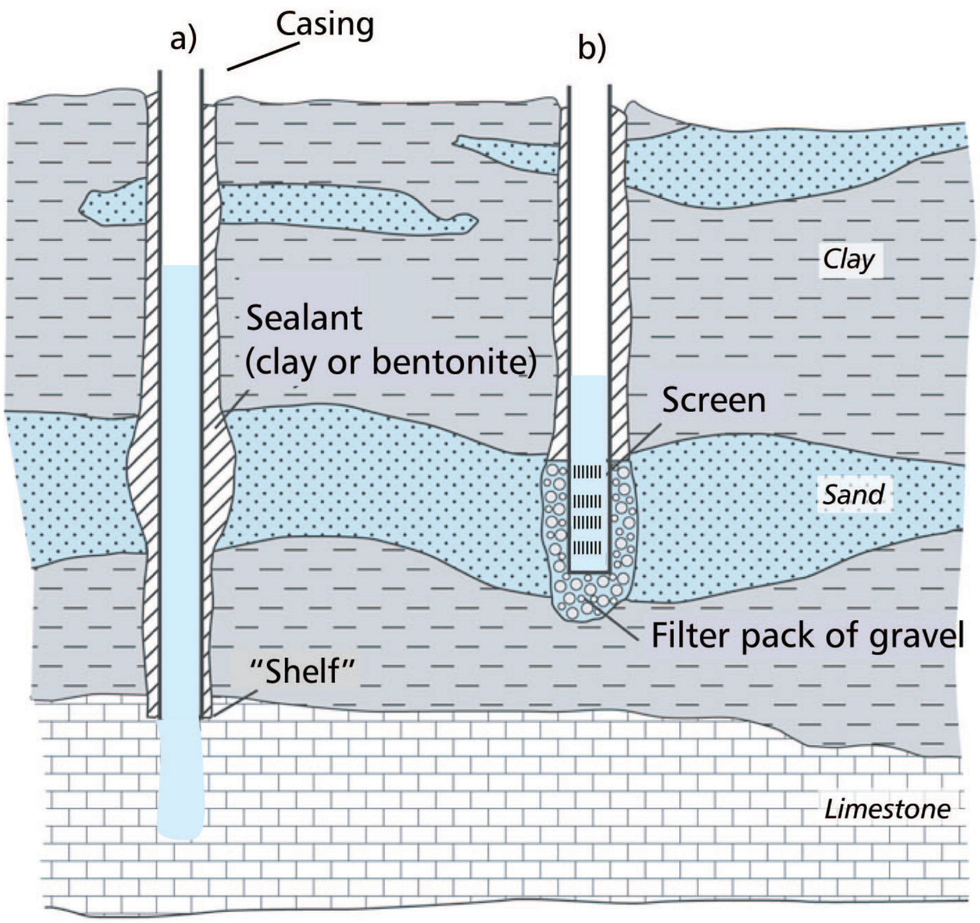

Figure 3.3. Well in a) limestone and b) sand. Both wells have casings, but only the well in sand is equipped with screen.

The casing serves to protect the well from the pressure of the surrounding rock and thereby prevent the well from collapsing. Note that the word "well" is used instead of "borehole", when the borehole has been completed with casing and screen.

The diameter of the casing and screens must, of course, be smaller than the diameter of the borehole. The borehole diameter is the diameter of the raw borehole - how big this is depends on the used drilling tool. A rough rule of thumb says that the borehole diameter should be about twice the diameter of casing and screen.

In limestone a screen may not be necessary because limestone is usually so solid and hard that it does not collapse. In such cases the pipe for casing is extended so as to protrude a few metres down into the limestone.

Once the well has been completed with a screen and casing the groundwater head can be measured. This is done by measuring the distance from a fixed point on the ground surface to the surface of the water in the well pipe using a water level meter. To compare the groundwater head in different wells the measurements are always expressed relative to sea level (value 0) by subtracting the depth to the groundwater head from the surface elevation.

After mounting of the screen, the well is ready to be pumped clean of mud and debris left by loosened material from the drilling process. When water is pumped from an aquifer, there will always be a drop in the groundwater head caused by the pressure release from pumping (Figure 3.4). Therefore measurements of the water level are taken before, during and after pumping. Furthermore, the time for restoring of the lowered water table to its original level is often recorded. This information must be reported on the well log together with a record of the beds penetrated.

On the well log the amount of water pumped up is named the *yield* of the well with the unit m^3/h also named the *capacity* of the well. When you want to compare the capacities of different wells you calculate the *specific capacity* of the well defined as the yield of the well divided with the drop caused by the pumping. The clean-pumping may subsequently continue to constitute a real *test pumping*, where the water levels in nearby wells (observation wells) are measured. A test pumping can last from one day up to a few months.

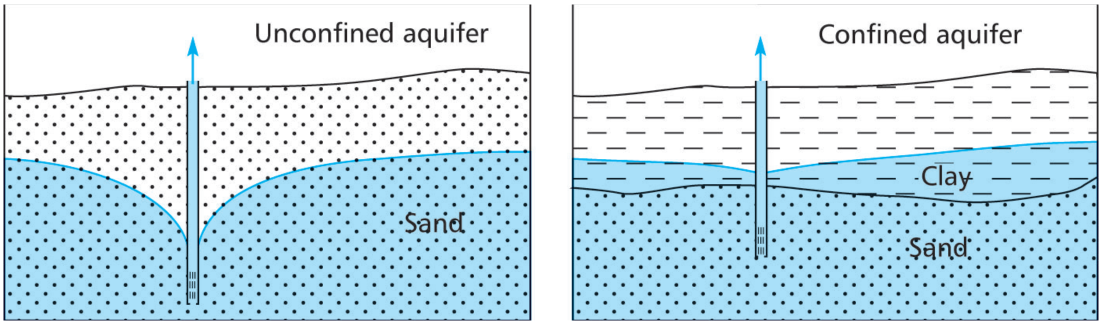

Figure 3.4. Drop in groundwater head caused by pumping.

3.4 Registration of boreholes

In Denmark boreholes are registered centrally in the National Well Database at GEUS, /3.2/. GEUS is an abbreviation for *Geological Survey of Denmark and Greenland*. The Well Database was created in 1926, but the database also contains information on many much older wells. According to Danish legislation /3.3/ all drilling for water or raw materials must be reported to GEUS.

The well-contractor must, in addition to written drilling information, also deliver soil samples of the penetrated beds. The well-contractor must take soil samples for every 5 metres of depth, but at least one sample for each bed that is different from the previous bed.

At GEUS, geologists and their specially trained assistants describe the submitted drilling samples. This means that in addition to a general characterization of soil type, incl. grain size, appearance, etc., an *interpretation* of the sample's original deposition environment and its geological age is also given. Conditions pertaining to the describing of soil samples are detailed in Chapter 11.

For many of the earlier water wells, only the well contractor's description of the different beds is available, as no samples of the actual penetrated beds have been submitted.

At GEUS, the boreholes are awarded a so-called "DGU number", which ensures that nationwide drilling is uniquely numbered. The system was adopted in 1890 when at that time DGU (Danish Geological Survey) was created.

The DGU-numbering system is based on the division of Denmark into atlas sheets (Figure 3.5). The division into atlas sheets corresponds to what at that time was the Geodetic (Mapping) Agency's division into maps with a scale of 1:40,000. Within each atlas sheet, the wells have serial numbers, and for older wells sometimes sub-cataloguing in the form of a), b), c). Wells in the Horsens area belongs to, for example, Atlas Sheet 107, and therefore all wells in this area begin with 107, followed by a dot and a serial number see Figure 3.5.

Today there are approximately 290,000 wells registered in the Well Database at GEUS. Approximately 232,000 of these wells are publically available online via the Internet in the *Well Database Jupiter*. Access to Jupiter, and how to get the well information, is explained further in Appendix 1.

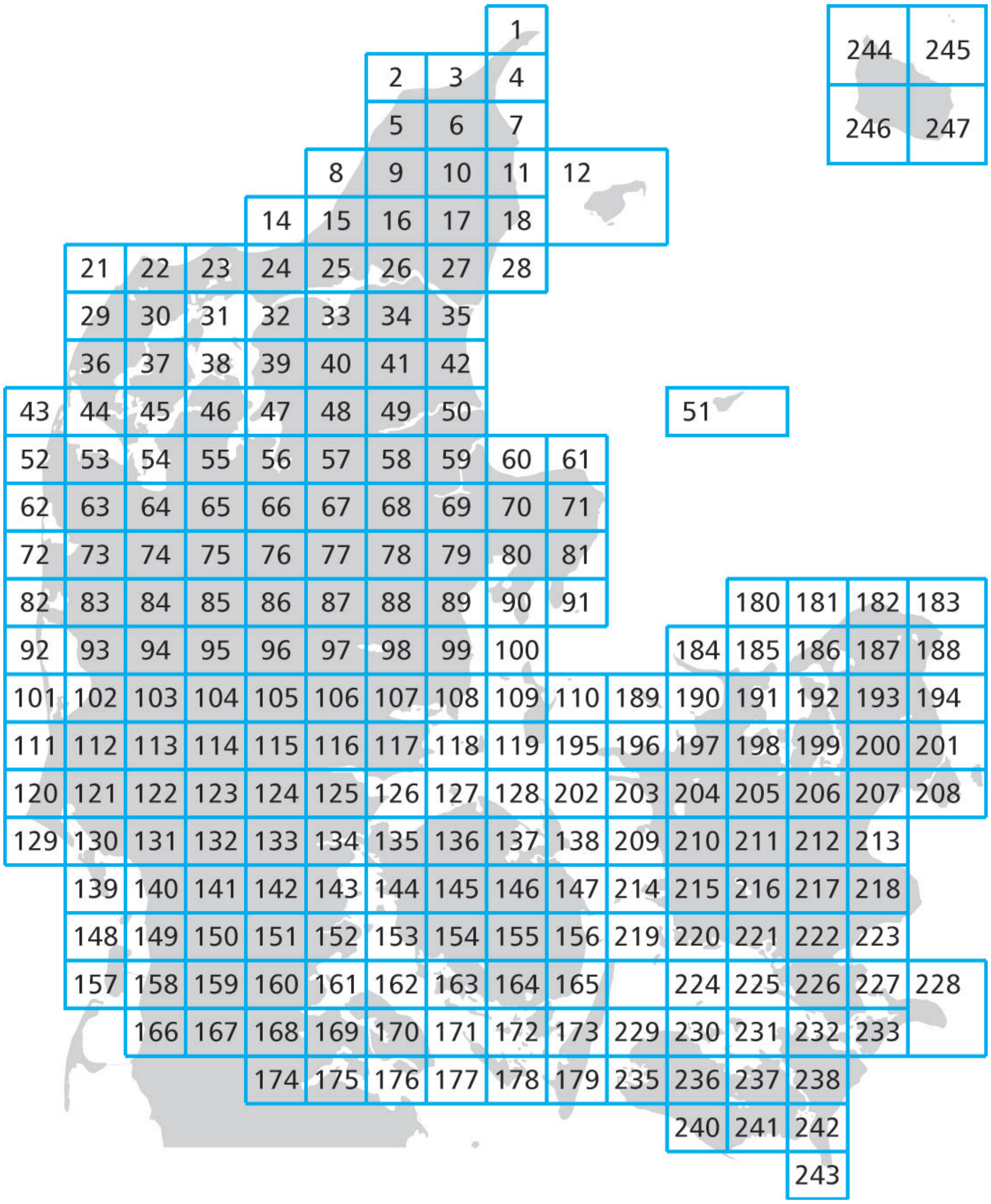

Figure 3.5. Division of Denmark into atlas sheets. This division has an impact on which file number GEUS assigns a new well.

3.5 Geotechnical and environmental boreholes

Geotechnical boreholes are performed in order to investigate the upper beds to assess foundation conditions for a given building, road construction, or other construction works. Environmental boreholes are performed to investigate soil contamination or groundwater contamination.

These two categories of wells must be reported to GEUS (as for water extraction wells) if casings or screens are left permanently in the borings, /3.3/. This does not occur in the majority of geotechnical and environmental technical borings, which are typically less than 10 metres deep and are closed after the investigation is completed.

Many companies perform geotechnical as well as environmental drilling. Normally there is no central access to drilling records from these shallow wells. Each company files its own wells, and if exchange of drilling information is needed, this can only be done by the company obtaining permission from the customer, who has paid for the drilling work.

With the opportunities that the Internet offers, the geotechnical boreholes, however, have started to become more accessible. Thus, the company GEO have opened their archives so that it is possible, through their website, to view a map with red dot signatures showing the locations where the company has carried out drilling or performed other studies, ref./3.4/. Then one can negotiate with the company for the purchase of information from their project database.

The drilling logs for geotechnical boreholes often have a common character, as the borehole-column is drawn in the middle of the paper. The description of the individual drilling samples with interpretation of the deposition environment and geological age is seen to the right of the boring-column, and the geotechnical test results are shown graphical on the left; see the example in Figure 3.6. Left of the borehole-column are also shown the measured level of the groundwater head together with well completion information such as placement of screen and casings.

The legend for the rock in the borehole column is defined in the Foundation Norm; DS 415, see Figure 3.7.

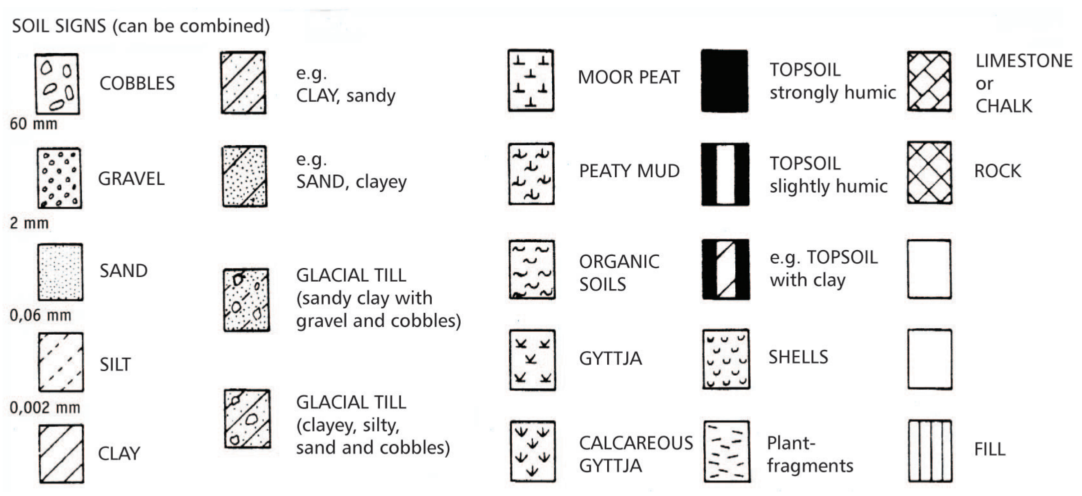

Figure 3.7. Soil and rock legend used on Danish geotechnical drilling logs. From /3.6/.

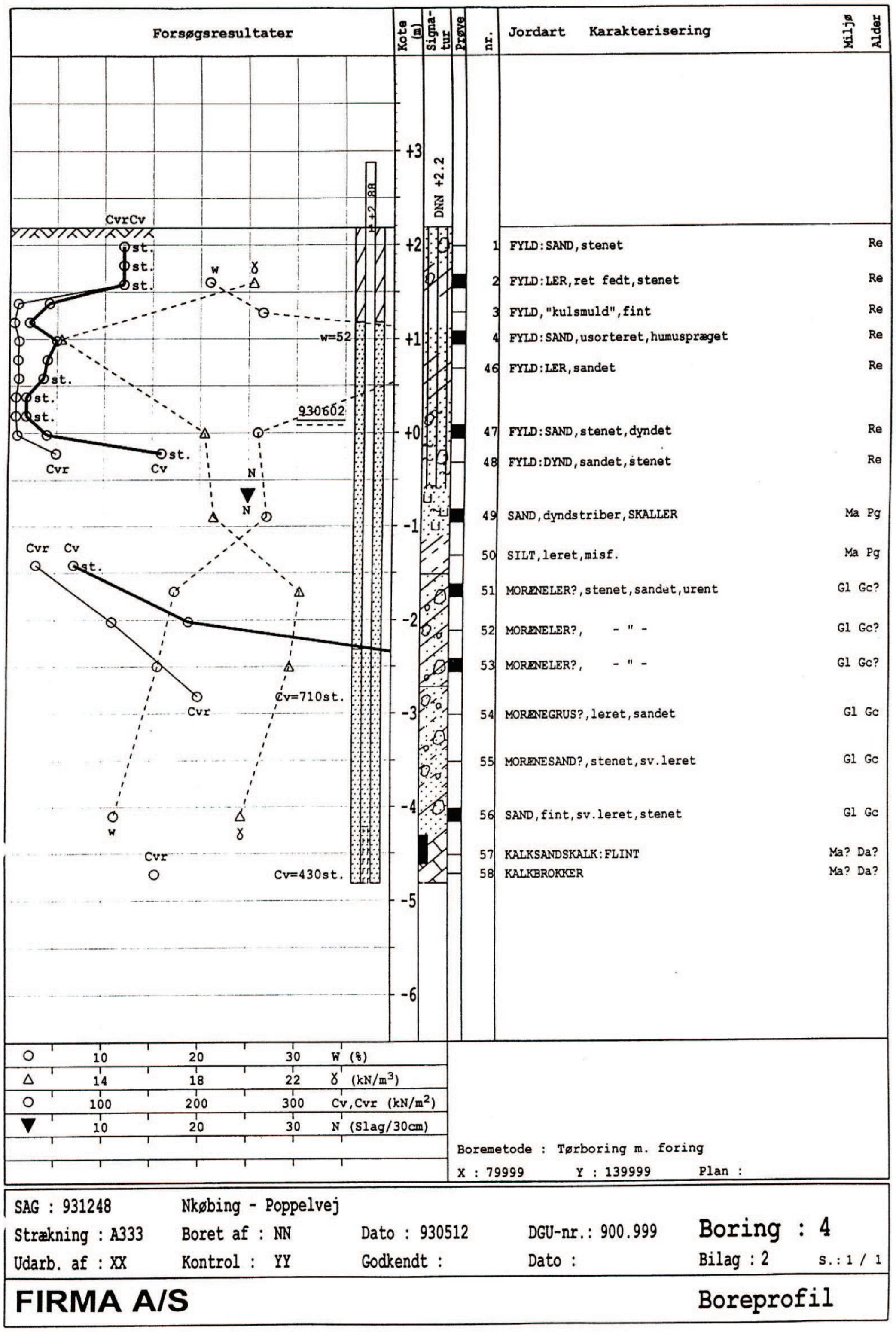

Figure 3.6. Example of a geotechnical boring record. From /3.4/.

3.6 Deep Wells

Most deep boreholes are carried out to search for oil and gas. These wells are called investigation wells. If sufficient quantities of oil or gas are found in a field, a series of deep drillings called production wells will subsequently be carried out. Because there are vast economic interests in the results from these deep drillings, the firm or company doing the costly drilling may keep the drilling information secret for up to 5 years after their execution. After this period, the most important data about the drilling work is published by GEUS.

Information about the deep drillings can be viewed on the Internet /3.7/. There is also a price list for all information on any given borehole. Figure 3.9 (next page) shows an example of how data on deep boreholes is shown on the Internet.

In total, there are 162 deep drillings from the Danish North Sea and 64 deep drillings registered on land. In addition, there are 5 deep drillings from inner costal Danish waters. In 2007 GEUS published a map of the location of all the deep drillings on land and in the North Sea area. This map can be viewed on the Internet along with maps showing the limestone structures in the substratum. /3.8/.

The samples that are extracted in connection with depth drillings usually undergo a careful examination of the micro-fossils present to interpret the deposition environment and geological age of the sediments and rocks, which have been penetrated. The results of these studies, together with geophysical surveys of the area, provide a model of the deep structures in the specific area.

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/3.1/ Karlby, H. and Sørensen, I.: *Vandforsyning* (Water supply). Teknisk Forlag 1998.

/3.2/ Jupiter Database. Available via http://www.geus.dk (Visited 02-04-2010).

/3.3/ *Bekendtgørelsen om udførelse og sløjfning af boringer og brønde på land* (Executive Order on Execution and Closing of Boreholes and Wells on Land). BEK No 672 of 26/07/2002.

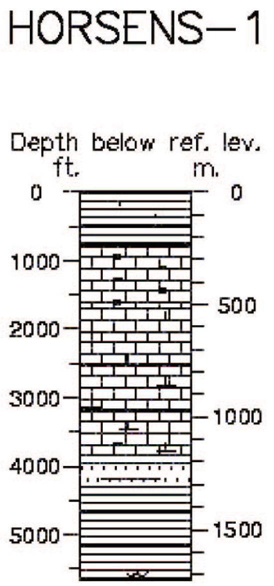
/3.4/ www.geo.dk. Link from the frontpage: “Har GEO lavet undersøgelser på din grund? Slå op i GEO´s projektdatabase” (Have GEO done studies on your land? Look it up in GEO’s project database). (Visited 02-04-2010).

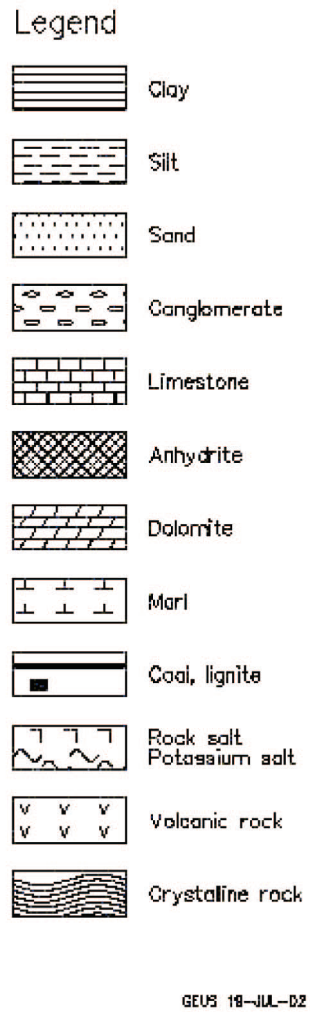
/3.5/ *Reference Sheet for Geotechnical Boring records*. DGF-Reference Sheet 2 August 1995. Danish Geotechnical Society

/3.6/ DS 415. *Norm for fundering* (standard for Founding) (4th ed. 1999). Nyt Teknisk Forlag.

/3.7/ www.geus.dk. Well data (deep wells) can be viewed via the menus Arbejdsområder / Energiråstoffer / Danmark. (Visited 02-04-2010).

/3.8/ Vejbæk, OV, Bidstrup, T., Britz, P., Erlström, M., Rasmussen, ES and Sivhed, U.: *Chalk depth structure maps. Central to eastern North Sea, Denmark*. GEUS Bulletin 13, 9-12. Available at www.geus.dk/publications/bull/nr13. Visited 02-04-10.





Technical and administrative data

Location	Land
Longitude	09°54'13".24
Latitude	55°56'11".1
UTM Zone	32
UTM Easting (x)	556454.8 (m)
UTM Northing (y)	6199508.0 (m)
Well block no.	5509/4-1
Reference point	RT 56 m above MSL
Ground level	53 m above MSL
TD log	1730 m below RT
TD drill	1729 m below RT
The well is	Vertical
Structure:	Horsens
Spudded	13/07-1958.
Completed	31/07-1958
Spud classification	Exploration
Status (completion)	Plugged and abandoned
License	Dapco
Operator	(Standard) Dapco

Chronostratigraphy (Periods)

Top	Bottom	Unit
m. below ref. level.		
3	170	Quaternary
170	472	Tertiary
472	1225	Cretaceous
1225	1287	Jurassic - Cretaceous
1287	1572	Jurassic
1572	1726	Triassic

Figure 3.8. Part of available information on the deep borehole Horsens 1, executed in July 1958. The borehole reached a depth of 1,726 metres and stopped in layers from the Triassic Period (about 200 mill. years old).

Review questions to Chapter 3

1) Is it possible, that one drilling log can show more than one aquifer ?

2) Can areas in Denmark be found, where there are no aquifers ?

3) What is the difference between an unconfined and confined aquifer ?

4) Boreholes for water abstraction are often completed with a casing and a screen. However, it is not necessary to put screens in all types of rock. In what types of rock is it unnecessary to put a screen in order to pump water up ?

5) What information is needed to calculate the level of the groundwater head in a given drill point ?

6) Which unit is used to indicate the yield of a well ?

7) In Appendix 1 is shown a well log from borehole no 64.719. What is the specific capacity of this well ? (you have to calculate the value from information given on the well log).

8) Many boreholes drilled for geotechnical or contamination investigation are not reported to GEUS. What criteria determine when a report of a borehole to GEUS is obligatory ?

9) Can the groundwater head be located above the ground surface ? If yes - what conditions are then prevalent on this site ?

10) Can the groundwater head be below sea level ? If yes - what conditions are then prevalent on this site ?

Chapter 4

Upper Cretaceous and Danian Periods

4.1 Depositional environment and sediments

The two periods Upper Cretaceous and Danian will be described together, because the materials from the two periods are generally similar. During these two periods, Denmark was part of a widespread ocean that covered most of north-western Europe.

Not much continental material was deposited in this sea because the adjacent land areas had a very low relief (uplift of the Scandinavian mountains had not yet begun). The deposits formed on the bottom of this sea were mainly composed of calcareous shells and other remnants of the organisms that lived in the sea at the time.

In the Upper Cretaceous Period, white chalk up to 2 kilometres in thickness was deposited in Danish territory. White chalk consists of microscopic calcareous plates of marine plankton. The size of each plate is between 0.001 and 0.01 millimetres. It is these small pieces of limestone flakes that we know as white, smudging dust from blackboard chalk (Figure 4.1).

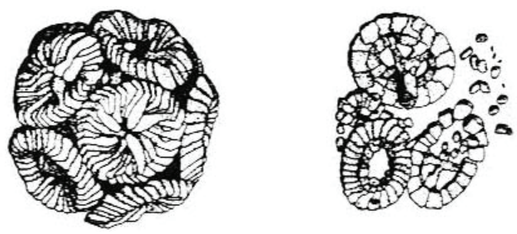


Figure 4.1. Typical calcareous algae (coccolite). The whole body (left), and broken as lime fragments (right). The coccolite is magnified approx. 4000 times. After /4.1/.

The Upper Cretaceous Period is followed by the Danian Age, around 65 million years ago; this is the oldest part of the Tertiary Period. The boundary between the Upper Cretaceous and Tertiary is mostly not clearly visible in the sediments, as Denmark was still generally covered by the ocean where calcareous sediments were deposited. However, there is a change in the biological life of the ocean, which allows geologists to distinguish between the Upper Cretaceous and Danian. More on the Cretaceous-Tertiary border in Section 4.6.

Danian	Marine (inner shelf)	*Alternating limestones including* **Clastic limestones (silt/sand grade)** **Bryozoan** and **Coral limestone** **Micritic limestone** (= chalk)
Upper Cretaceous	Marine (outer shelf)	**Chalk** (very fine-grained limestone)

Figure 4.2. Geological age, environments and sediments from Upper Cretaceous (100 - 65 million years) and Danian (65 - 60 million years). Part of Figure 2.3.

Compared to the quite deep ocean of the Upper Cretaceous (100 - 600 metres), the ocean during the Danian Period was shallower and had varying water depths. Hence different types of limestone ware deposited in Danian compared to Upper Cretaceous. In the deeper parts of the ocean, fine-grained write chalk was deposited as previously, while at lower water depths, the sediments were of a more coarse nature like *Bryozoan limestone* and *Coral limestone* and *lime-sandstone*.

Bryozoan limestone is defined as limestone dominated by small stalks from moss animals (bryozoans), which form banks on the seabed. Coral limestone is formed from the remains of large colony-forming organisms that established coral reefs on the seabed. Lime-sandstone consists of degraded limestone and skeletal remains with a grain size distribution similar to that of sand (0,04 – 2 mm). The components in lime-sandstone were eroded from already deposited calcareous sediments and then transported by currents in the sea before their final deposition.

Internally within the limestone is found varying amounts of the mineral *flint*, which is formed by chemical precipitation from water in voids and “empty places” between the limestone grains. So the flint is precipitated later, that means after the limestone was deposited. The flint can occur as a layer of nodules or it can be finely distributed within the limestone. Besides flint there are also occurrences of lumps or small needles of the mineral *pyrite*.

4.2 Characteristics of samples from Upper Cretaceous and Danian

Since both the chalk and limestone consist of calcium carbonate, $CaCO_3$, these sediments will always effervesce strongly when mixed with diluted hydrochloric acid. It may not always be easy to determine whether a given sample of limestone belongs to the Upper Cretaceous or Danian Period. When the location of the limestone is known, the Pre-quaternary map mentioned in Chapter 2 can be useful. However there are also the following simple characteristics (Figure 4.3) to distinguish between limestone from the two periods:

Limestone from the Upper Cretaceous	Limestone from the Danian
Uniform and homogenous appearance	Varying appearance
Only one type of limestone (white chalk)	Many different types of limestone
White colour	Gray to white colour
Flint components are usually black	Flint components are typically gray
Always fine-grained	Can be sandy and coarse
General not hard but soft	Typical occurrence is a hard limestone

Figure 4.3. Typical differences in limestone characteristics from Upper Cretaceous and Danian.

As shown in Figure 4.3, the limestone from Danian is typically harder than white chalk. There are often visible fossils in the limestone from the Danian (sea urchins, shells, etc.). The types of limestone we usually distinguish between in Danish territorial areas are listed below (in the limestone in the North Sea, however, it may be different).

Varieties of limestone from the Upper Cretaceous and Danien

- **Bryozoan-limestone** consists of small stems and stalks in a mesh. The spaces between the stalks are typically filled-in with finely grained calcareous mud.

- **White Chalk** from the Upper Cretaceous is very fine-grained and so soft, that it rubs off when touched. The colour is white or light gray. Flint nodules in white chalk are typically black and sharply demarcated.
- **Coral limestone** consists of larger stems in a mesh often with an intermediate mass of calcareous mud. The appearance of coral limestone may vary widely because of different degrees of dissolution.
- **Lime-sandstone** consists of disintegrated lime grains and skeletal remains that are more or less coarse grained and typically cemented together of dissolved and re-precipitated lime.
- **Lime-mudstone** is fine-grained limestone, which can be a little coarser than white chalk and typically more solidified. The lime is often found with large quantities of flint, which may be finely distributed within the limestone or may be in the form of nodule layers.
- "**Copenhagen Limestone**" is (according to /4.2/), a silty and sandy lime-mudstone with about 20-30 % calcareous sand and 40-60 % lime-mud. In addition, Copenhagen Limestone has a small content of clay. The flint content is relatively high and can locally constitute up to 25 % of the limestone. Pure flint is also found in layers up to 0.5 metre thickness.

Earlier names for Copenhagen Limestone is *Saltholm limestone* (named after the island Saltholm east of Copenhagen) or *Klang-limestone* because of the sounding from the hard limestone with finely distributed flint. Copenhagen limestone is subdivided into Lower, Middle and Upper Copenhagen Limestone during the civil engineering works on the Metro Project in the 1990s, and the Øresund Bridge /4.2/.

4.3 Present outline and exposures

Limestone from Upper Cretaceous is found today throughout Denmark except for the island Bornholm in the Baltic Sea and Skagen (in the very northern part of Denmark). Limestone from Danian period is not found in the most northern and south eastern parts of Denmark – e.g. north of the Limfjord in Jutland and on the south eastern islands Lolland, Falster and Møn.

The distance from ground surface and down to the limestone varies a lot. In some places the limestone is found just at the surface, and in other places this rock is more than 1000 metres below ground surface. A good overview of the varying relief is obtained by looking at the printed Danish map *Kalkoverfladens struktur* in scale 1:500.000 – the title can be translated to "The Structure of the limestone surface", /4.3/. This map shows with coloured intervals the level of the limestone surface relative to sea level as seen on the reduced part in Figure 4.4. "Limestone" includes here both the white chalk from Upper Cretaceous period, and limestone from the Danian period.

The Limestone relief in the whole North Sea area (including Danish territory) was described and published by GEUS in 2007, see /4.4/. The publication is available on the Internet, and offers, among other things, a map with the title "Top Chalk depth structure map" and another map showing the entire thickness of the limestone layers (Chalk Group isopach map).

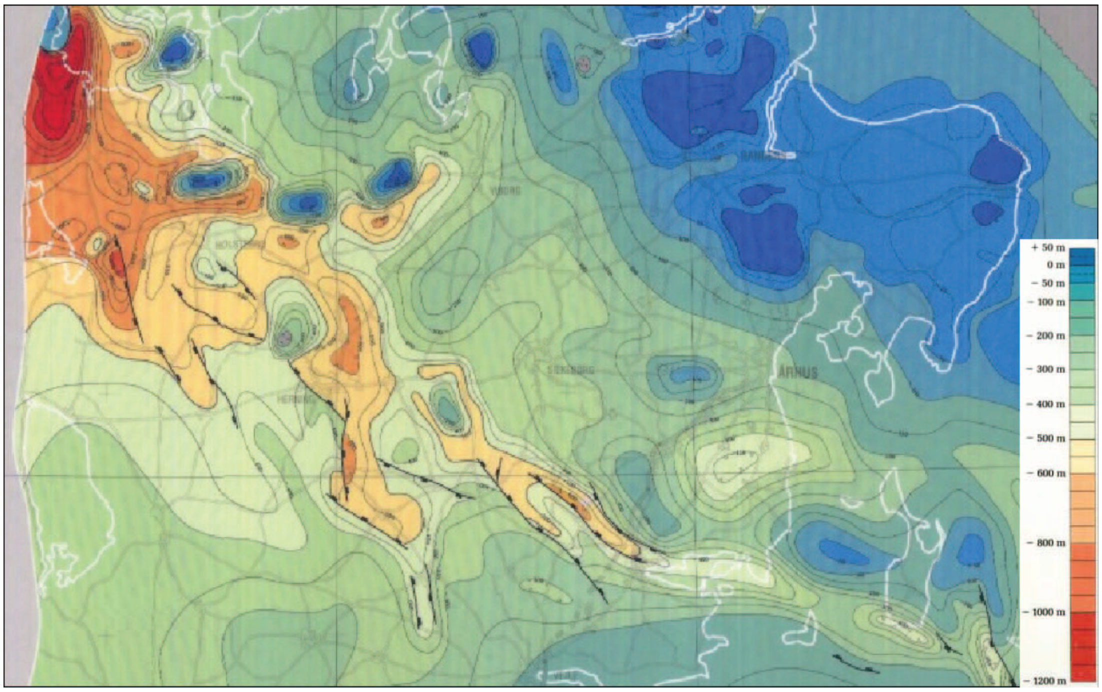


Figure 4.4. Reduced section of the map showing the the structure of the limestone surface. Dark blue indicates that the limestone is relatively elevated. Note the salt domes in Central Jutland seen as small blue islands. The original map is printed in scale 1:500.000. /4.3/.

Coastal cliffs with limestone exposures can be seen in several places in Jutland. For example, Bulbjerg Cliff on the North Sea coast, and Karlby and Sangtrup Cliffs north of Grenå. All three localities show Bryozoan-limestone from the Danian, see Figure 4.5.

Previously, a high limestone rock stood beside Bulbjerg about 100 metres offshore in the water. It was called *Skarreklit* and consisted of Bryozoan-limestone which, because of its extra hardness, had avoided being eroded away by the sea. In 1978, the waves finally managed to undermine the cliff so much that Skarreklit crashed into the sea, and today one can no longer see where it had been.

Møns klint is a famous cliff of white chalk situated on the east point of the island Møn in South East Denmark. The cliff shows disturbed bedding with 20 to 30 large outcrops of moraine clay, and glaciofluvial sand is seen as slices between the limestone exposures. At Stevns Klint on East Zealand the border between the white chalk and Bryozoan-limestone is seen in the cliff section. The bedding is here nearly horizontal and relatively undisturbed.

4.4 Geotechnical properties of chalk and limestone.

Generally speaking chalk and limestone is good for foundations of buildings. In the case of white chalk, however, this rock may be soft and somewhat weak in load capacity. Thus, white chalk locally can be partially dissolved by in-seeping water so the chalk ends up having a texture almost like toothpaste. This was particularly noted in the construction of the Farø Bridge, which links Zealand and Lolland-Falster.

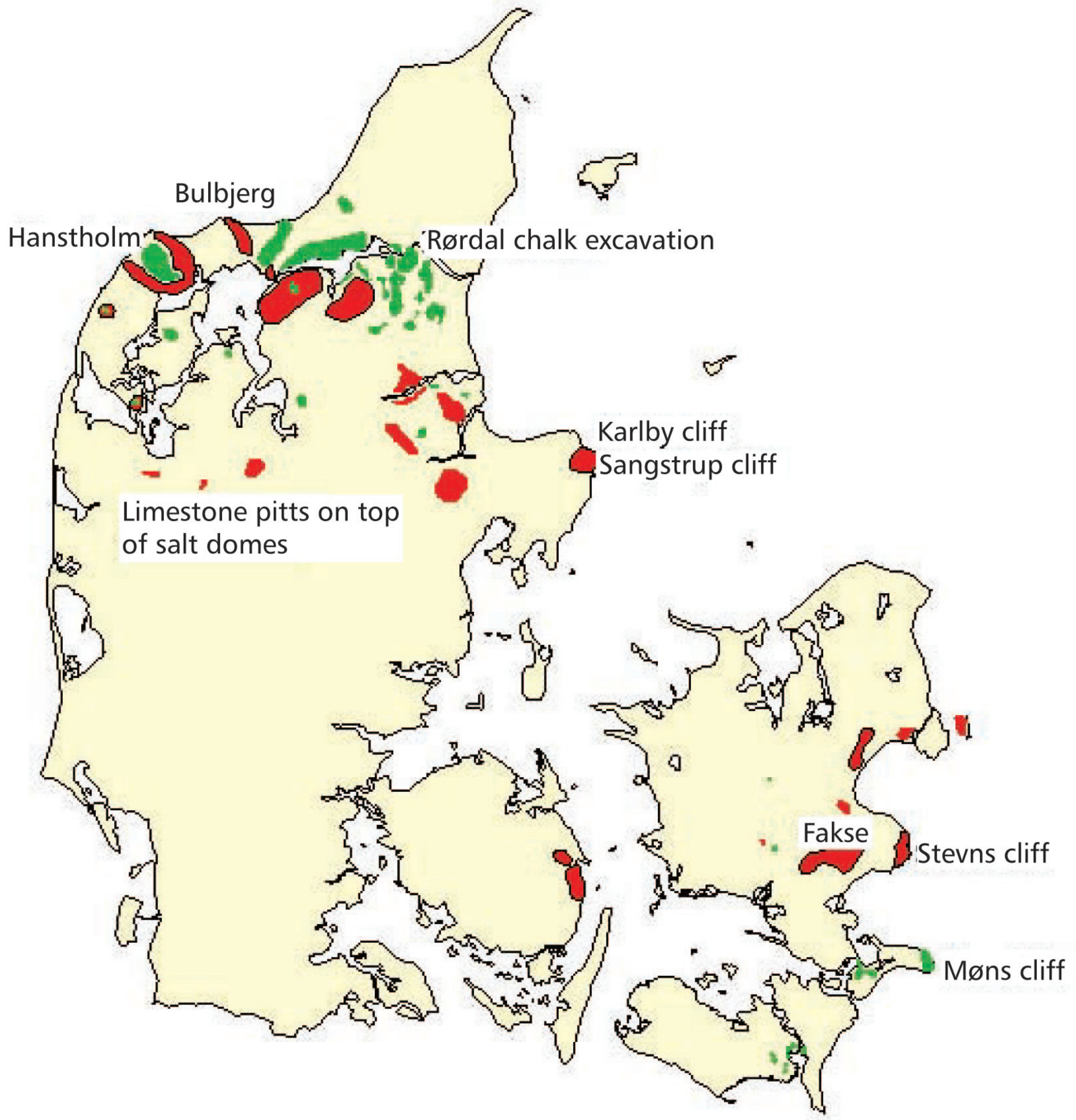


Figure 4.5. Areas where chalk or limestone are close to ground surface. Green colour indicate white chalk and red areas are limestone from the Danian. This map is compiled from GEUS Surface geological map, /4.5/ and the limestone surface map, /4.3/.

In areas where the surface of the chalk or limestone is close to the ground surface, one often sees hollows and holes formed because infiltrating rainwater gradually has dissolved parts of the limestone. The elongated holes that are formed in this way are sometimes referred to as "chimneys" because the holes now are seen filled with loosely deposited material, e.g. dark topsoil. Hence the name "chimney" because the black mould in the white limestone resembles the outline of a chimney.

Dissolution of limestone by infiltrating water from above is a well known process from many areas with limestone rocks. The process have been named *karst phenomena* named after a region near the Adriatic coast, where this phenomena is especially well developed with dripstone caves and even underground river channels. In Denmark the holes from dissolved limestone may be several metres in diameter and gradually increase in size as new, slightly acidic rain continues to seep down from above. This can cause collapse at the ground surface and the formation of so-called *sinkholes*.

The dissolution phenomena can also be seen indirectly when drilling in areas, where limestone is present in the unsaturated zone. Here you can sometimes experience, for example, a half metres of sand under several metres of limestone, indicating that sand has been washed down into a channel formed by dissolution.

These dissolution phenomena can make an area with surface-near chalk or limestone problematic as to foundation of buildings. Groundwater lowering can also be difficult to establish in these areas, because water flow can be very rapid in fractured limestone. Because of its hardness, limestone is often strongly cracked and fractured in the upper layers, so water will quickly accumulate if excavation is done in these layers.

4.5 Chalk and limestone as excavated material

Since the Middle Ages, limestone and white chalk have been excavated for building purposes in Denmark. Therefore many open limestone excavations are seen in areas where limestone is close to the ground surface. Closed mineshafts are also found in Mønsted and Daubjerg in Central Jutland, at places where limestone is located high due to salt structures that have lifted the older strata up into younger layers, see Section 2.5.

Today limestone and chalk is used mainly in the cement industry and for soil improvement. Extraction occurs in Aalborg, where Rørdal cement plant has a large excavation into white chalk layers. The excavation here is carried out down to 38 metres below ground water head, which has gradually resulted in the excavation of a large artificial lake. In Zealand, the Faxe Limestone Excavation has an large production of limestone material. These excavations include extractions of limestone from large coral banks formed in Danian period.

Besides production of cement and soil improvement limestone is also used for cleaning of flue gas (desulphurization), for food additives within agriculture, for filler in production of asphalt, rubber and paper, and finally limestone ($CaCO_3$) is used in production of carbonic acid.

Flint, which occurs sub-layered and in nodular form together with limestone, has previously been a very important raw material. In the Stone Age, this material was therefore used in the production of tens of thousands of tools, and raw flint blocks were even exported from Denmark to the rest of Scandinavia, where this raw material was not present in the subsoil.

4.6 The boundary between Cretaceous and Tertiary periods.

At the boundary between the Cretaceous and Tertiary, a certain number of animal groups disappeared because of extinction, including the big lizards (dinosaurs). It is estimated that approx. 75 % of the species found in the Upper Cretaceous no longer exists in the Danian Period, initiating the Tertiary Period, see Figure 2.1.

In Danish territory, the transition between the Cretaceous and Tertiary is marked by the presence of an approx. 10 cm thick marl layer (calcareous clay), which clearly differs from the soils both below and above the layer. At Stevns Klint, the marl is called “fish clay” because a content of fossil fish remains in that layer. The bottom of the fish clay is estimated to be the border between the Cretaceous and Tertiary. Elsewhere in the world, a similar trend is seen, i.e. the border layer is clearly distinguishable from adjacent sediment layers and, as something special, this border layer is clearly enriched with the rare element Iridium.

There has been several theories throughout time that has tried to explain why so many animal groups disappeared.

One of the theories explains the sudden extinction of dinosaurs as being the result of a especially large cosmic radiation or even bombardment of celestial bodies from outer space. So earth is believed to have been suffered from meteor storms killing a wide range of animal groups. Whether it has been as direct as Figure 4.6 shows is probably not very likely. There is however reasonable consensus that the extinction of the animals has been caused by particles and gases from meteor storms having polluted both sea and land, and presumably also subdued sunlight for a long period of time.

Another theory explains the catastrophe as being the result of a violent and prolonged volcanic eruption that mainly had taken place in present day India. Dust and ash from here would have blackened the sky and shielded the sunlight to such an extent that many plants, and thus herbivorous animals, died.

We do not know what actually happened on the border between the Cretaceous and Tertiary, but there is fair agreement that something violent happened, which was disastrous for many animal groups. Mammals were few and small at that time, so they could better hide and survive in caves as illustrated at lower left corner in Figure 4.6.

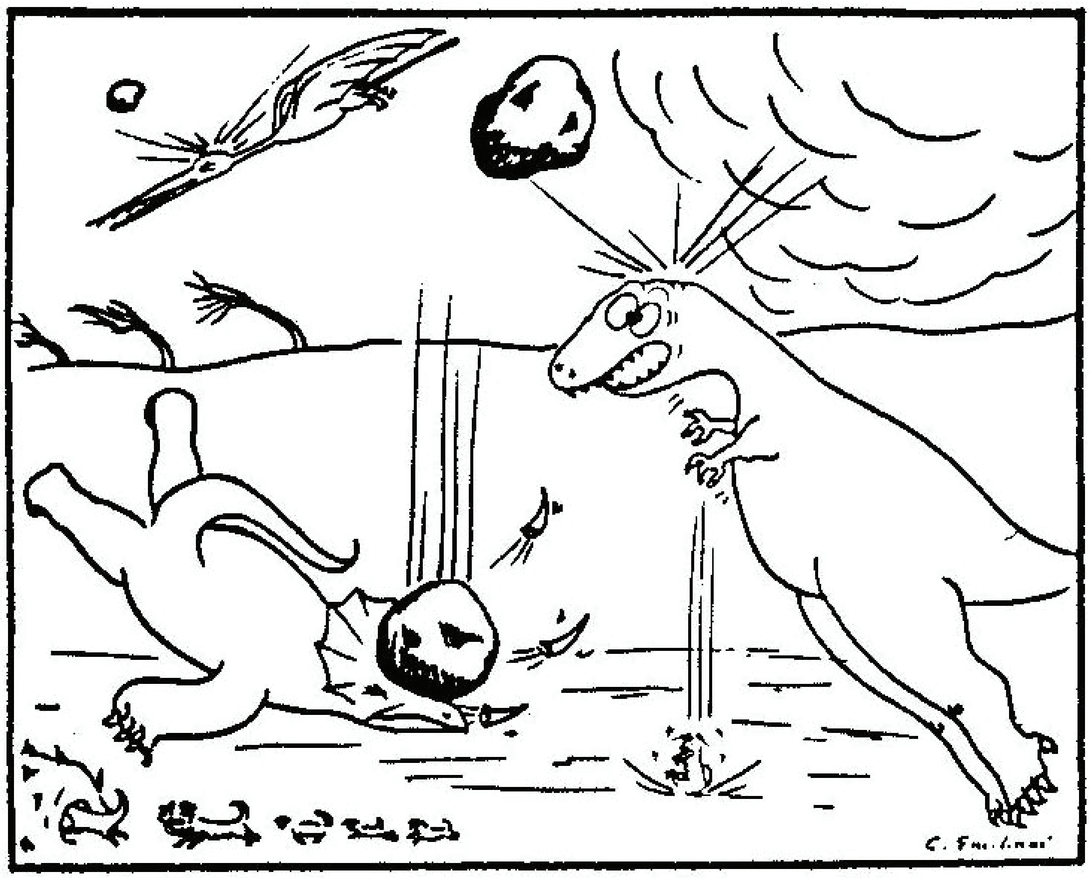


Figure 4.6. Meteor storm over the dinosaurs. From C. Emiliani, 1980.

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Review questions to Chapter 4

1) Is there white chalk below the whole of Denmark?
2) What does Lime-mudstone look like ? Name the characteristics.
3) What does Copenhagen Limestone look like ? Name the characteristics.
4) How is flint in white chalk formed? (Select one of the following four options):
   - The remains of free floating plankton; when dead they were deposited on the sea-bed
   - Chemically precipitated from seawater and deposited on the seabed in layers
   - Chemically precipitated from pore water in the already deposited lime
   - Conversion from certain types of limestone rich in pyrites
5) During the Upper Cretaceous Period, Denmark was part of a large sea area, which, towards the north east, bordered up to the Scandianavien land areas including today´s Norway and Sweden. How were the elevation of this land area ? (compared to present Norway and Sweden).
6) How is it usually possible to distinguish whether a given sample of limestone is from the Upper Cretaceous or Danien?
7) Sinkholes and chimneys can form in areas where the limestone subsoil is close to the ground surface. Describe the process forming these phenomena?
8) Danish moraine clay from the Ice Age consist of many different components. Which of these components have their origin in sediments from the Upper Cretaceous and Danian ?
9) What does lime-sandstone look like? Which kind of particles is this rock type made of ?
10) White chalk in limestone excavations and cliffs may sometimes display small scattered parts of rust. How can this be explained? (Which component of the chalk can weather into rust ?)
11) At Mønsted in Central Jutland there are old mines in limestone near the ground surface. Why is the limestone so close to the ground surface just here ? (Outside this local area, the limestone is located much deeper).
12) How can you usually distinguish if a flint stone is from the Upper Cretaceous or the Danian period?

Chapter 5

Lower Tertiary

5.1 Depositional environment and sediments

First sub-periode in Lower Tertiary is named the *Selandien* time, see figure 2.2. The transition from the Danian to Selandian is characterized by Denmark being over sea level for a period. In this continental period the previously deposited limestone was slowly eroded by wind and weather. When the sea again washed in over Denmark in the Selandian time, clastic *limestone pebbles* and *green sand* were deposited.

Limestone pebbles is nodules and tubers from the eroded limestone surface. Green sand consists of calcareous grains that are re-deposited together with a greenish mineral, named glauconite. Often, the sandy layers are hard and cemented together by $CaCO_3$ into a greenish limestone named *grønsandskalk* in Danish.

During the Selandian Period, the depth of the sea in Danish territory became deeper and deeper, and the green sand was replaced by marl (calcareous clay) and later by very fine-grained non-calcareous clay, which was the absolute dominant soil type in the Lower Tertiary Period. The very fine-grained clay is often referred to as plastic clay – especially in geotechnical contexts, see Figure 5.1.

Lower Tertiary Comprises lower part of **Oligocene** **Eocene** and **Palaeocene** (without **Danian**)	Denmark is part of a sea floor, probably deep water Negligible sediment supply from adjoining land areas Volcanic eruptions in the North Atlantic region	**Plastic clay** *can be divided into* **Søvind Marl** **Lillebælt Clay** **Røsnæs Clay** **Ølst Clay** **Holmehus Clay** *Also* Volcanic ash beds Diatomite Kerteminde Marl and glauconitic calcarenites

Figure 5.1. Summary showing the different period-names that comprise Lower Tertiary Period (from approx. 60 to 30 million years). Depositional environments and sediments are also shown.

The depositional environment for plastic clay is very calm seawater, which we can find in today's deep-sea plains at the ocean bottom. Figure 5.2 shows an interpretation of how land and sea was distributed in North-western Europe at the time this plastic clay was deposited. The Denmark we know today was completely covered by sea, and the coastline at that time went up along Norway and Sweden. The greatest thickness representing the Lower Tertiary sedimentary sequence is found in the North Sea's central area where it can be over 1000 metres thick.

The deposition rate of the plastic clay has been very slow. The time needed to deposit just one centimetre of the clay, we find today, has probably been hundreds of years – or maybe thousands of years. Since the thickness of the plastic clay is several hundred metres thick, this gives an impression of the very long time (about 30 million years) that the Lower Tertiary encompasses.

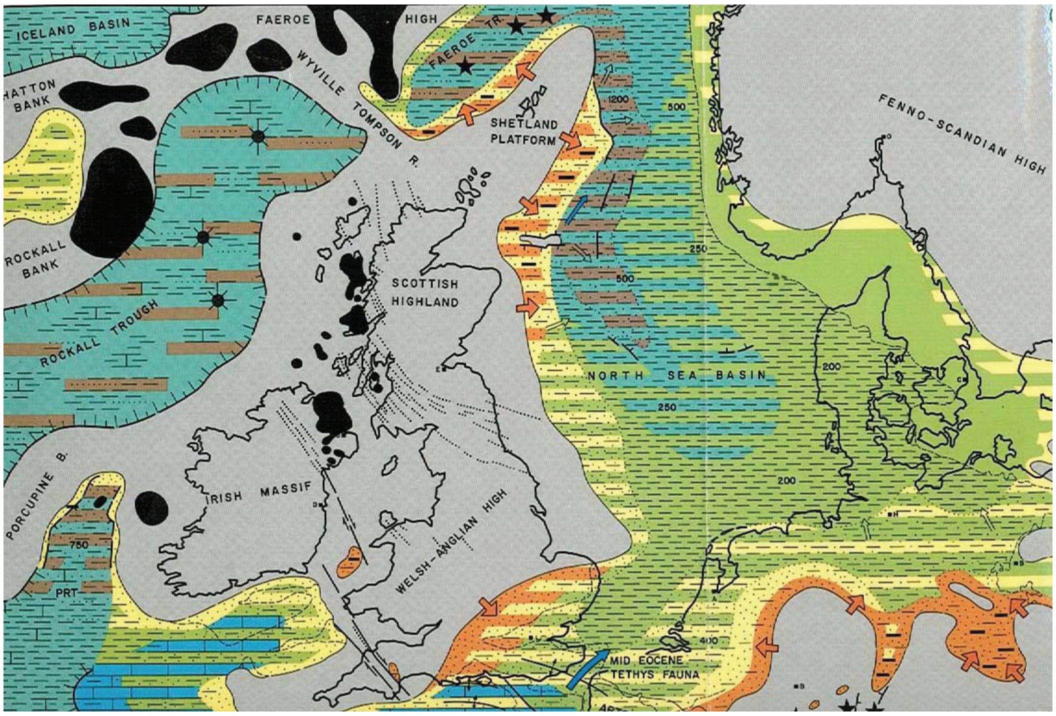

Figure 5.2. The paleogeography of the Lower Tertiary. Gray colours are former land areas and the black colour indicates active volcanoes. Orange and yellow are coastal sediments, while green and blue displays marine sediments in deeper water. From /5.1/.

In the plastic clay sudden colour changes may appear. The colour changes are interpreted to represent sudden environmental changes at the sea bottom due to varying water circulation and oxygen supply.

In today´s Limfjord region, exposures of Lower Tertiary rocks show very special sedimentary environment with a high production of diatomite (this rock type was described in Chapter 1, page 3 and 13). The deposition of empty siliceous shells (constituting the diatomite), went on for a very long time in the transition period between the Selandian and Eocene periods, The reason for this blooming of the diatomite organism is believed to be the counteraction of two bottom ocean current stirring up a lot of nutrient for the silica-shelled plankton.

Another peculiar natural phenomenon during the Lower Tertiary was the occurrence of a series of volcanic eruptions, each of which sent a rain of ash over Denmark and the North Sea area. The locations of these are shown in Figure 5.2. There are 200 registered thin ash layers in the plastic clay. Each ash layer corresponds to one volcanic eruption. There may have been hundreds or thousands of years between the eruptions of these volcanoes, in the same way as for present day volcanoes.

In the Limfjord region, the diatomite and ash layers can locally be cemented together by calcareous cement precipitated from circulating pore water. This has formed the so-called *cement-stone*, which is often seen as stones at the shores of the western part of the Limfjord.area.

Sometimes siliceous hard layers are seen in both the diatomite and in the widespread plastic clay, and this is often referred to as “slate”. The hard layers are formed because the clay have been cemented by chemical siliceous precipitation from circulating pore water squeezed out after the clay was deposited as fine-grained mud on the seabed. The process can be compared with precipitation of flint in the soft calcareous mud deposited during Upper Cretaceous and Danian.

Characteristics of sediments from the Lower Tertiary

- **Greensand** and **glauconitic limestone** from the Selandian are more or less solidified calcareous sands, i.e. each grain consist of clastic limefragments, eroded and transported from other locations than finally deposited. Mixed with the limestone particles are small round grains of the green mineral called glauconite (previously mentioned in Section 1.2 of Chapter 1).
- **Marl** from the Lower Tertiary is fine-grained and usually gray with plastic habit (Kerteminde Marl from the Selandian). However it may also be blue-green in colour tone (Søvind Marl from the Eocene). The marl can always be identified because it effervesces vigorously in diluted hydrochloric acid.
- **Plastic clay** from the Lower Tertiary is typically so fine grained, that it does not "crunch" when bitten with your teeth and have a texture similar to chocolate. When dry, numerous small cracks are visible and when moist and cut with a knife a glossy cut-surface appear. The colour can be gray, green, red or blue pastel. The plastic clay is usually totally lime free, but parts of it may be calcareous (particularly in the case of Røsnæs Clay).
  Variations on the plastic clay are:
  Lillebælt Clay (greenish), **Røsnæs Clay** (mostly red/yellowish), **Holmehus Clay** (seen largely with a chocolate brown colour) and **Ølst Clay** (dark gray, gray or light gray).
- **Diatomite** (in Danish called *Moler*) has laminated structure and always very light weight when dry (low density because of the empty shells that constitute the diatomite). The colour is typically light, but can also be dark. It may resemble chalk, but it does not effervesce with diluted hydrochloric acid.
- **Volcanic ash** can be identified as dark (or yellowish) sandy layers in the plastic clay or diatomite. However, the ash is often so weathered, that it is difficult to distinguish it from the clay. In diatomite, however, the ash layers are usually evident as thin black, sandy layers.
- **Cement-stone** consists of diatomite and volcanic ash cemented together by calcareous precipitations. It is identifiable by its striped appearance and the way it effervesces when diluted hydrochloric acid is added. Moreover, cement-stone is very heavy compared with pure diatomite.

5.2 Present outline and exposures

Lower Tertiary rocks and soils are found as the top Pre-Quaternary layer in a broad belt from the western Limfjord area, down over East Jutland and Fyn and including most of Zealand, see Figure 5.3. North-east of the belt, the deposits from Lower Tertiary are missing, and southwest of the stripe, the Lower Tertiary is covered by strata from Upper Tertiary.

Originally, the Lower Tertiary Sea stretched all the way up to Scandinavia, as seen in Figure 5.2, but due to a later uplifting and erosion of the deposited layers (which is discussed in detail in the next chapter), the material from that era is gone today - eroded away northeast of the present distribution (the gray line in Figure 5.3).

In some areas beds from Lower Tertiary are present just below ground surface as shown in Figure 5.3. These beds are also visible in several coastal cliffs whereof the most important ones are shown in Figures 5.4 and 5.5. Because the plastic clay has a very soft texture, there are many cases of landslides, and it may therefore be difficult to see the original bedding and occurrences of the clay.

It is only possible to see good cliff profiles where there has been a solidification of the clay. This may be found as cement-stone in the areas with diatomite, where Hanklit (on the north side of Mors in Denmark) is an example with an impressive format. The same applies to many other diatomite cliffs in the Limfjord region, see Figure 5.4. The features that mainly make the diatomite cliffs impressive are the many ash layers, seen as thin millimetre or centimetre broad bands in layered series.

The best coastal cliffs with plastic clay can be seen in the Lillebælt area (Figure 5.5) and at Røsnæs on Zealand. In a coastal cliff at Moesgaard south of Aarhus, it is possible to observe Søvind marl, which is also seen at the bottom of some cliffs on the Juelsminde peninsula between Horsens and Vejle.

In the interior of the country it is not uncommon to find local deposits of plastic clay as transported ridges surrounded by moraine deposits within the broad belt where the Lower Tertiary represents the upper layers of the Pre-Quaternary surface. This can be seen, for example, at some locations on Mols, in the southernmost part of Djursland, where it occasionally also stands out in coastal cliffs (Ørby Cliff and Lushage).

A clear look into the plastic clay is seen in the raw material excavations at Ølst, south of Randers. Here, plastic clay is excavated for producing lightweight clinker. Earlier, plastic clay was excavated on Zealand at Holmstrup, approx. 20 km east-southeast of Røsnæs.

Marl and clay from the Palaeocene can be seen on Fyn, where it stands out in the coastal cliffs at Stavnshoved near Røjle, and Lundsgaard Cliff on east Fyn.

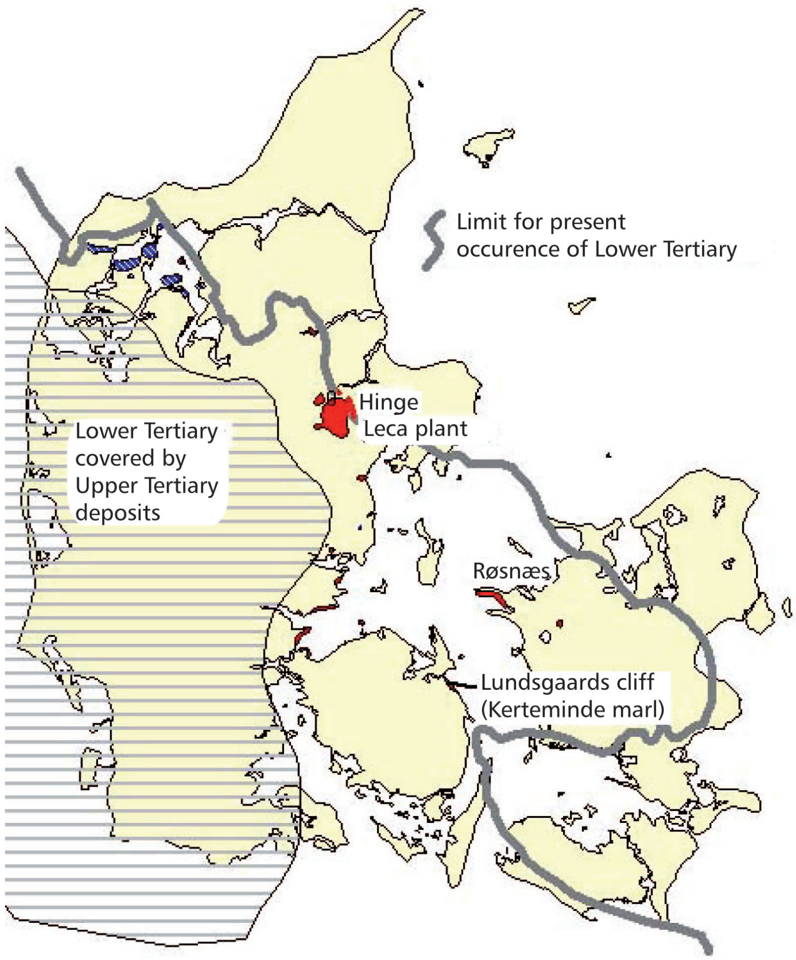

Figure 5.3. Present outline of Lower Tertiary and selected localities. Areas where Lower Tertiary deposits are close to ground surface are shown in red (plastic clay and marl) and blue (diatomite). This map is compiled from the geological surface map /4.2/ and the Pre-Quaternary surface map, Figure 2.6. Enlarged parts are shown in Figure 5.4 and 5.5.

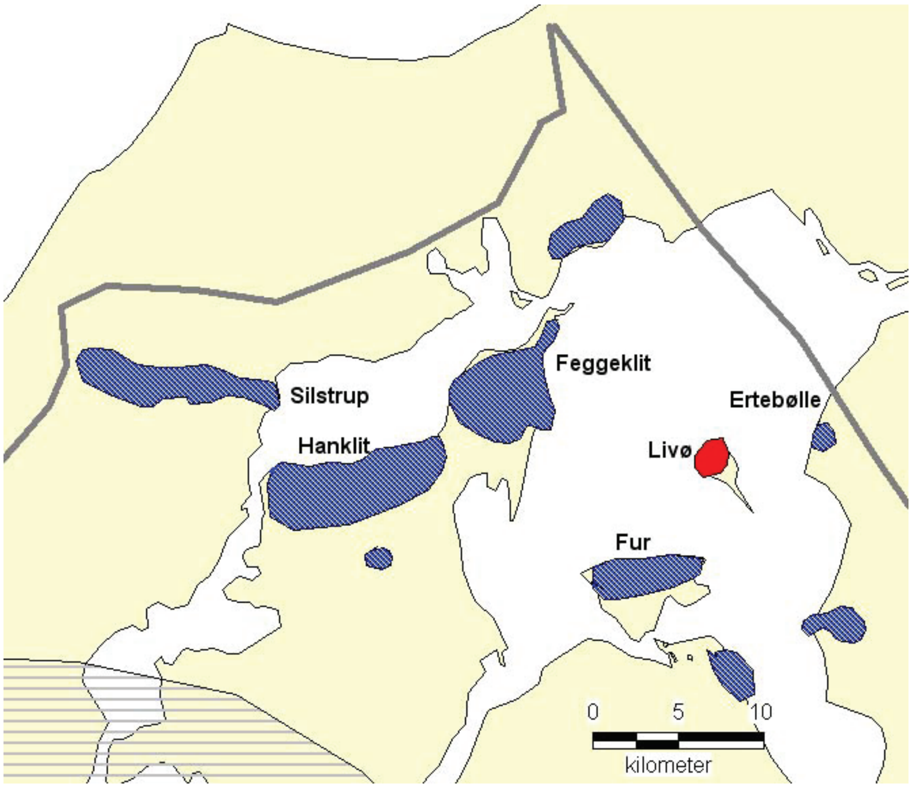

Figure 5.4. Lower Tertiary localities in the Limfjord region. The blue indicates areas with diatomite, and red areas are plastic clay. Enlarged part of Figure 5.3.

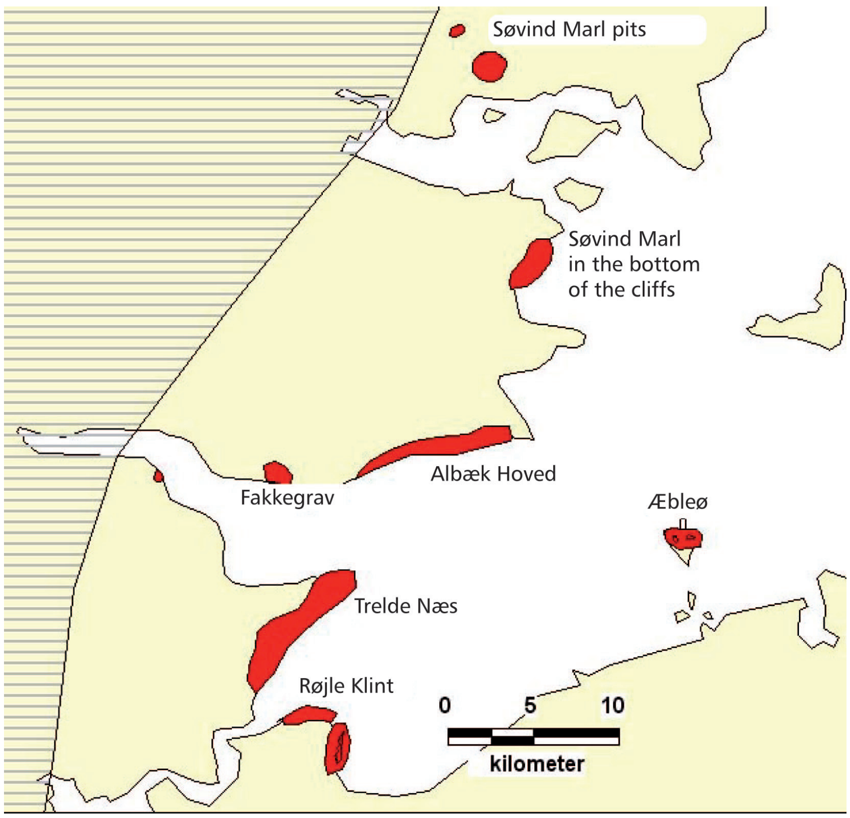

Figure 5.5. Lower Tertiary localities in the area around Horsens and Vejle. Red colour shows areas with plastic clay. Enlarged part of Figure 5.3.

5.3 Geotechnical issues related to the Lower Tertiary

Plastic clay is extremely moisture-binding and the moisture content is often greater than 50 % for a solid, naturally moist sample. Plastic clay is, therefore, a very problematic type of soil to found on, because the clay can absorb and release large amounts of water.

When water is absorbed, the clay swells, which among other things can lift constructions and also can cause slippage, even on small slopes.

When water is released, the clay shrinks and creates drought cracks, which can lead to subsidence in the foundations. Therefore, dry summers typically cause damage to houses that are founded on plastic clay (or moraine clay that is heavily mixed with plastic clay). Alternating expansion and contraction can also be a problem when foundation is made on very fine grained melt water clays from the Quaternary period.

According to Eurocode 7 DK NA:2008 /5.5/ all foundation work must be carried out by observing ”High consequences class CC3” when the excavations or the drilling samples reveal plastic clay.

Road embankments in areas where the upper soil layers consist of plastic clay must not have slopes with higher inclination than 16 degrees because of the risk of slippage. Normally, slope angles up to 34 degrees are permitted.

The high water retention (swelling) in plastic clay is due to the content of the clay mineral Smectite (also known as Montmorillonite). Smectite occurs when volcanic ash weathers. The background for the geotechnical problems with the Danish plastic clay must, therefore, be sought in the great volcanic activity during Lower Tertiary in the North Atlantic Region, see Figure 5.2.

A clay that contains at least 75 % of smectite minerals may be described as “bentonite”. Part of the Danish plastic clay from the Lower Tertiary meets this criterion.

5.4 Plastic clay and diatomite as excavated materials

Plastic clay is used in lightweight clinker – better known in Danish under the name “Leca-klinker” because of the name of the factory producing the lightweight clinker. Leca clinkers are mainly used as insulation materials, both as loose granules and as solid building blocks. Leca clinkers are also used for lightweight fill in connection with the construction of road embankments over week soil areas. By building the road on a base of lightweight clinker, the total load from the road is spread by the clinker material, thus preventing subsidence. The lightweight fill is also used as back-fill behind retaining walls and foundations of buildings on soft sediments, see /5.3/.

Pea-sized granules of lightweight clinkers are produced by mixing the plastic clay with oil or coal and baking it in a rotary kiln. This releases some of the water that is bound in the clay minerals, resulting in the clay bloating-up into light, porous “popcorn”. The factory for this production is located in the “Ølst hill” south of Randers town in Jutland. The hills themselves contain reserves that are able to satisfy future exploitation of plastic clay for many years to come.

Much of the plastic clays are used as the sealant *Bentonite*. Bentonite is a trade name for clay that contains a minimum of 75 % of the clay mineral Smectite. Bentonite is used in places where you want a tight clay membrane or a closed joint. It may, for example, be used at water wells where the space between the borehole and the casing pipe has to be a close-fitting material to prevent infiltration of surface water. Or it may be used as the bottom membrane or "cap" on landfill sites.

For many years Denmark has imported all Bentonite for construction and drilling. A large part of the Danish Lower Tertiary clays, however, has just as much "swelling index" as the imported Bentonite. The clays´ swelling index is a measure of the ability to absorb water, and it is this characteristic that causes the clay to form a strong membrane.

There have previously been plans to exploit Danish Bentonite in Lolland, but these plans have not been realized. However, the company NCC started extracting Bentonite in Bjerreby on Tåsinge island in 2003. The Bentonite here is around one metre below the ground surface in an area that is approx. 20 hectares. There is estimated to be enough raw materials for the excavation of total 1,000,000 tons of Bentonite. Exploitation is expected to span over a total of 30 years, /5.4/.

Diatomite is used as an insulating material. It has a naturally light weight and porous structure due to the siliceous algae shells. Diatomite is mixed up in water to a mud that can be formed into plates. These are especially used for the interior lining of ships, where their light weight is exploited in combination with their insulating and non-combustible properties. Baked diatomite bricks tolerate very high temperatures and are therefore used for interior cladding of kilns and ovens.

Baked granules of diatomite can absorb bad smelling substances, hence its use as an absorbant for cat urine. Denmark has a large export of this article because the Limfjord region is the only place in the world where such a pure form of diatomite can be directly excavated near the ground surface

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Review questions to Chapter 5

1) During Lower Tertiary plastic clay was deposited in Denmark. In which sedimentary environment was this plastic clay deposited ?

2) Greensand from the Selandian Period contains grains of the green mineral glauconite. Which other particles are present in greensand ?

3) Diatomite was deposited during a part of the Lower Tertiary in the present Limfjord region. Is diatomite the same as "plastic clay" ? If not, what difference is there between diatomite and plastic clay ?

4) How can you during a sample description distinguish between plastic clay from the Lower Tertiary Period and moraine clay from the Quaternary Period ?

5) The Eurocode 7, DK NA: 2008 considers plastic clay from the Tertiary as being quite problematic for construction works. What is the reason for this ?

6) In the Limfjord region, there is in some places cement-stone in the layered series from the Lower Tertiary. What is "cement-stone" ? and how is it formed ?

7) Is there plastic clay from the Lower Tertiary in the soil and rock sequence below Horsens ?

8) The Lower Tertiary sequence in Denmark shows, among other things, different layers of "marl", e.g. "Kerteminde marl" and "Søvind marl". What is "marl" characterized by, and how can you recognize marl during for instance a sample description ?

9) There were some volcanic eruptions in the Lower Tertiary, in particular in the North Atlantic. How can these volcanic eruptions be detected in the Danish geological beds ?

10) "Bentonite" is a trade name for a very specific type of clay. What criteria must clay comply with before it is allowed to use the name "Bentonite" for the clay ?

11) Can you use plastic clay for anything ? Is it exploited as a raw material ?

12) When you soak the plastic clay from the Lower Tertiary in water, it will nearly always become very "sticky" and soft - but not always. Sometimes the clay continues to be rock hard and does not change shape. What process has been effective here?

Chapter 6

Upper Tertiary

6.1 Depositional environment and sediments

After the deposition of plastic clay in the Lower Tertiary, a long period followed where Denmark was above sea level and part of the Scandinavian continental area. This land-period marks the boundary between the Lower and Upper Tertiary.

When the sea again transgressed Denmark, *glauconitic sandstone*, *mica clay*, *mica sand* and *quartz sand* were deposited, see Figure 6.1. These new types of sediments (in comparison to the former limestone and plastic clay) were caused by elevation of the Scandinavian landmass during the Upper Tertiary. This elevation resulted in erosion of the old Scandinavian mica-containing bedrock and old sandstones. The degraded materials were transported via rivers down to what is now Denmark, where the materials were deposited as alternating layers of quartz sand, mica sand, mica silt and clay.

The reason that quartz and light mica are so dominant minerals in the sediments is that these two minerals are stable towards chemical weathering, which occurs when bedrock is degraded in a relatively warm climate, as was the case in the Upper Tertiary. The other minerals from the bedrock (mainly feldspar and dark minerals) are not as stable, so they are attacked by chemical weathering and thus converted into clay minerals.

The grain size of the clay minerals is so small that they are carried in a suspension state in river water, and are only deposited when the water becomes very calm. The stable mica grains are flake-like, and they stay suspended in the water for long periods of time, just until the water becomes so calm that they can sediment. In the calm water, the bright mica grains are mixed with fine grained components such as fine sand, silt and clay. This is why we ALWAYS find mica grains along with the fine grained deposits of sand, silt and clay in the Upper Tertiary.

In the Upper Tertiary, Denmark lay between the sea in the west and the hinterland towards northeast. The Kattegat did not exist yet and, probably, neither did the Baltic Sea. The coastline in the west was not stable, but shifted continually location across present-day Jutland.

Upper Tertiary (comprises **Pliocene, Miocene** and Middle and Upper **Oligocene**	Marine (mostly western Jutland) Freshwater and brackish River systems and lakes Deltas at river mouths Lagoons, tidal flats and other coastal environments	*Alternating beds of* **Mica (fine)sand** **Mica silt and mica clay** **Quartz sand and –gravel Brown coal** also Glauconitic sand / sandstone Branden clay and Viborg clay (low mica content)

Figure 6.1. Summary of period names, depositional environments and sediments in Upper Tertiary period (from approx. 30 to 2 million years ago). Part of Figure 2.3.

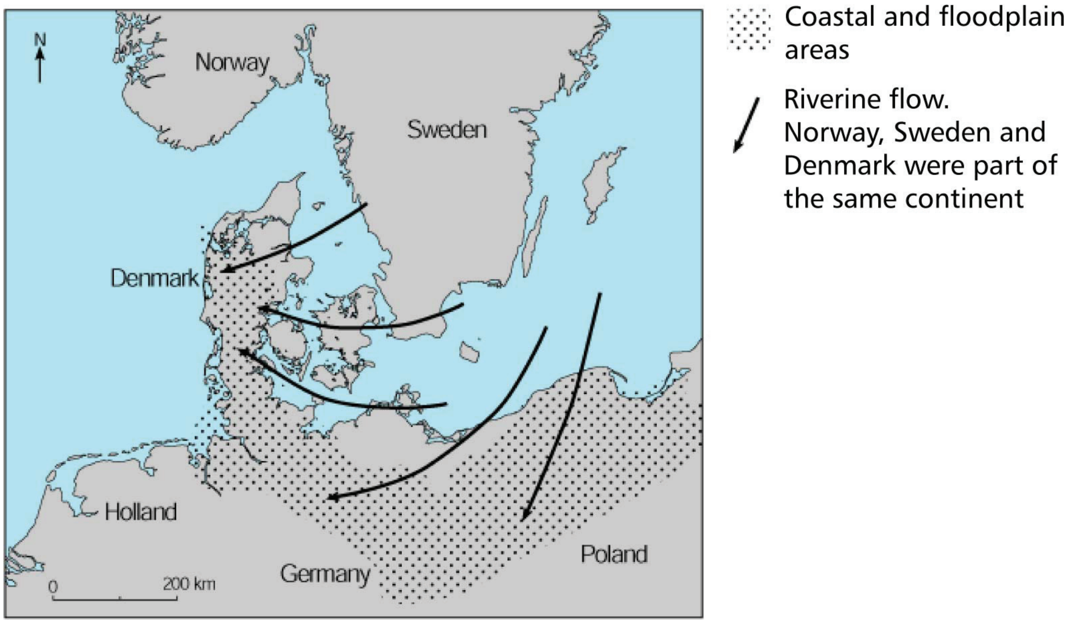

Figure 6.2. Coastal areas and floodplains in the Upper Tertiary. Previously the flood plain probably extended further north and east, but the Upper Tertiary sediments from here are now eroded away caused by uplift of the area. From /6.1/.

The alternating coastline is reflected in very variable sedimentary environments in what is now Denmark, see Figure 6.3. In the sea, clay and silt were deposited in deep water, while sand was deposited at shallower depths where wave movement could reach the bottom. In the rivers mainly sand and sometimes gravel were deposited. In the river delta and in restricted and abandoned river channels the flow rate was so low as to enable deposition of fine sand, silt and clay (along with mica grains).

In lagoons behind the barrier islands the water was so calm and the bottom water so oxygen-depleted, that black clay containing organic matter was deposited. (Figure 6.3) Due to the rich vegetation, plant remains, pieces of wood and whole stems often accumulated in the elongated lakes on the floodplains. These plant remains and pieces of wood have now turned into lignite (brown coal).

Many well preserved seeds, fruits, twigs, leaves and even entire tree trunks have been found in the brown coal and the intermediate layers of sand. Many of the plants found in Upper Tertiary beds are in present time common to grow only in areas with a subtropical climate. A contemporary parallel to the Upper Tertiary sedimentary environment can be found today in the hot and humid swamps of the Mississippi Delta in the southern USA.

The current Mississippi delta covers an area about the size of Denmark. Here present day subsidence can be up till approx. 2 cm per year. For towns in this region the subsidence is a problem for wastewater pipes and other supply systems below ground surface.

As the coastline has changed location frequently during the Upper Tertiary, soil samples from the same borehole can reveal different sedimentary environment vertically above each other. In one and the same borehole you typically will find for example quartz sand (from the offshore sandbanks), black mica clay (from the inner lagoon) and mica silt and fine sand (from the river delta).

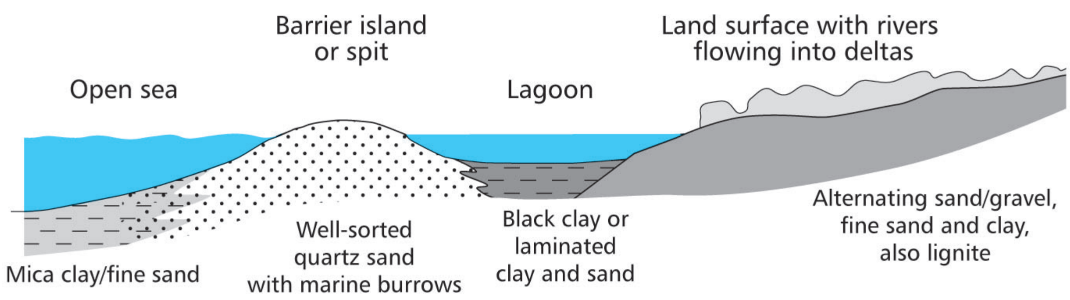

Figure 6.3. Section through different depositional environments in the Upper Tertiary. From /6.1/.

The Upper Tertiary stratification has been subdivided into various geological formations as shown in simplified form in Figure 6.4. The formations were initially deposited horizontally, but, as shown in the figure, they now have a general slope towards the west. The geological formations consist of:

- River and delta sand, occasionally with lignite (i.e. in The Ribe Formation). The formation consists of medium to coarse grained quartz sand with thin layers of mica-clay and -silt and lignite (brown coal). The quartz sand is excellent as aquifer for water abstraction.
- Marin clay and silt (i.e. The Gram and Hodde Formations and Arnum Formation). The formations consist of dark mica clay and mica silt with subordinate layers of fine mica sand. The dark mica clays generally have a high content of the mineral pyrite. In some areas are thin sandy layers enriched with the green mineral glauconite and a natural high concentration of heavy metals.
- Brackish-water clay and silt (i.e. The Vejle Fjord Formation).This formation is also marine deposited and begins with glauconite sand or sandstone followed by mica sands, mica clay and quartz sand.
- Marine, near shore sand (i.e. The Odderup Formation). Also this formation consist of medium to coarse grained quartz sand with thin layers of mica-clay, mica-silt and lignite (brown coal). The quartz sand is suitable as aquifers for water abstraction.

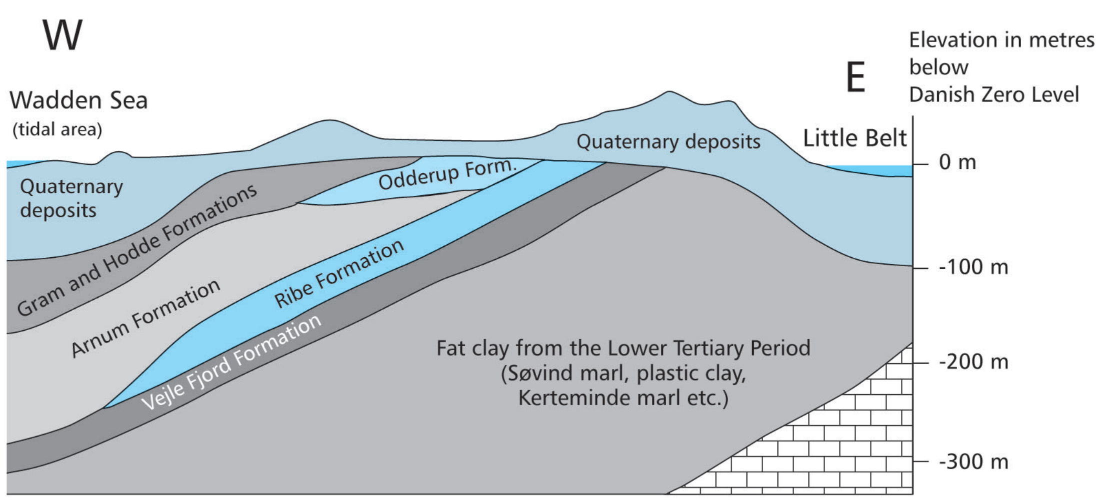

Figure 6.4. Schematic cross-section from east to west through South Jutland. From /6.1/.

From Central Jutland are known deposits of very fine grained clay that are older than the Vejle Fjord formation, but younger than the Lower Tertiary Søvind marl. This clay is called Viborg clay (eldest) and Branden clay (youngest).

Viborg clay and Branden clay are not as plastic as the characteristic plastic clays, which are below the Søvind marl, but Viborg clay and Branden clay are however more fine grained than the typical dark mica clay from Upper Tertiary. And as they do have a small content of mica grains, Viborg clay and Branden clay can be regarded as a kind of transitional layer between the Lower and Upper Tertiary.

As a result of recent years' intense mapping of groundwater aquifers, new beds of Upper Tertiary sand have been identified and described, /6.2/. The new beds are *Hvidbjerg sand* and *Billund sand* that lie below the Ribe Formation and *Bastrup sand* that is below the Odderup Formation.

The Scandinavian hinterland raised more and more during the Upper Tertiary period, which, among other things, means that the supply of quartz sand increase, and the sand becomes more and more coarse grained. It is this medium and coarse grained sand, we find today in the big quartz sand excavation at Addit in central Jutland. Towards the end of the Upper Tertiary period, the whole of Denmark became part of the uplifted area, so that the country lay as a land area exposed to erosion and weathering.

6.2 Characteristics of the Upper Tertiary sediments

Although the deposition of the Upper Tertiary varies widely, there are certain common characteristics. There is always mica in the fine grained deposits, i.e. in fine sand, silt and clay. Sand and gravel consists almost entirely of well rounded quartz grains and depositions are always uniform in grain size, i.e. they are well graduated.

Deposits from the Upper Tertiary can be divided into the following six groups, since mica clay and mica silt are considered as belonging to the same group. The same with quartz sand and quartz gravel.

- **Mica clay** and **mica silt** from the Upper Tertiary always contains clear mica flakes. The colour is typically black or brown. The silt may be greenish and feel sandy because of glauconite grains. Finely divided pyrites can be weathered to yellowish coatings and small gypsum crystals and to rust.
- **Mica Sand** is typically found in the form of fine sand and is easy to recognize because of its mica flakes. The colour is mostly bright white, but brown grey colours from organic content may occur. The sand particles are composed of quartz grains in addition to the distinctive, bright, sparkling mica grains.
- **Quartz sand**, whose typical grain size is medium to coarse, consists almost entirely of quartz grains, but there are also rare grains of old flint, feldspar and other minerals. The colour is typically light or white, corresponding to quartz grains´ own different colours. The individual grains show very well rounding, and the sand is well sorted.
- **Lignite** (brown coal) is smudgy, and is lightweight in the dry state. Preserved tree structures are frequently found and they may take the form of e.g. growth rings.
- **Glauconite sand** or sandstone is found as dark, green sediments, which very easily weather to brown rust in open air. Sometimes remnants of shells from snails and mussels can be seen preserved in the sandstone.
- **Very finegrained clay** with few mica grains. Gray to dark gray. Occasionally there are glauconite grains and fossils of mussels and snails, and concretions of the mineral siderite (Clay ironstone).

6.3 Present outline and exposures

Deposits from the Upper Tertiary are known only from Jutland, as shown in the subsurface map Figure 2.5 and also Figure 5.3, where Lower Tertiary areas covered by Upper Tertiary are shown. The general pattern is that the thickness of the Upper Tertiary strata increases towards the west, as shown by the section Figure 6.4.

A number of coastal locations with Upper Tertiary beds are present in East Jutland, i.e. Vejle Fjord and around Lillebælt, see Figure 6.5. Here you often see Søvind marl at the bottom of the exposure, and above this a thin bed of sand or sandstone with glauconite, followed by alternating mica-containing sediments and quartz sand.

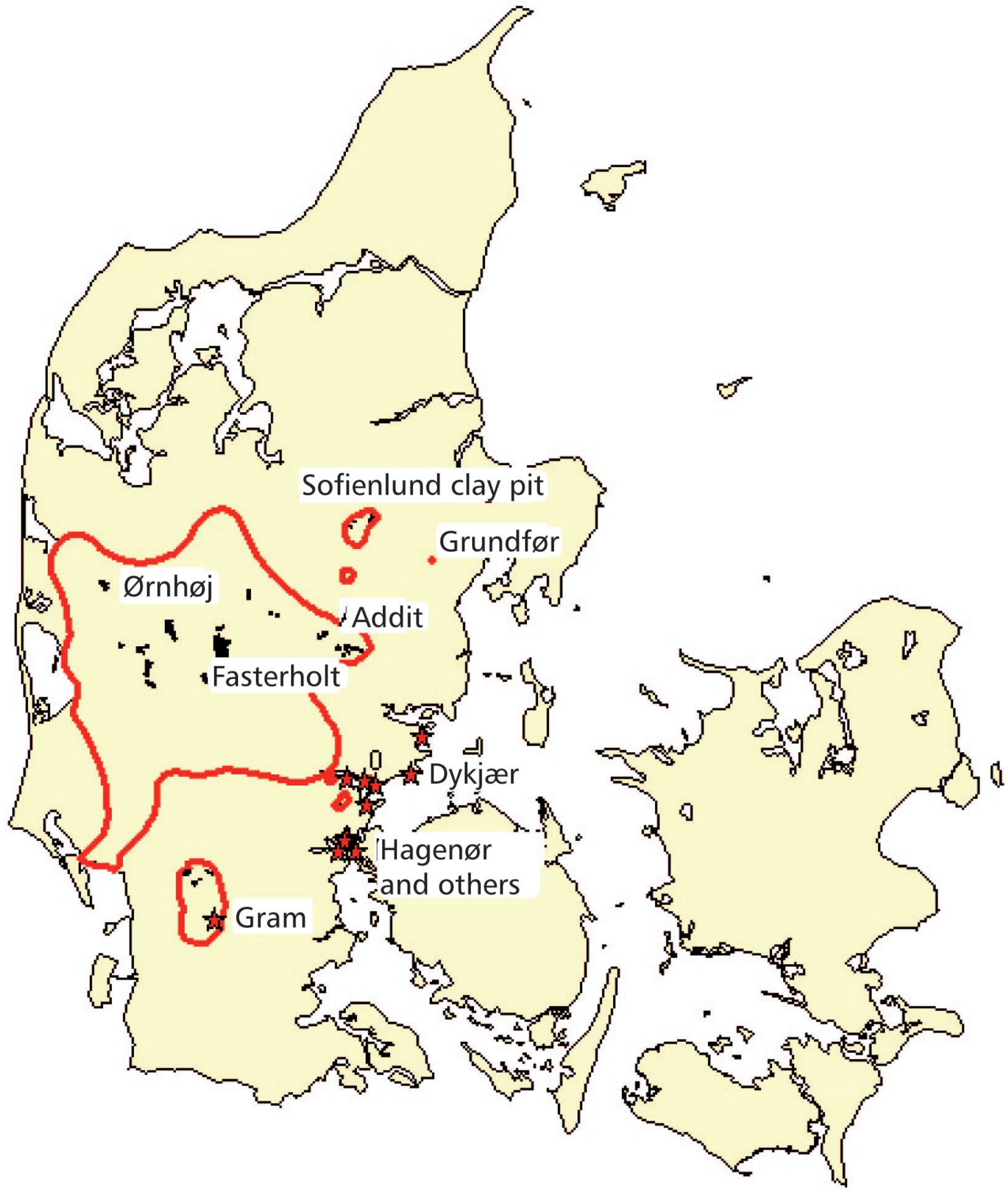

Figure 6.5. Areas surrounded by red lines indicate regions where Upper Tertiary sediments at present are close to ground surface. Coastal cliffs with exposures of Upper Tertiary sediments are marked with red asterisks.

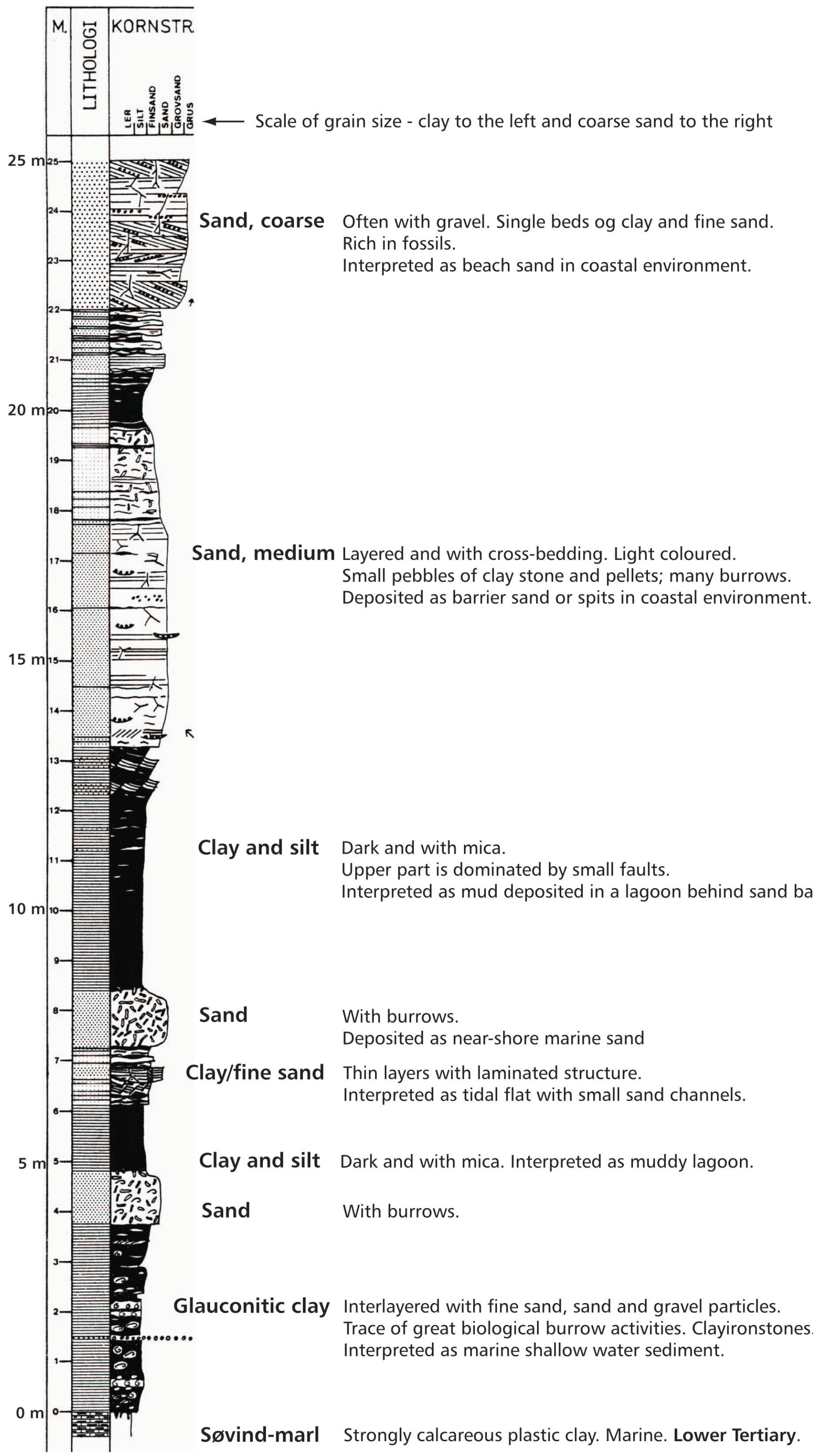

Figure 6.6. Upper Tertiary deposits in a coastal cliff at Dykjær, Juelsminde. Figure copied from /6.3/.

Dykjær, which is located immediately west of the city Juelsminde, is a typical location at Vejle Fjord. Figure 6.6 shows the total stratification and thickness as it is presumed to have been before the layers were shifted to their current oblique layer position.

Between the Søvind marl and the glauconitic clay at Dykjær (bottom of Figure 6.6), there is a sharp erosion border, which represents perhaps up to 10 million years - the period when Denmark was raised above sea level and was part of the Scandinavien continent. During this period there was erosion instead of deposition, and many metres that we cannot account for today may be missing.

Besides Dykjær, the following locations are situated at the north side of Vejle Fjord: *Stouby Forest*, *Fakkegrav*, *Rhoden*, *Daugaard Beach*, *Ulbækhus* and *Tirsbæk* /6.3/.

Cliffs with exposures of Upper Tertiary sediments can be seen on the south side of the fjord at *Ibæk*, *Ankær Vig*, *Brejning Hoved*, *Skansebakken*, *Hvidbjerg* and *Bøgeskov* /6.3/. Localities at the Lillebælt include, in addition to *Hagenør*, also *Børup*, *Rønshoved*, *Hindsgavl* and *Øksenrade*, /6.4/.

Those eastern Jutland coast localities show stratifications of approximately the same characteristics as Dykjær (Figure 6.6), i.e. alternating layers of coastal sediments from the Vejle Fjord Formation, which is the oldest part of the Upper Tertiary in the east Jutland area.

At the same time as the area at Dykjær was still landsurface, there was probably sea in Central Jutland in the Viborg area; at least during some part of the time, because we find deposits of the relative finegrained Viborg clay and Branden clay here. This clay can be seen in a former brickwork excavation *Sofienlund claypits*, where beds from Oligocene are visible (Oligocene is the oldest part of Upper Tertiary). The site is now a park, but a wide stripe of the slope (labelled P in Figure 6.7) is kept cleared of debris and vegetation, see Figure 6.7.

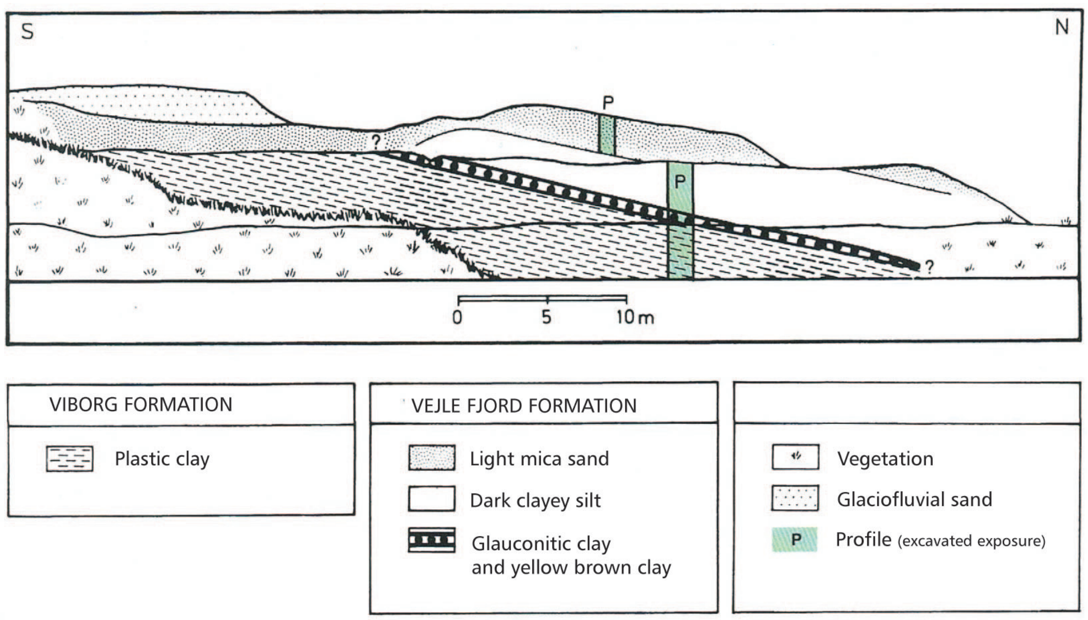

Figure 6.7. Sofienlund clay pits at Ulstrup in Central Jutland, /6.5/.

There are many good exposures in raw material excavations in Central Jutland because of the exploitation of quartz sand as e.g. at Addit. Other famous sites of the Upper Tertiary are the *Salten profile*, which is a so-called inland cliff, and *Sukkertoppen* (the sugar top) that has gotten its name because of the white quartz sand at the top that has the appearance of sugar. Previously, there were good exposures from Upper Tertiary in brown coal excavations. However, after the exploitation of brown coal has stopped, most of these excavations are now partly filled with former excavated sand and clay (these layers had to be removed temporarily to get the valuable thin brown coal beds). During excavation the groundwater was often lowered and therefore many of the excavations today are flooded and form lakes in the excavated areas.

Gram clay pits, in South Jutland, shows good exposures in the very youngest Tertiary - the marine Gram clay. The clay pits belong to Central South Jutland's museum, and there is public access to the pits where you can find many remnants of ancient marine wildlife, including bones of whales and porpoises, as well as snails and seashells.

6.4 Geotechnical properties of sediments from Upper Tertiary

Mica clay from the Upper Tertiary has by no way the same capacity to shrink and swell with water as clay from the Lower Tertiary. Therefore, generally, no problems are seen when buildings are founded on mica clay or other deposits from Upper Tertiary as these sediments are solid and pre-compressed by glaciers in Quaternary time.

The black mica clay, however, often contains finely distributed pyrites (mineral with the chemical formula FeS_2), which can be weathered by oxidation to sulphuric acid and rust. This allows pore water from mica clay to become very acidic and highly corrosive to structures made of concrete because the acid dissolves the calcium-containing concrete and attacks the reinforcement steel so that it rusts.

The weathering of pyrites in mica clay has also caused ochre problems in rivers and lakes. In connection with the excavation for brown coal, many cubicmetres of mica clay was moved, which then became oxygenated to form sulphuric acid. Water with low pH (because of the content of sulphuric acid) is able to keep iron in solution as Fe^{++} - i.e. the water will look as a clear liquid. When this water subsequently gets diluted by, for example, flowing out into a stream, the rise of pH will get the iron to precipitate in the form of orange or rust red ochre, $Fe(OH)_3$. The fluff of tiny ochre particles may then destroy fish and plants in the stream.

6.5 Excavated materials from the Upper Tertiary

The Upper Tertiary sand and gravel (quartz sand and gravel) are a valuable resource because it is so clean and well graduated. It is used for a range of applications such as filter sand in wells and filter material in water treatment plants.

A lot of quartz sand is used as aggregates in concrete that is able to withstand very aggressive environments. The reason for this is that quartz sand has a great chemical stability and a natural hardness able to stand many physical impacts. The great bridge projects (The Great Belt and Øresund) have almost exclusively used aggregates from Vestbirk Stenleje near Voervadsbro North West of Horsens. The sand here is very quartz-rich, and can therefore meet the stringent quality requirements for materials to be used in the production of concrete elements for the bridges.

Clay from the Upper Tertiary has previously been used in brickwork clay, but many of the excavation pits are now closed. This is also the case for Gram Tile Work's pit, where in addition to clay for tiles, also skeletons of whales from the ancient sea were excavated. Branden clay was previously mined in a pit south of Skive, but it was closed along with Sofienlund at Ulstrup and some brickyard excavations near Mariager Fjord.

Brown coal occurrences in Central Jutland have been subjected to intense exploitation during the two world wars. The low calorific value, the coal's moisture content, ash and sulphur, and the low layer thicknesses, however, have made its use unprofitable. Midtkraft in Aarhus used lignite in the production of electricity in the early 1970´s. It has been calculated that the remaining brown coal reserves in Jutland are sufficient for approximately one year´s consumption of energy in whole Denmark.

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Review questions to Chapter 6

1) Clay from the Upper Tertiary always contain grains of mica flakes. Why are there no mica flakes in clay from the Lower Tertiary ?

2) Mica grains in the Upper Tertiary beds are almost always seen in the fine grained deposits (clay, silt and fine sand). Why are there nearly no mica grains in the medium sand and coarse sand from the Upper Tertiary ?

3) Are there marine sediments from the Upper Tertiary in Danish land areas ? If so, in what part of Denmark can you observe them ?

4) What characteristics can be seen in the marine sediments from the Upper Tertiary compared with fresh water layers from the same period ?

5) What did Denmark look like during the late Upper Tertiary ? Was Denmark covered by sea, or were Denmark part of a land area ?

6) What is the appearance of sand from the Upper Tertiary (e.g. compared with melt water sand from the Quaternary Period) ?

7) What colour is typical of clay from the Upper Tertiary ?

8) Are there sediments from Upper Tertiary on Zealand ? If so, where on Zealand ? If not, why are there no deposits from the Upper Tertiary of Zealand ?

9) There have been some problems with ochre precipitations in rivers because of the excavation of Upper Tertiary brown coal in Central Jutland. How can this be explained ?

10) How is it possible to distinguish clay from the Upper Tertiary and clay from the Lower Tertiary from the description of a sample ?

11) What are the features of brown coal (lignite) ? Which differences can you see between dark clay and lignite ?

12) What part of Denmark has the greatest thickness of layers from the Upper Tertiary ?

Chapter 7

Glacial and Interglacial periods in Quaternary

7.1 General about the Quaternary

Towards the end of the Tertiary Period, Denmark was part of a large landmass called Fennoscandinavia, which also encompassed present-day Norway and Sweden. The Kattegat had not yet been formed at that time.

There are no known deposits in Denmark dating from the period approx. 10 to 2 million years ago. It is therefore assumed that the landmass including Denmark was continually exposed to erosions, and that the eroded material was led out into the North Sea, where very thick beds from the youngest part of the Tertiary Period are preserved. It was not until the present geological period, the Quaternary Period, that materials was once again deposited in Denmark – on this occasion with ice and meltwater as the transport medium.

The Quaternary Period is generally a cold period compared to the Tertiary Era. A characteristic phenomena in the Quaternary Period is that ice cover occurs at the poles, which is quite rare in the earth's geological history as can be seen on the time-spiral in Fig. 2.1. We must, therefore, go back approx. 200 million years in time (to the Permian Period) to find deposits from glaciers and melt water of the same type as those from the Quaternary Period. In total, traces of 4 periods in the earth's history are known for having ice at the poles.

As a result of continental drift, the old Ice Age sediments from the Permian and more ancient times are currently spread across the globe. One example of this is the fact that traces from an early ice age in Ordovician time can today be found in present Sahara in Africa. On the other hand, continental drift is also the reason, that traces of tropical plants from the Carboniferous Age can be found today in present Antarctica.

The Quaternary Period is characterized by very rapid climate changes. This means that the icecaps from the poles and from the high mountains would spread more or less beyond their custom surroundings, resulting in alternating ice ages (glacial periods) and inter ice ages (interglacial periods). Denmark has been covered by ice several times during the Quaternary Period. The Ice slid forward as glaciers from Norway, Sweden and the Baltic region bringing large amounts of materials from these areas to be deposited in the present Danish and North Sea areas.

The cause of climate change to the colder, and the variations between glacial and interglacial periods, is presumably due to small variations in the slope of the Earth axis relative to the sun. Another potential explanation is that the movement pattern of the major continental plates changed from time to time due to changes taking place in the convection streams of the liquid magma within the Earth's mantle. Because of main landmasses changing their location, the major ocean currents also changed their directions, which had implications for climatic conditions.

Using keywords, Figure 7.1 shows a rough overview of the processes and materials present in the Quaternary Period. However, the schedule does not cover the last 10,000 years, which includes the Late-and Postglacial Periods to be described in the next chapter.

Glacial Periods *alternating with* **Interglacial**	Active Glaciers Meltwater streams and outwash Meltwater lakes Landslides and soil creep *During interglacials similar processes to Late Glacial and Postglacial (see above)*	*Alternating beds of* **Moraine clay –sand –gravel** **Glaciofluvial sand –gravel and –boulders** **Glaciolacustrine clay and -silt** *During interglacials similar deposits to Late Glacial and Postglacial (see above)* also Diatomite in lakes

Figure 7.1. Overview of processes and deposits from the Quaternary Period. Part of Figure 2.3.

7.2 Processes and materials in the Quaternary Period

The most important processes in the Quaternary Period can be divided into:

- glacier activity
- flowing melt water
- changes in sea levels
- the effects of frost.

Glacier activity

Large masses of snow will eventually accumulate in areas where there falls more snow during the winter than can melt during the summer. The bottom snow masses will then, given the pressure, be converted into ice. With ever increasing pressure, the ice will become plastic and start to spread downwards along the terrain as “ice-tongues” (glaciers).

If the terrain in the areas of snow surplus is relatively flat, a large ice-shield will accumulate behind the snow border, which will eventually press the ground surface downwards several metres. This is, for example, visible in Greenland where the bottom of the inland ice sheet in some places is pressed down to around 400 metres below sea level. The thickness of ice in Greenland is, in large areas of the country, over 3000 metres.

With the forward thrusting movement, the ice can scrape up the ground and erode materials, which are then transported over long distances. Clay, sand, stones and even boulders of rocks, deriving from different land areas, are mixed this way because the ice is not able to sort the transported materials. Unsorted material that is deposited by ice is called *moraine*. Deposition of moraine is shown in Figure 7.2.

Flowing melt water

Melt water generally arises at the surface of the ice from where it penetrates down into the ice via a branching system of channels. The largest of the channels can develop into big tunnels in the ice containing violent flowing currents of melt water. When melt water flow very rapidly, stones and very coarse-grained layers can be deposited – provided that the current is not so strong as to completely prevent deposition taking place. Due to the advance of the ice the channels eventually become closed off and replaced by new channels elsewhere in the ice. Together these channel processes result in the formation of a number of elongated sand and gravel bodies separated by more impermeable layers of moraine clay or meltwater silt and clay.

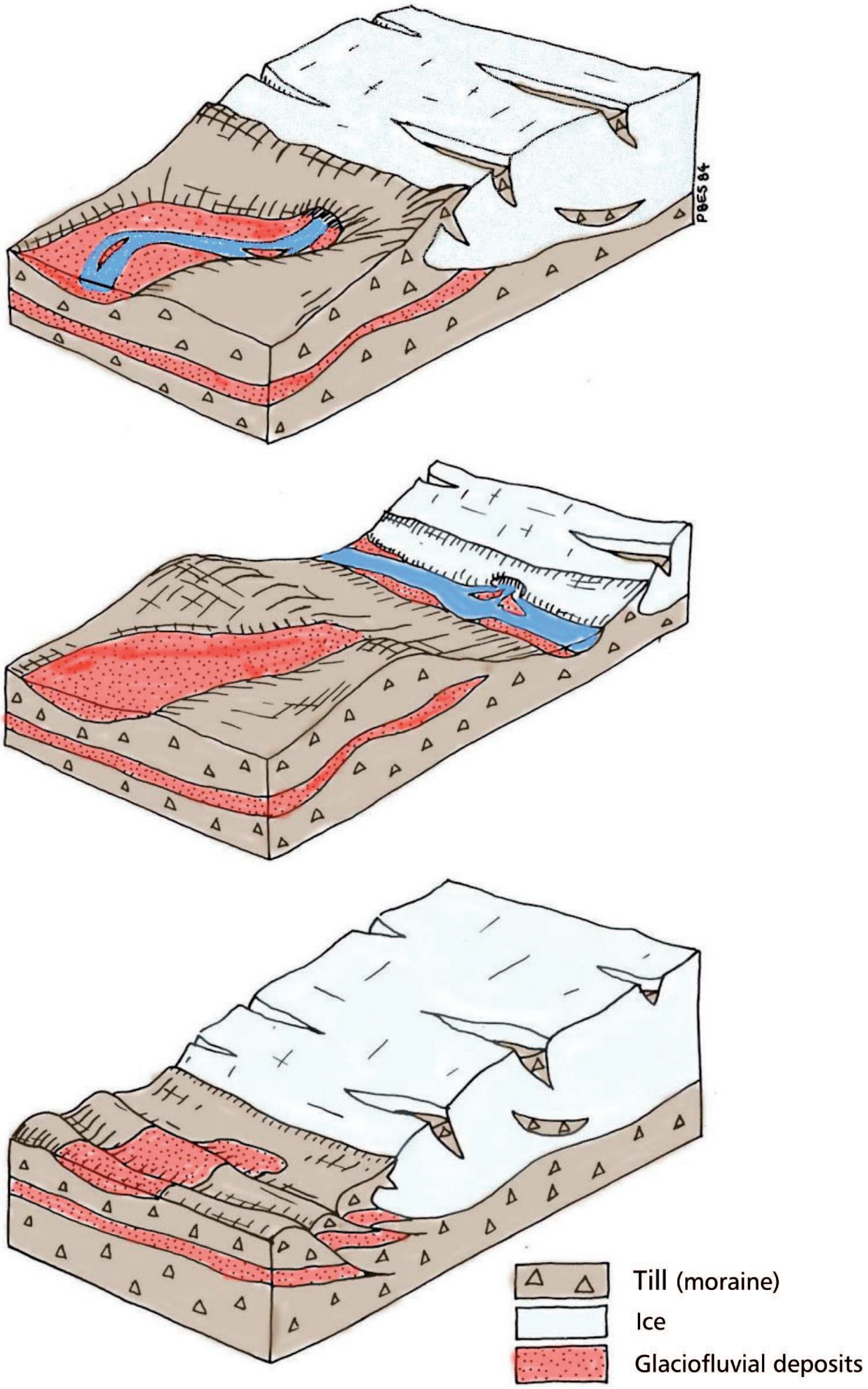


Figure 7.2. Glacier activity and streams of melt water. During relative cold periods, ice will move forward and push the already deposited material together into ridges with disturbed bedding.

Once the melt water leaves the ice it spreads out on a plain (washout plain), or runs in the bottom of a valley (melt water valley), see Figure 7.2. Here materials are deposited in widespread layers varying in grain size depending on the velocity of the melt water. In strong streams, coarse materials are deposited, and in slower streams, fine-grained materials. A common name for sediments deposited by melt water is *glaciofluvial sediments*.

The mechanism actually controlling the amount and velocity of the melt water is the climate as the amount of ice that melts depends on the intensity of the summer heat.

Due to the varying temperature conditions, glaciofluvial sediments often alternate between coarse-grained and fine-grained layers. An example of the variation in grain size and structure of these sediments is shown in Fig. 7.3. The figure shows four typical units deposited in a single episode that could for example have been an early summer thaw.

The four units are:

- Gravel, stones and coarse sand with large-scale cross bedding.
- Medium-grained sand with megaripple bedding.
- Fine-grained sand with small ripple bedding.
- Fine sand, silt and clay with horizontal bedding deposited in virtually stagnant water.

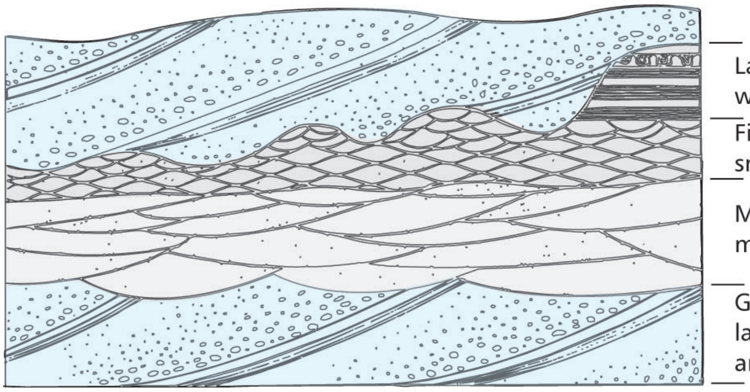


Figure 7.3. Examples of variations in glaciofluvial sediments deposited by melt water. From /7.1/.

Changes in sea levels

Rapid climate changes is also the cause of large variations in sea levels during the Quaternary Period. In cold periods very large water masses from the oceans are bound in the extensive polar ice caps causing the sea level to be generally low during an ice age, in fact, up to several hundred metres lower compared to the “normal” sea level during the warmer interglacial periods.

When the ice melted, so much water was released that the sea once again rose and flooded the former land areas. This kind of rise in sea level is called *eustatic sea level rise*.

Sea levels are also influenced by the weight of the heavy ice caps pressing down on the earth’s crust and, consequently, slowly raising the land areas again when the ice disappeared. This form of raising and subsidence of land surfaces also impact the sea level, and is called *isostatic rebound*. Since large parts of Denmark lie relatively low, these changes in sea level had significant consequences in terms of switching between floods (*transgressions*) and drainage (*regressions*). The next chapter on the Late and Postglacial Periods will reveal more of this topic.

The effects of frost

Apart from the activity of glaciers and melt water, there is also reason to mention *permafrost* as an important process during cold periods. The name permafrost refers to the soil being permanently, i.e. persistently frozen.

During periods of permafrost, the upper layers of soil thaw during the summer. But as the ground is still frozen underneath, the melt water cannot seep downward and the soil thus attains a mud like consistency. If the thawed soil layers are located on a sloping surface, soil creep material is created, which flows down and fills the low-lying areas of the surrounding terrain. Soil creep material is often poorly sorted and can have great similarity to moraine deposits. Soil creep material is, however, less solid and has less shear strength than moraine.

So-called "ice wedges" can be formed when water in the soil freezes to ice. These wedge-shaped ice bodies are up to several metres long in vertical section. Viewed from the above the ground, the ice wedges often form large, meshed polygon patterns. When the climate again became milder, the ice melts and the wedge are filled either by the collapse of the layers surrounding them, or by deposit of material from the wind or running water.

Silt constitutes a "frost hazard" soil type, because silt is capable of using capillarity forces to absorb water up from deeper layers, and, as a result, to form horizontal ice lenses in the soil. These ice lenses can cause damage to constructions such as roads and embankments.

7.3 Individual glacial and interglacial periods

In Northern Europe, ice ages (named glacial times) are perceived as the periods when the average temperature in the summer sank to less than 10 to 12 degrees Centigrade. With so low summer temperature forest growth is no longer possible, and ice glaciers spread from the highlands down to the lowlands. The interglacial are the periods when summer temperatures rose to as much as 16 to 18 degrees Centigrade for sufficiently long periods of time to allow the forest to be establish again. The ice melted away and remained only as small glaciers in mountainous areas.

The so-called *interstadial periods* represent short periods with warm climate during an ice age where ice only partially melted away, and only sparse vegetation managed to hold on to the land areas.

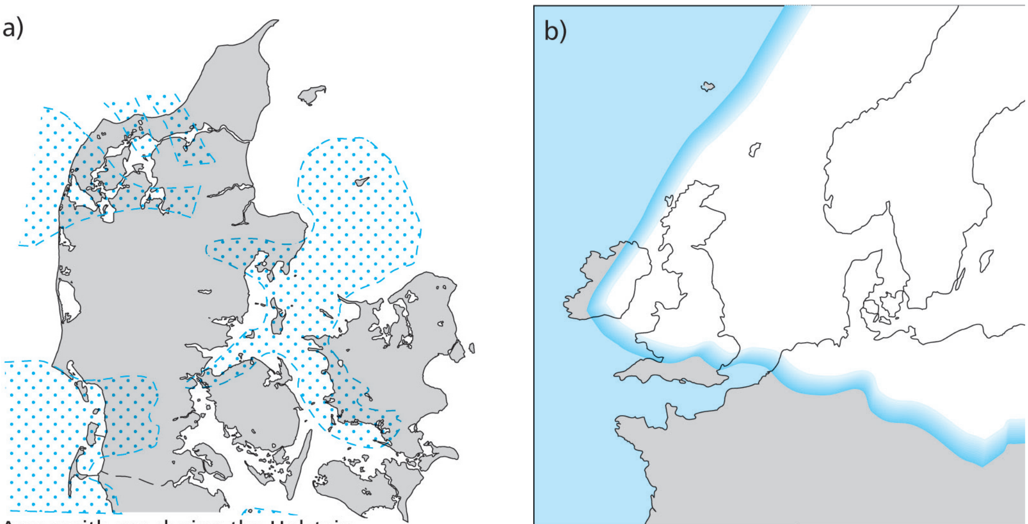
In Denmark, we have evidence of Glacials and 3 Interglacials (see column 4 in Figure 2.1). The present period, the Postglacial Period, may possibly be only an Interglacial – we do not know this for certain until 50 to 100,000 years from now!

Before the first glacial, there were several cold periods, resulting in widespread ice cover in more northern regions while Denmark was free of ice.

The following lists the known glacial and interglacial periods with names and their dated time interval as well as brief comments on the types of deposits that characterise them. The names of the glacial and interglacial periods are international standard and refer mostly to areas or places in Europe, from where sediments have been investigated and dated for the specific period, and the result published in scientific literature.

- **Menap Glacial** (approx. 750,000 years before present time). This is the first known glacial periode in Denmark.
- **Cromer Interglacial** (around 750,000 to 490,000 years before present time). No known marine deposits in Denmark. Only fresh water sediments.

- **Elster Glacial** (around 490,000 to 410,000 years before present time). All of Denmark covered by ice. Gray, sandy moraine known from, among other places, southwest Jutland. There are some melt water clays and silt from the Late-Elster present in Jutland.
- **Holstein Interglacial** (approximately 410,000 to 390,000 years before present time). Holstein is known for both freshwater and marine sediments. The distribution of the latter can be seen in Figure 7.4a. Marine Holstein sediments from Southern Jutland have been known for many years under the name *Esbjerg Yoldia clay*. (Yoldia is the former name for an arctic sea mussel, now called "Portlandia Arctica"). Freshwater sediment from the Holstein is best known from the region between Vejle and Fredericia. Lake deposits in the form of empty shells from siliceous alga (= diatomite) are found here.



Areas with sea during the Holstein interglacial period.

Maximum ice cover during the Saale glacial period.

Figure 7.4. Outline of presumed land and sea during the Holstein Interglacial and the subsequent Saale Glacial. From /7.2/.

- **Saale Ice Age** (around 390,000 to 130,000 years before present time. The Saale Ice Age is also called "the great ice age", because the moraines from this period are found further south than moraine from other ice ages, see Figure 7.4b.
  At least two ice-thrusts are known from the Saale Glacial Period. The first, the Norwegian-thrust that reached Holland, and the second, the Baltic-thrust from the Baltic countries. The two moraines are very different; the Norwegian ice-thrust deposited a very sandy moraine deposit, while the thrust from the Baltic region resulted in a very calcareous moraine with a carbonate content up to 50 %. The high calcium carbonate content is due to glacial erosion down into the white chalk in the substratum of eastern Denmark. In West Jutland, the Saale moraines form the surface of the hilly islands outside the main border line from the latest glacial period (Weichsel).
- **Eemian Interglacial** (about 130,000 to 117,000 years ago). This interglacial is known for a large number of lake, marsh and marine deposits. Freshwater sediments from Eemian Interglacial is primarily deposited in bogs and lake basins. Here, clay and sand is found, as well as peat deposits and siliceous-algae gytja (diatomite). Marine deposits from this ice age, comprising clay and sand, are found in many localities in South Jutland, on Fyn and North Jutland, see Figure 7.5c. In North Jutland, the marine sediments of Eemian age traditionally are named *Older Yoldia clay*.
- **The Weichsel Ice Age** (117,000 years to approx. 16,000 years ago). The Weichsel glacial period is divided into three phases, Weichsel I, II and III (see the temperature curve in Figure 8.2). Denmark was only covered in ice during Weichsel III, which la-

sted from approx. 25,000 to 15,000 years before the present. In Weichsel I and II, the ice only reached southern Norway and Sweden, while Denmark was tundra grassland. Here, animals such as mammoths and longhaired elephants grazed (both species are now extinct).

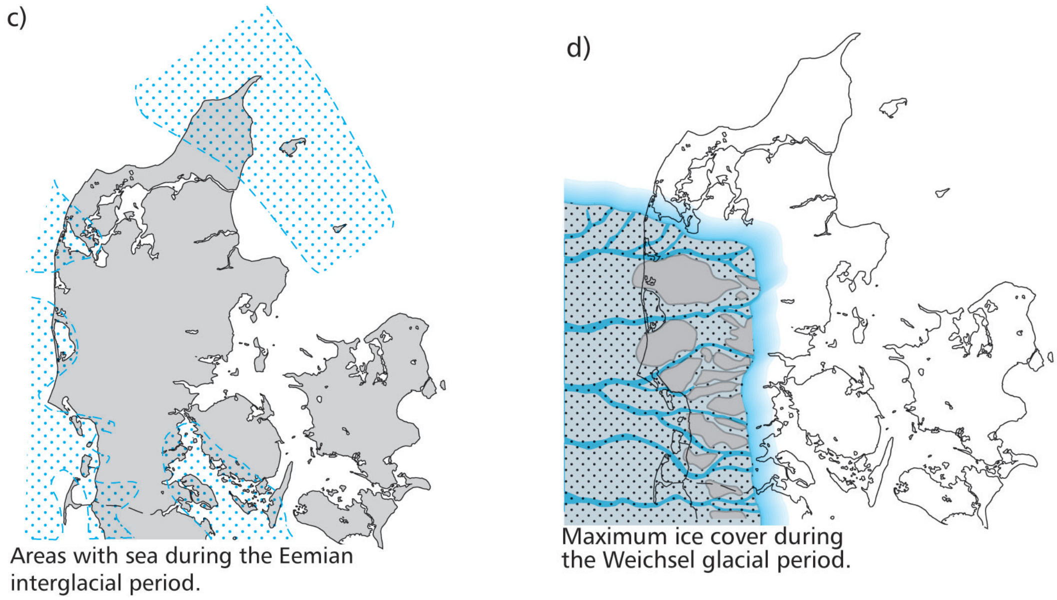


Figure 7.5. Outline of land and sea during the Eemian Interglacial (from /7.3/) and presumed maximal ice extent during the subsequent Weichsel Glacial. From /7.4/.

When the ice in Weichsel III was most widespread, it reached the “main borderline” down the middle of Jutland, see Figure 7.5d. From this ice-margin, melt water rivers flowed over the existing Saale landscape, where the highest areas were hilly islands in the flat melt water plain. Since sea level was much lower than now, the melt water rivers stretched beyond the present coastline far out in the North Sea area. See also Figure 7.6.

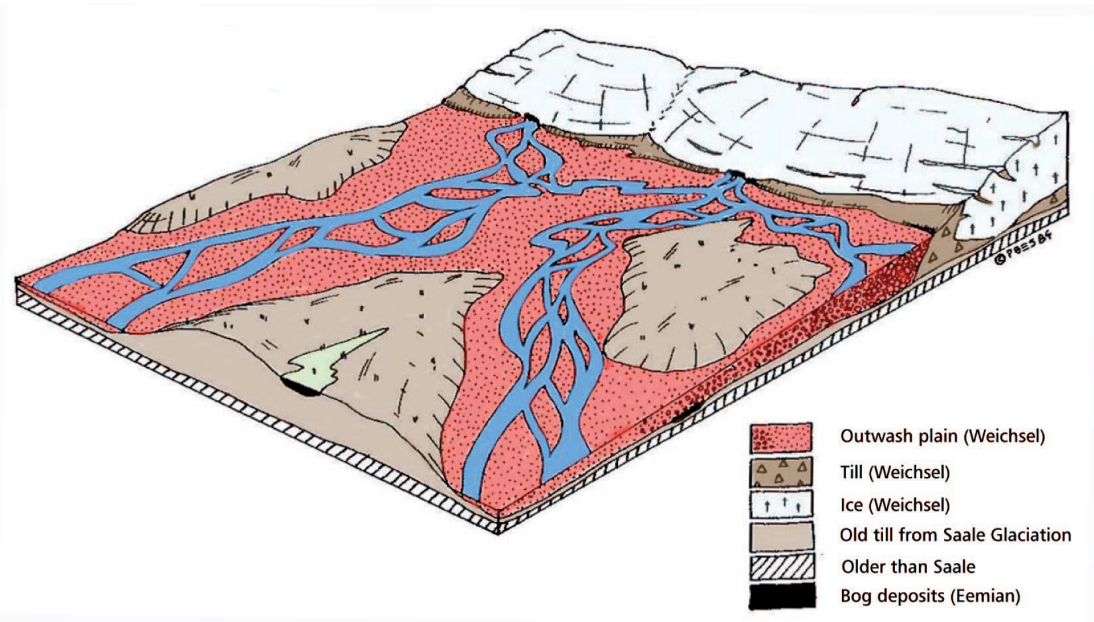


Figure 7.6. Melt water flowed away from the main stationary ice margin during Weichsel Glaciation. Notice the braided river system of meltwater streams.

7.4 Characteristics of glacial deposits

During the Quaternary Period, Denmark have been repeatedly subjected to advancing glaciers, flowing meltwater and changing sea levels, which partly flooded land areas. The beds, which were deposited as a result of these rather violent processes, can be broadly divided into *moraine deposits*, *melt water deposits*, *marine deposits* and f*reshwater deposits*.

The following describes the characteristics of the glacial deposits consisting of moraine and melt water deposits. The interglacial deposits consist of marine deposits and freshwater deposits of the same type as deposited in Late-and Postglacial periods. They will, therefore, be discussed in connection with the description of these periods in Chapter 8.

- **Moraine clay** is always unsorted. It always contains clay (typically 10 to 15 %) and sand, gravel, cobbles and boulders. Moraine clay is usually always calcareous (below the upper weathering zone). The colour is usually gray in un-weathered condition; in the upper weathering zone, the colour is reddish and yellowish, sometimes brownish, see Figure 1.7. There is usually no trace of organic matter, but sometimes moraine clay can be enriched in local subsurface of for instance black mica clay.
- **Moraine sand** and **moraine gravel** have the same features as moraine clay, but sand and gravel particles are dominant in relation to the clay.
- **Melt water clay** and **silt** – also named glacio-lacustrine sediments – are deposited in former ice-dammed lakes. The deposits are sorted and often finely laminated in varve. Varve is contrasting beds representing seasonal sedimentation, as summer (light) and winter (dark) within a single year. Besides clay and silt, there may also be layers of fine sand and sometimes single cobbles and boulders dropped from floes of ice. Melt water clay is always calcareous below the upper weathering zone. The calcareous content can be so large, that the sediment is a marl (more than 15 % $CaCO_3$). The colour of melt water clay and silt is usually gray or dark grey in un-weathered state, and reddish and yellowish in the weathered zone. Usually there is no trace of organic matter.
- **Melt water sand** and **gravel** – also named *glaciofluvial sediments* – is always sorted in contrast to moraine deposits. Poor sorting may occur especially in coarse beds. There are typically many different minerals and rock particles present in the same sample. If the components include shells and pieces of limestone, these are always worn and re-deposited. The grains are typically angular or sub-angular (poor rounding), except for quartz grains, which can be quite rounded, see Figure 7.7.

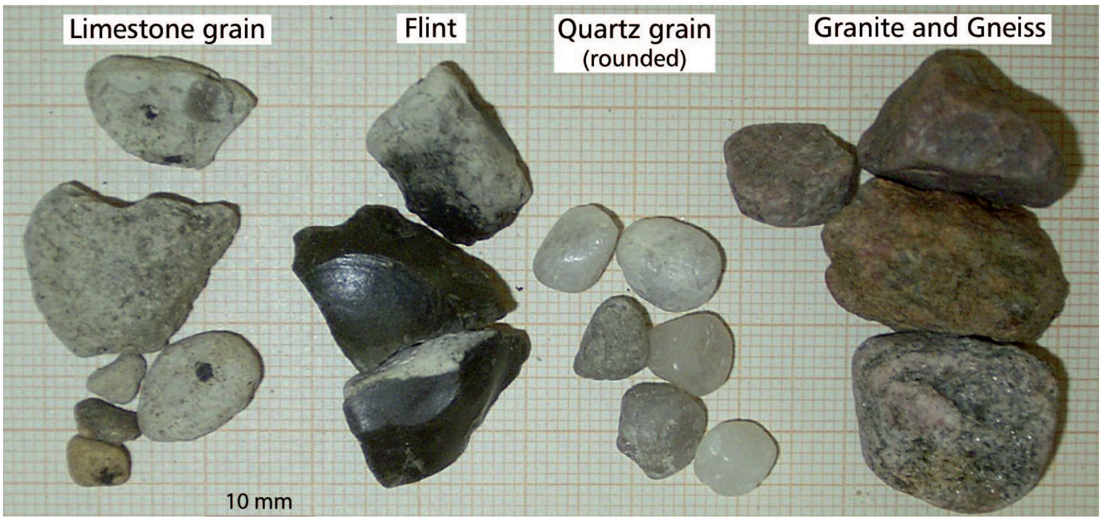


Figure 7.7. Examples of components in glaciofluvial sand.

7.5 Present outline and exposed localities

The Ice Age deposits are widespread throughout Denmark, and lie typically in the upper layers where drilling and excavation is done from the ground surface. The thickness varies according to the location of the ground surface and the Pre-Quaternary surface as (described in Chapter 2, Figure 2.3).

The distribution of the different types of glacial and interglacial deposits can be seen on the geological surface map. The following three types of geological maps are generally very useful, when the expected Quaternary soil types are to be assessed in a given area.

- Maps with contour lines to show the surface terrain forms.
- Geological surface maps (also named soil type maps) showing the dominant soil types in the upper 1 metre.
- Per Smed´s landscape map divides the country into different types of landscape elements, and gives an interpretation of how these elements have been formed.

The above mentioned three maps are detailed in Chapter 10, which deals with Quaternary geological maps.

The interglacial occurrences are very seldom compared to the glacial deposits. Interglacial layers of any significance may only occur in areas previously covered by the sea during the Holstein and Eemian. As, for example, in south-western Jutland and North Jutland; see Figures 7.4 and 7.5.

Exposed sections through glacial sediments are seen in the majority of excavations for raw material in Denmark. Especially sections in glacio-fluvial sand and gravel often reveal fine structures of bedding planes including cross-bedded layers, see Figure 7.3.

Sections through ice age deposits can also be seen in many coastal cliffs. Denmark has approx. 7000 km of coastline, and about 15 – 20 % of these coastlines is steep enough to form cliffs. The heights of Danish coastal cliffs vary from a few metres to over 100 metres. A map where the coastline is shown together with contour lines can indicate the height of a given cliff by showing the elevation of land surface just next to the sea

7.6 Geotechnical properties of glacial deposits

In geotechnical terms, there is usually no problem with glacial deposits, as they are *pre-compressed* by the ice. However, the glacial deposits vary in strength depending on where in the glacier the material was located – whether it was at the bottom or near the surface.

Moraine deposits can thus be divided into two main types: *bottom moraines* deposited at the bottom of the glacier, and *surface moraine* (ablation moraine) being the surface near material released when the ice melted.

Bottom moraines have been exposed to large pressure from the load of the thick ice and are therefore pre-compressed. Their texture is usually very firm and without visible structures. Surface moraines have not been loaded by the pressure of the ice and are therefore usually looser than the bottom moraine and have a lower strength.

When describing soil samples it is generally not possible to distinguish surface moraines from bottom moraines. If, however, testing of soil strength is performed in intact soil, it is usually possible to distinguish surface moraine from bottom moraine. Testing of in-situ soil strength can be done with a rod mounted with a vane, see Figure 7.8. The rod is placed perpendicular to the soil surface and then turned around. The force required to turn the vane is measured until the breakpoint of the soil, and then the strength can be calculated following some standard formulas related to the specific vane in use.

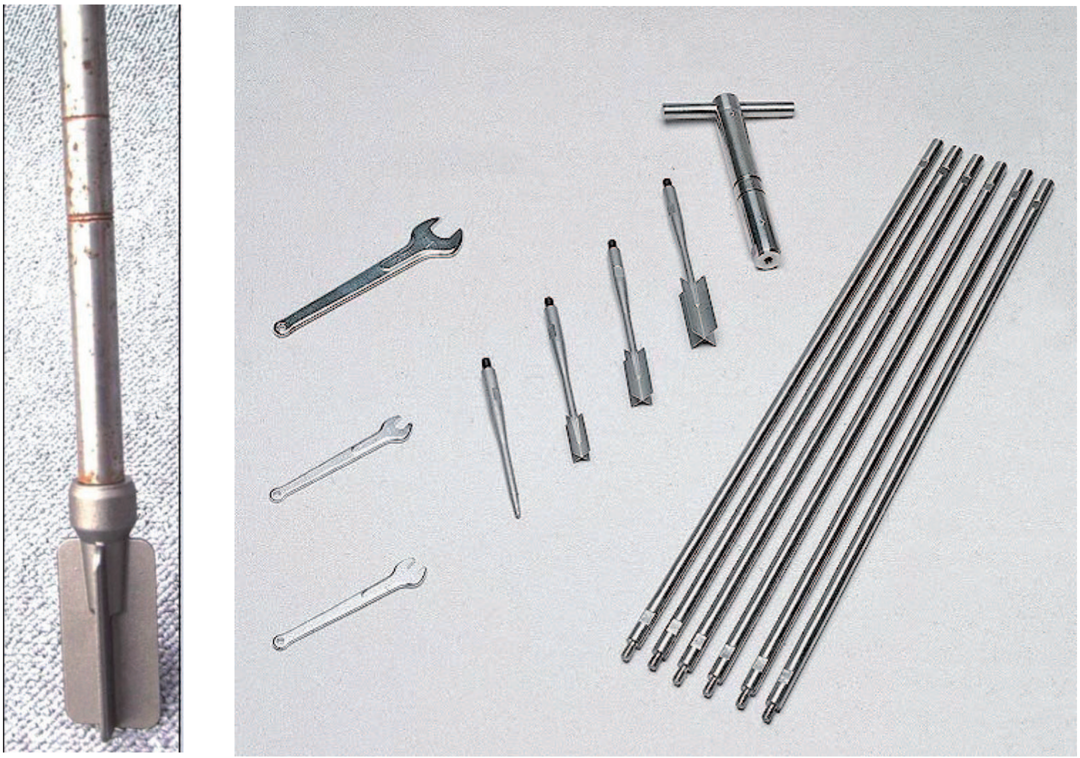
For bottom moraines, it is necessary to use a force of hundreds of kN/m^2 to turn the vane, while for the surface moraines, a somewhat smaller force is required. The practical execution of measurements using the vane strength method is, for example, described in /7.7/.

The shear strength of moraine clay also depends on the clay's content of calcium carbonate, so the upper calcareous free zone generally has a lower strength than the calcareous moraine clays (zoning of moraine clay can be seen on e.g. Figure 1.7 in Chapter 1). This relationship is used in road construction, where in some areas the upper calcareous free and week clay soils are mixed with powdered lime to increase its strength.

The above text about moraine clay's strength also applies to melt water clay. Here, there may also be varying degrees of load from the ice resulting in varying strength of the clay.

Glaciofluvial sand and gravel are always good for foundation as they have a stable grain skeleton, where the individual sand and gravel particles rest firmly on each other.

The interglacial deposits of fine grained and more or less organic soils may be problematic for foundation if they are not pre-compressed by the ice. This is not the case west and south of the main borderline for the latest Glacial period (Weichsel), see Figure 7.5.



A **B**

Figure 7.8. Examples of equipment for in-situ testing of soil strength. A is a standard Danish vane from the company Rotek /7.5/, and B is equipment with different vanes from the company Eijkelkamp /7.6/.

7.7 Excavated materials from glacial and interglacial deposits

The most important excavated materials from the Quaternary are glaciofluvial sand and gravel that are excavated in many places in Denmark. Large boulders are also used, either in their full size, or crushed down to rubble. There are many qualities of sand and gravel, depending on the local materials eroded by the ice and melt water. The producers sorting and control of mixtures and fractions also offer various grades and qualities.

Melt water clay and silt is used in the brickwork industry. The most wanted clays are the calcareous free clays, because they give red colour to the bricks when baked. Calcareous clay gives yellow bricks. Previously, clay was dug in several small clay pits, but now it is extracted from some 10 to 15 active excavations throughout Denmark.

From the mid-1900´s, diatomite was dug from interglacial lake deposits. Diatomite was used for insulation material, for filtering purposes, as a polishing agent, and as filler in dynamite. At Rands, north of the town Frederica, there were 4 locations where diatomite was excavated. In 1956, close to 10,000 tonnes in total were produced yearly, which was equivalent to 400,000 bags of 100-liter size. Production ceased in 1978. Other sites where diatomite was excavated are Hollerup, West Langå, and Egebjerg, north of Horsens.

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/7.3/ Seidenkrantz, M.: *Nye oplysninger om kvartærstratigrafi – baseret på foraminifeer fra en ny boring på Anholt* (New Data on Quaternary Stratigrafy - Based on foraminifera from a new borehole at Anholt, Kattegat). Danish Geological Society, Årsskrift for 1990-91 [1992], pp 81-87.

/7.4/ Schou, A.: *Atlas of Denmark. Landforms*. H. Hagerup. Copenhagen, 1949.

/7.5/ ROTEK A/S. *Nyhedsbrev nr. 3, 2005*. Available at http://www.rotek.dk/ Visited 04-04-2010.

/7.6/ Eijkelkamp. Shear Stress Measurement: *Field inspection vane tester*. Available at http://www.eijkelkamp.com Visited 04-04-2010.

/7.7/ Danish Geotechnical Association: *Felthåndbogen* (Field Manual). Bulletin No. 14 (1999).

Review questions to Chapter 7

1) Why is the sea level generally very low during an ice age ?

2) In an ice age, changes in sea level will occur because of isostatic movements. How does this process work when the country is covered with ice and how does it work after the ice age ?

3) Was all of Denmark covered by ice in the Saale Ice Age ? (Second last ice age)

4) Mention some components that may be included in moraine material

5) Glaciofluvial sediments often show layered bedding. How does this layering occur ?

6) In what season (summer or winter) were the largest quantities of glaciofluvial sediments deposited ?

7) How can we generally distinguish moraine clays from melt water clays ?

8) Marine sediments and freshwater sediments are known from the Holstein Interglacial. Name a typical soil that is marine deposited, and a typical soil from the fresh water environment.

9) Was all of Denmark covered by ice in the Weichsel Ice Age ?

10) Moraine clays in Denmark are typically calcareous below the upper weathering zone. How can this be explained and where does the calcareous content come from?

11) What characteristics are typical of interglacial deposits (i.e. characteristics for sediments deposited between two ice ages) ?

Chapter 10

Quaternary Geological Maps

The map of the Pre-Quaternary surface and its relief was introduced in Chapter 2, Section 2.4 and 2.6. Now in Chapter 10 we will look at maps showing landforms and soil types from the latest and present geological period, the Quaternary period. These maps can be divided into three main types:

- Topographic maps with contour lines (see Section 10.2)
- Per Smed's geomorphological maps (see Section 10.3)
- Geological surface maps from GEUS (see Section 10.4)

Previously, the above mentioned maps were only available as printed paper maps, but during the last 10 years there has been a rapid change away from paper maps and towards digital maps available on PC. The digital map-themes can be combined in several ways using GIS-software as for example MapInfo (GIS stands for **G**eographic **I**nformation **S**ystem). At the same time, the Internet has made digital maps much more available, so that it is now possible via the PC quickly to learn what a specific locality looks like on different types of maps. This could, for example, be via the public service Danish Area Information to be introduced in the following Section 10.1.

10.1 Danish Area Information

The internet service *Danish Area Information*, was created as a common map service in connection with an administrative structural reform in Denmark 2007. The service is able to show various environmental and planning issues in a uniform manner for all Denmark and with the ability to switch between several background maps. Some of these background maps show terrain conditions and contour lines very clearly and are therefore relevant in geological interpretation of Quaternary beds and processes in a given area.

Public access to Danish Area Information is made via the internet address: *http://kort.arealinfo.dk/*. The first screen picture shows a map of Denmark with a menu bar from which it is possible to choose a variety of different tools that can zoom in and out, turn different layers on and off, and highlight areas and points. The menu bar also contains a *Find* utility from where you can search for example a particular address, a grid reference, or a place name. Moreover, it is possible to view the planning and public records linked to a particular area.

The left side of Danish Area Information's screen contains a menu from which you can choose to view a number of environmental and planning data, and select what kind of background maps the data should appear together with, see Figure 10.1.

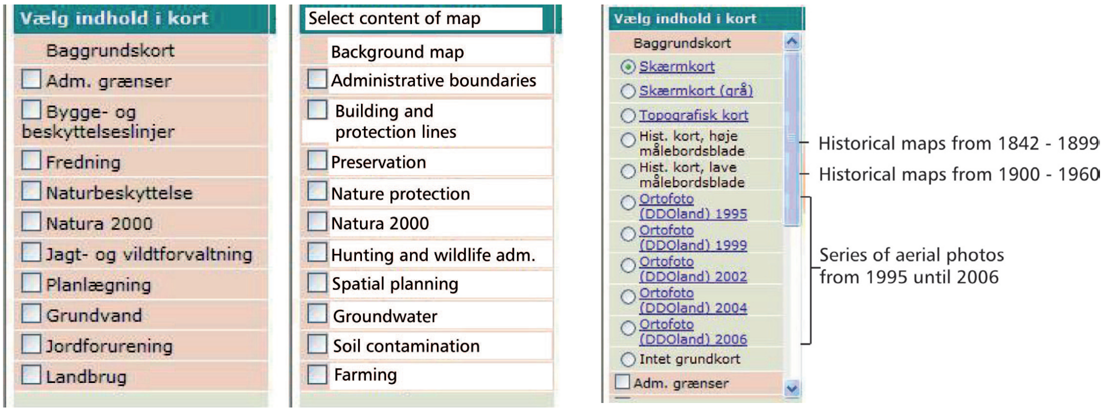


Figure 10.1. Names of the different groups of environmental and plan data (left side) and optional types of background maps (right side). Screen print from /10.1/.

From Danish Area Information environmental topics can be downloaded in file formats directly to use in the most commonly GIS programs like *MapInfo* and *ArcView*. One of the great advantages of using a GIS system is the option to link data from a database with a geographic map if only the database contains specific information on location. This may, for example, be an address, as all addresses in Denmark in recent years have been associated with specific coordinates – a fact used in many public map services available online today.

When a map from the Danish Area Information appears on the PC screen, it is possible (via the menu bar settings) directly to follow the coordinates of the cursor location, see Figure 10.2. The right side of the bottom line also displays the name of the copyright owner of the background map, which is currently on screen. In the example Figure 10.2, the National Survey and Cadastre Authority has the copyright, but when the background map show an aerial photograph, the company COWI is the copyright holder.

Figure 10.2. Copyright and UTM-coordinates shown on maps from the Danish Area Information. Screen print from /10.1/.

10.2 Topographical maps with contour lines

Contour lines are often seen together with roads, houses, rivers, etc., as can be seen in Figure 10.3. Here, the brown lines are contour lines with 2.5 metre interval between the lines. Every second line is dotted (2.5 m, 7.5 m, 12.5 m, etc.). The other lines (5 metres, 10 metres, 15 metres, etc.) are shown with solid lines, and for each 25th metre, the line is drawn extra thick (25 metres, 50 metres, 75 metres, etc.).

Parallel lines show a *slope*. See for example the slope down towards the map's south-westerly section in Figure 10.3. V-shaped, parallel curves show a *gorge*. Long distances between curves indicate a *flat* land area – see for example the flat bottom of a valley in the map's south western part. Curly contour lines and many closed lines show an undulating terrain with small hills and depressions. *Streams* and *lakes* are important to notice as they show downward directions and also where the lowest parts of the terrain are.

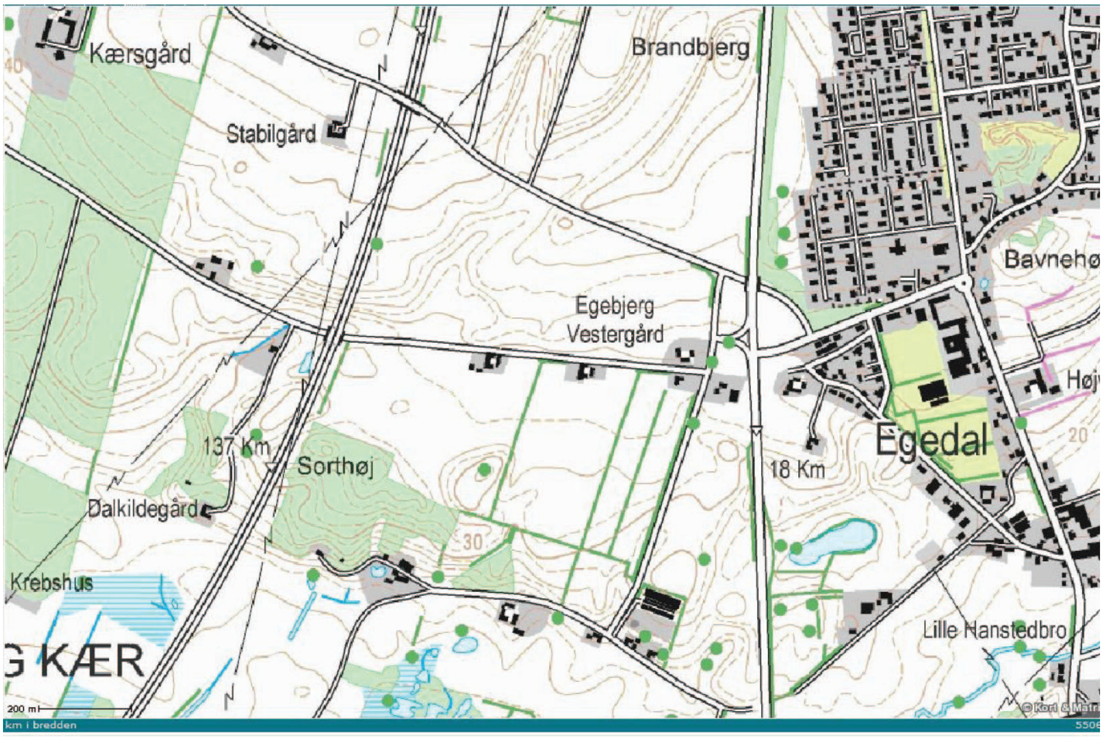


Figure 10.3. Topographic map with contour lines from The Map and Cadastre Authority. Scale is shown on the bar at the bottom left.
Sample from an area in Egebjerg north of Horsens. Screen Print from / 10.1 /.

Map themes on topographical maps, as shown in Figure 10.3, correspond to the themes of the printed 4-cm maps, which, in one generation from the 1970s onwards, was absolutely essential for all public planning and administration in Denmark. The maps were called "4-cm maps" because they were printed in scale 1:25,000 - i.e. 1 cm on the map corresponded to 25,000 cm (= 250 metres) in reality. 1 km in reality corresponds to 4 cm on the map - hence the name.

In the 1990s, all 4-cm maps were scanned as image files by the Map and Cadastre Authority. The maps can now be viewed online at, for example, the website "*Fund og Fortidsminder*" at the Culture Heritage Authority /10.2/. There it is also possible to see scanned 2-cm maps and 1-cm maps with contour lines (2-cm and 1-cm maps correspond to 0,5 km and 1 km in the real world, respectively). Distance between the contour lines of 1-cm and 2-cm maps is 5 metres (compared to 2.5 metres for 4-cm maps). Especially 1-cm maps can be recommended to get a good overview of the terrain in an area.

Figure 10.4 shows an example of a scanned 4-cm map (a sample of the area from Figure 10.3). It is seen that the contour line picture on the printed 4-cm maps are a little different from shown on the screen from the Danish Area Information. Thus, hill tops on the printed 4-cm maps are marked with a small dot and a number for the height level, whilst depressions are indicated with a small cross, see Figure 10.4. These facilities from the printed maps have not been transferred to the digital maps created "layer upon layer."

The printed paper maps always were divided according to the cell division shown on Figure 10.8. Today, the maps are sold as "print on demand", i.e. you choose exactly the section you need with optional themes and scale, and then the map is printed from a computer. This flexible production form may fail some of the graphic "fineness" of the old printed paper maps. On the other hand, today we have some very big advantages using the digital map themes, including contour lines, in optional combination on a PC screen via a GIS system. Here it is possible to show the pure contour line image and clarify it through automatic colouring. Some applications are also able to show the terrain conditions three-dimensionally viewed from optional directions.

Printed 4-cm maps are not updated anymore, which can be seen, for example, from the highway under construction to the far left in Figure 10.4. In reality, this highway was opened in 1988. In the geological interpretation of landforms, it is, however, an advantage that the maps are old, because the contour line image then is clearer. Natural depressions and hill tops often disappear because of human terrain adjustments, and therefore it may be difficult to see the original landforms on new maps.

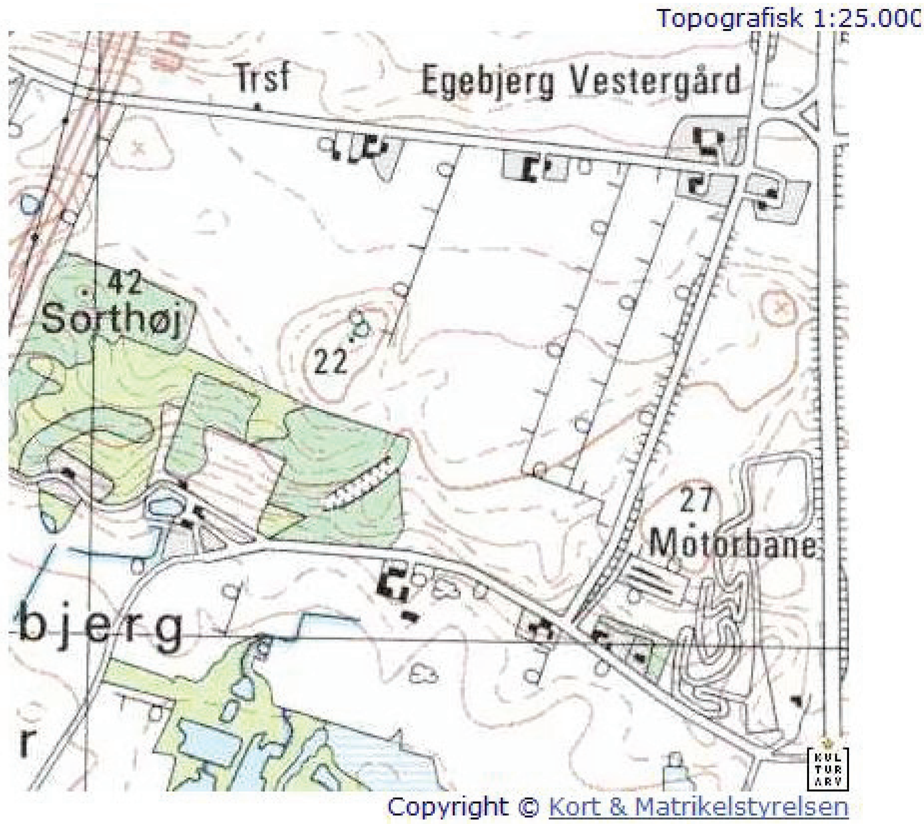


Figure 10.4. Scanned sample of a 4-cm map. Note the hill top with level 22 and the closed curve with a cross representing the depression in the right side of the map. Screen print from /10.2/.

Scanned old maps can be seen at other internet services than "Fund og fortidsminder". Background maps at Denmark's Area Information can thus be the old Danish survey maps in scale 1:20,000 (the maps are named "Målebordsblade" in Danish). These old survey maps can be viewed on the internet in two versions. The "Høje målebordsblade" are the eldest and were produced during a period from 1840 to 1899. Figure 10.5 shows an example of such a "målebordsblad" from the same area as shown in Figure 10.3. The contour lines here are very clearly and there are more of them because they are specified in feet instead of metres. (1 feet is 31.39 cm and there are 5 feet (= approx. 1.5 m) between the individual contour lines at the old maps. The old map, (Figure 10.5), highlights, among other things, the slope to the southwest as consisting of two steps - something that is not seen so clearly on the new map in Figure 10.3. Moreover, the original terrain features of existing urban areas are seen very clearly on the old map – see, e.g. Egebjerg on the map section's eastern part, where the contour line image on the new map is subdued by the development of building and houses in the area.

The old maps are very useful for geotechnical studies because old bogs and depressions are clearly marked. This indicates where bad foundation conditions with organic and weak soil types may be expected. In modern areas, these depressions and potholes may be completely blurred by terrain regulation and back-fill.

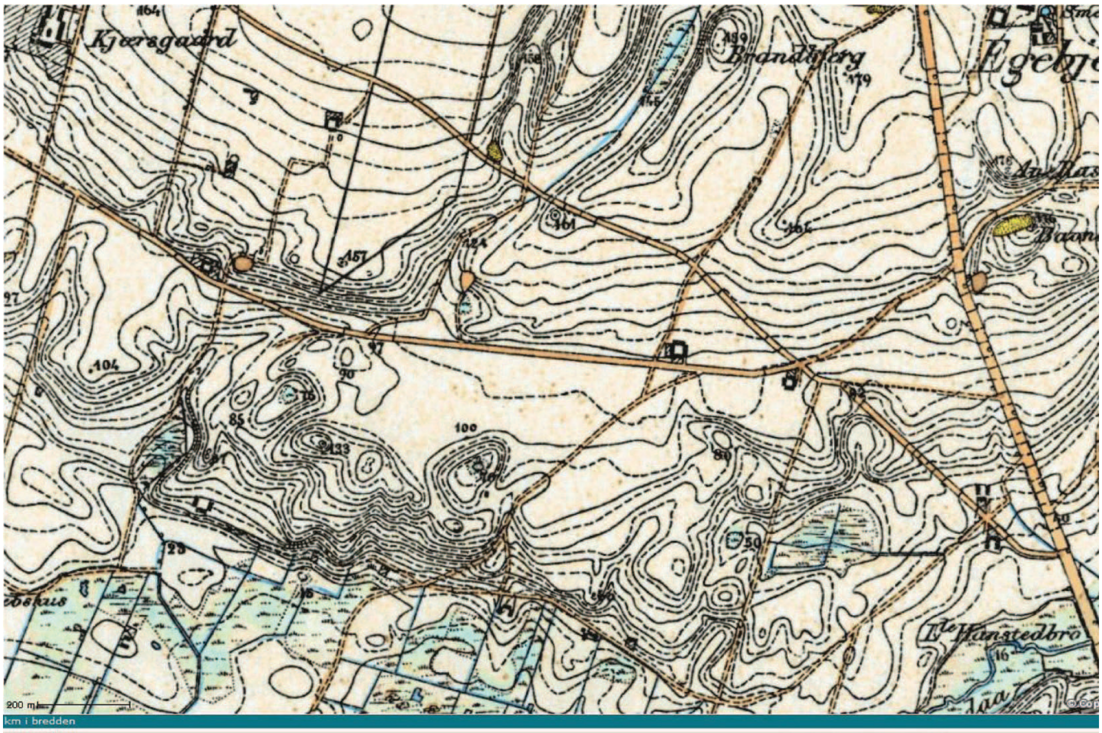


Figure 10.5. Example of old survey map ("målebordsblad") from the area shown in Figure 10.3. Contour lines are for every 5 feet (about 1.5 m). Screen print from /10.1/.

10.3 Per Smed´s landscape map

In the period 1978 to 1982, 4 landscape maps compiled and drawn by the geologist Per Smed were published. The maps have been very widely used because they give a good overview of the Quaternary geological features in the landscape and show the relationship between the large valley systems and other landscape forms.

Generally, the maps show an *interpretation* of the landscape-forming processes. They distinguish between a total of 17 different terrain features, as shown in Figure 8.9. Many of the terrain features are the same as described in Chapter 9 on Landforms.

A total of four different Per Smed maps have been published together covering the entire Denmark with some overlap.

- Sheet 1; Nord Jutland (Nordjylland).
- Sheet 2; Central Jutland (Midtjylland).
- Sheet 3; South Jutland, Fyn (Sønderjylland og Fyn).
- Sheet 4; Zealand (Sjælland).

The maps are available both in a large edition (A2, scale approx. 1:360,000) and in a small A4 version. The small version is only a zoom out of the large one and contains the same information as the large A2 version.

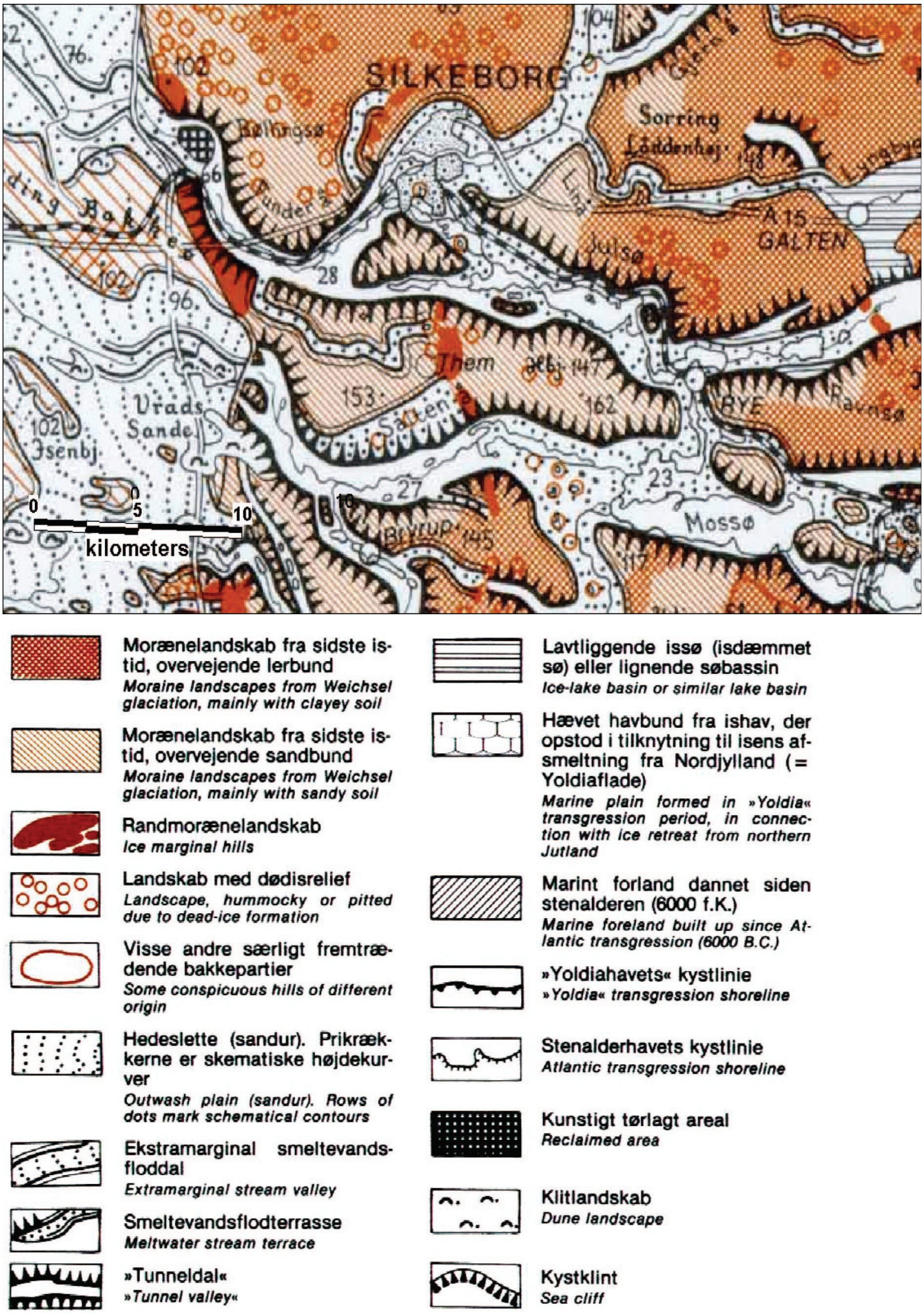


Figure 10.6. A section of Per Smed's landscape map from Silkeborg in the Central Jutland region.

10.4 Geological surface maps from GEUS

The geological surface maps are also referred to as "soil-type maps". These maps show the dominant soils in 1 m´s depth, i.e. just below the top soil. The soil types are evaluated during a field investigation with a soil probe. The probe consists of a 1 metre long bore, which is pressed into the soil for every approx. 100 to 200 metres. From the soil resistance to the probe and a small soil sample in a furrow at the tip of the probe the nature of the upper metre of soil layer is assessed.

During the investigation the result from each boring is briefly marked in a field geological map with specific signatures. Also nearby excavations and cliffs in the area are visited, to see larger exposures of the local soil types. Borders between the different soil types and beds are outlined in the final draw-up from the area. A distinction between 67 different Quaternary and 16 Pre-Quaternary soil types are made – see the list in Appendix 3. GEUS's colour table for the soils is also shown in this Appendix.

An example of a coloured soil type map can be seen in Figure 10.7. The map is copied from the Internet, where it can be seen as a background map for Jupiter Version 2, see /10.4/. The map section in Figure 10.7 shows approximately the same area (north of Horsens) as can also be seen in Figure 10.3 and 10.5.

On the map, Figure 10.7, the soil types are shown using both a two-digit letter code and a colour. For example, ML means moraine clay and DS means glaciofluvial sand (deposited by meltwater). The table in Appendix 4 shows all the letter codes for the soil types. Letter codes are an abbreviation which can refer to both the deposition environment and the geological age as well as the name of soil type. In some cases, the abbreviation also refers to old geological names that are no longer used. The abbreviation DS is thus an abbrevia-

Figure 10.7. Example of a coloured soil type map. The legend for letters and colours is found in Appendix 3. The map is copied from /10.4/.

tion for "Diluvial Sand", where "Diluvial" is a term for "flood" (as that mentioned in the Bible story about Noah's boat). This is the reason why we today use the the generic term DS for glacio-fluvial sand.

The white colour on the soil type map of Figure 10.7 shows that no investigation has taken place here. Nationally, there are about 16 % of these white non-investigated areas. Their distribution in Denmark is shown in Figure 10.8.

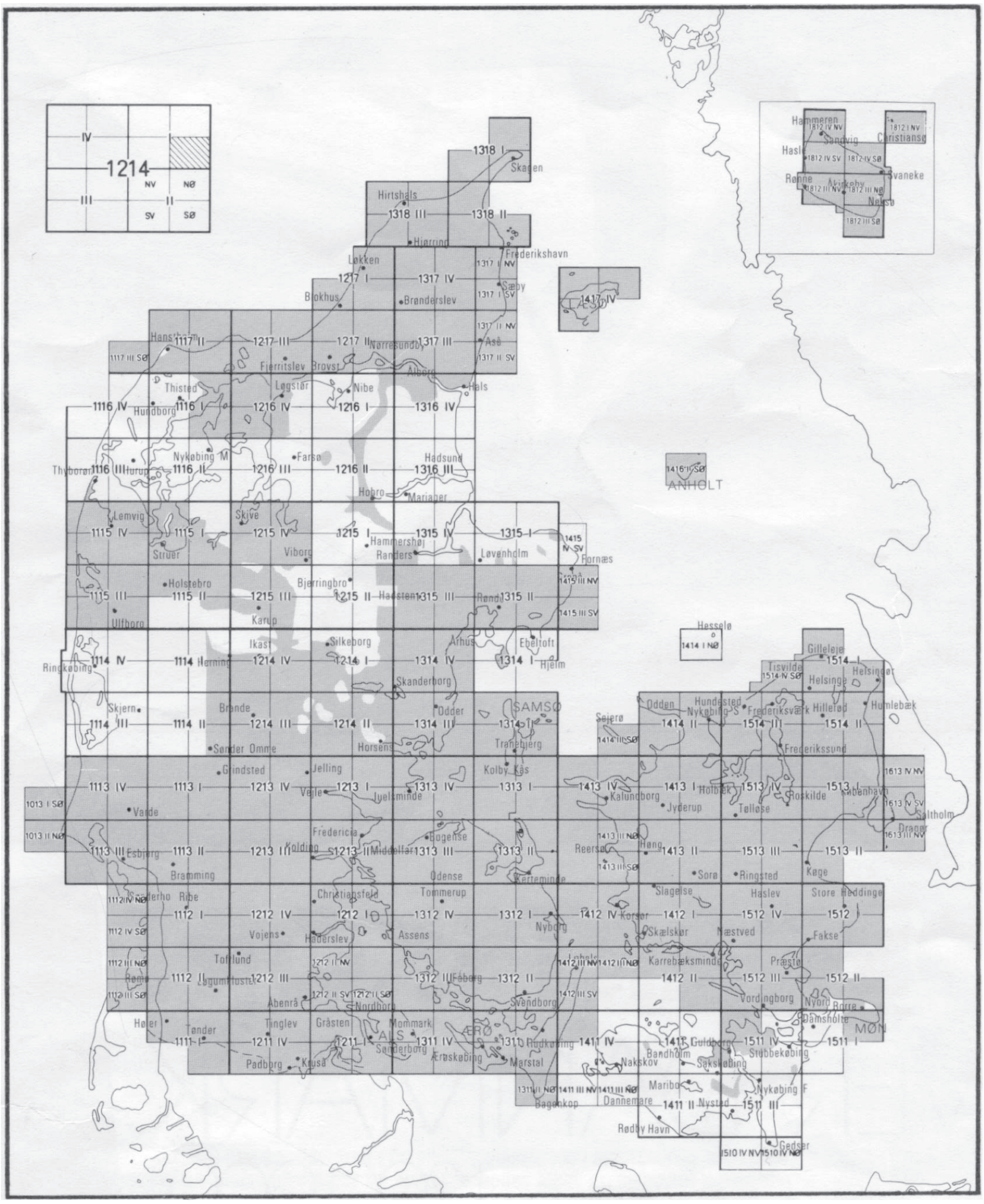


Figure 10.8. Distribution of the investigated areas as basis for the geological soil type maps. The white areas are not investigated. The subdivision in cells on the map show the boundaries for the printed paper maps mentioned in Section 10.2. Copy from /10.5/.

The accuracy of the digital versions of the soil type maps are difficult to determine because each map has been rescaled and redrawn during the course of time. Moreover, the borders between two soil types are not always drawn as clear transitions, as there may be diffuse transitions between different soil types in nature.

GEUS informs in /10.3/ that the maps can be considered usable in scale 1:25,000, and that a border between two soil types may be displaced up to 50-100 metres in reality. A technical description of the production of the geological surface maps and their uncertainties are found in /10.5/.

In 1989, the detailed geological surface maps were compiled and simplified to form 4 nationwide geological surface maps printed as paper maps in scale 1:200,000 for the whole of Denmark, see /10.6/. 10 years later (in 1999), simplified soil type digital maps were issued on CD-ROM.

The soil type maps in scale 1:200,000 are, however, only usable as a summary maps. For professional use the detailed soil type maps in scale 1:25,000 are recommended. They can be bought in a digital edition at GEUS for use in a GIS-software, where you pay according to the size of the extracted map-section. Alternatively, they can be viewed on the Internet, see /10.4/.

References

/10.1/ http://kort.arealinfo.dk/. Danmarks Areal Information. Visited 27-04-2010.

/10.2/ http://www.dkconline.dk/. *Fund og Fortidsminder*. Visited 19-08-08.

/10.3/ http://www.geus.dk/departments/Quaternary-marine-geol/gis/produktliste-dk.html Information (in Danish) about the Danish geological surface maps 1:25,000. Visited 27-04-2010.

/10.4/ http://arcims.mim.dk/website/geus/dk/ms/JUPITER_2v1/viewer.htm
Link to Jupiter version 2, where geological surface soil type maps can be seen as background maps. Visited 27-04-2010.

/10.5/ *Kortteknisk beskrivelse af Danmarks digitale Jordartskort.* Pdf file available via www.geus.dk > Afdelinger > Geologisk datacenter > GIS > Danmarks digitale Jordartskort 1:25,000. Visited 27-04-2010.

/10.6/ Pedersen, S.A.S. and Others (1989): *Jordartskort over Danmark, 1:200,000.* 4 colour printed map sheets published by DGU (now GEUS) in 1989.

/10.7/ *Digital maps of Denmark´s soil types. 1:200,000*. Published by GEUS in 1999.

Review questions to Chapter 10

1) When you see relatively closely spaced, parallel contour lines on a map, it shows a slope in the landscape. What options do you have, from a topographical map with contour lines, to determine what is up and down on this slope ?

2) On a map in scale 1:25,000 you mark, for example, the location of a borehole with a dot 1 mm in diameter. How many metres does 1 mm on the map equal in the real world, when the scale is 1:25,000 ?

3) Is it possible to download digital topographical background maps from Denmark's Area Information ?

4) How can old maps be useful in a geotechnical investigation ?

5) The following statements about Per Smed's landscape maps are either true or false. Write an F for false and a T for true next to the statements.
a) Per Smed´s map shows the soil types in the upper 1 metre below ground surface.
b) Per Smed´s map shows where there is an outwash plain from the last ice age.
c) Per Smed´s map shows only terrain types formed by ice and melt water.
d) Per Smed´s map summarises the contour lines of the ground surface.
e) Per Smed´s map shows an interpretation of the how landforms are made.

6) How are soil types determined on the geological surface maps from GEUS ? (How has one figured out where there is moraine clay, melt water sand, etc.)

7) Are there geological surface maps for the entire territory of Denmark ?

8) What sort of accuracy can be expected for the boundary between the different soil types on the geological surface map ?

9) Do the geological surface maps only display soil types from the Quaternary Period - or is it possible, in certain areas, to see signs of Pre-Quaternary soils on these maps ?

10) Can you download digital editions of surface geological maps from GEUS' homepage ?

Appendix 1

Jupiter Database

1. Access to the database

(All screenshots are from 30/3-2010.)

Jupiter is the Danish national well database at GEUS. Since 2004 Jupiter has been available for public access from the website http://www.geus.dk/geuspage-uk.htm. (this is the English entrance). From the top menu of this website select *Digital data and maps*. Here the top section shortly describes Jupiter and gives the link http://www.geus.dk/jupiter/index-dk.htm - and from this point all text is in Danish, giving the menu seen in Figure 1.

Figure 1. Menu from http://www.geus.dk/jupiter/index-dk.htm with translation.

From the above menu the link *Adgang til alle data* will give you a text with link to an overview map of Denmark (named *interaktivt kort* in the text, see Figure 2) as well as links to a search formular (named *søgeformular*) and to ”Goggle Earth”.

Figure 2. Screen print of Danish text, with red arrow pointing to the link “interaktivt kort”.

2. Borehole information from a specific area

The link to the map (= *interaktivt kort* in Danish) is recommended if you look for well information from a specific local area. This map has different menus or dialogue boxes, shown here as figure 3, 4, 5 and 6. With the *zoom ind* tool from the top right menu (Figure 3) you can zoom in until you have the wanted local area on the screen.

Figure 3. Top left menu from the map (=" interaktivt kort" in Danish). Active tool is marked with orange edge. To see well profiles – click the tools "detaljer" or "tværprofil".

When the wanted local area is on the screen, you can turn on the wells by ticking *Boringer* in the dialogue box shown on the right top screen of the map, see Figure 4. When *Boringer* is ticked an extended dialog box is shown – see Figure 5 – giving the possibilities to search for specific borehole numbers or properties. Click the button *Opdater* (update) to see the well points and their numbers on the map.

Figure 4. Top right dialogue box from the map (= "interaktivt kort" in Danish).

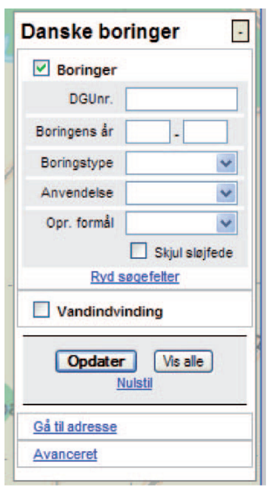


Figure 5. Extended dialogue box from the top right dialogue box of the map.

To see the information from a well, click one of the two buttons "*detaljer*" or "*tværprofil*" on the top left menu, see Figure 3. A click on the number of the map with one of these tools will show a yellow label with link to the well profile, see example Figure 6.

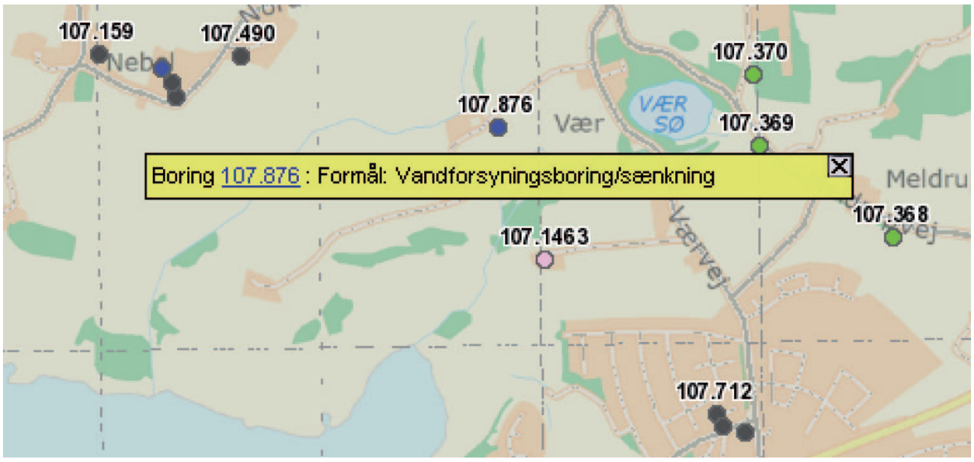


Figure 6. Map with borehole numbers and yellow label with link to well profile 107.876. Different colours of borehole number is explained in the legend available from the bottom menu of the map, see Figure 7.

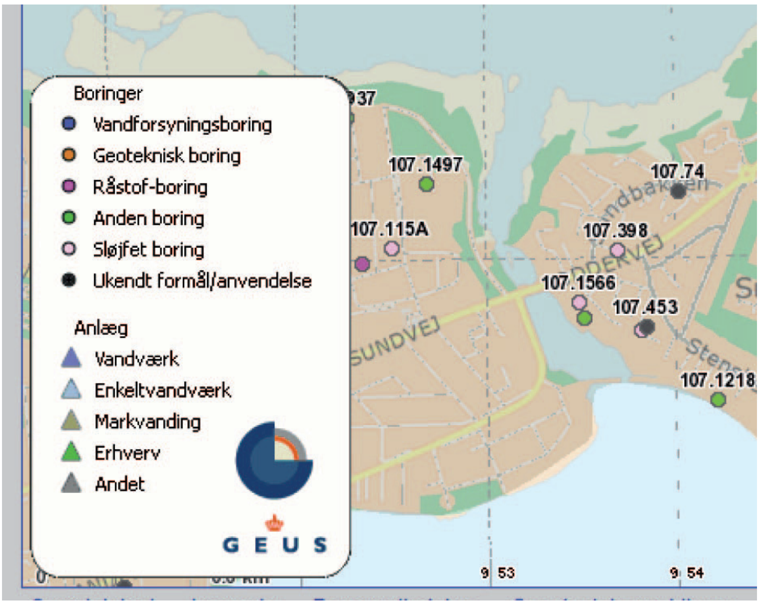


Figure 7. Bottom menu of map, with legend for borehole application shown.

A click on a yellow labelled borehole number results in a screen where the borehole location is shown on a satellite photo together with some table information about the borehole, see Figure 8.

Figure 8. First view of information for well no. 64.719. Only upper part of the screen is shown.

Clicking the red link *som Pdf* in figure 8 will give the graphic view of the well log shown as Appendix 2.

The graphic well log will often give a quick overview of the present data in the database, since the upper part of the graphic file has the most important information about ground surface level, groundwater head, pumping yield etc. as seen in Appendix 2. Also the placement of the screen below ground surface is shown in a clear way as can be seen on the bottom part of Appendix 2.

The penetrated soil and rock types are shown with a rock symbol letter in the well column (besides the Danish description). An overview with English translation of the rock symbol letters is shown as Figure 9.

Jupiter well data – rock symbols selected from http://jupiter.geus.dk/tabellerKoder **Translated by IS 2008**

b	Well (hole bored in the earth)		**i**	Silt, *unspecified*		**pv**	Alternating thin beds, *Selandien*
bk	Bryozoan or coral limestone, *Danien*		**id**	Freshwater diatomite gyttja *Interglacial*		**qg**	Marine gravel, *Interglacial*
c	Coal, lignite, *unspecified*		**ig**	Freshwater gravel, *Interglacial*		**qi**	Marine silt, *Interglacial*
d	Diatomite, *unspecified*		**Il**	Freshwater silt, *Interglacial*		**ql**	Marine clay, *Interglacial*
dg	Meltwater gravel, *Glacial*		**ij**	Ochre, *Interglacial*		**qp**	Marine gyttja, *Interglacial*
di	Meltwater silt, *Glacial*		**il**	Freshwater clay, *Interglacial*		**qs**	Marine sand, *Interglacial*
dk	Limestone, *Late Cretaceous*		**ip**	Freshwater gyttja, *Interglacial*		**qt**	Marine peat, *Interglacial*
dl	Meltwater clay, *Glacial*		**is**	Freshwater sand, *Interglacial*		**qv**	Alternating marine beds, *Interglacial*
ds	Meltwater sand, *Glacial*		**it**	Freshwater peat, *Interglacial*		**r**	Shale, *unspecified*
dv	Alternating thin meltwater beds, *Glacial*		**iv**	Alternating thin freshwater beds, *Interglacial*		**rl**	Fat clay, "Røsnæs clay", *Eocene*
dz	Meltwater stone, *Glacial*		**j**	Claystone, siltstone, ochre clay ironstone		**s**	Sand, *Unspecified geological age*
e	Volcanic ash, *Eocene*		**k**	Limestone, *unspecified*		**sk**	White chalk, *Late Cretaceous*
ed	Moler (marine diatomite), *Eocene*		**kg**	Quartz gravel, *Miocene, Late Tertiary*		**sl**	Fat marl, "Søvind marl", *Eocene*
ee	Volcanic ash, *Eocene*		**kk**	Lime-sandstone, *Danien*		**t**	Peat, *unspecified*
es	Eolian sand (deposited by wind)		**ks**	Quartz sand, *Miocene*, *Late Tertiary*		**tg**	Freshwater gravel, *Late Glacial*
ev	Alternating thin beds, *Eocene*		**l**	Clay, *unspecified*		**ti**	Freshwater silt, *Late Glacial*
fg	Freshwater gravel, *Postglacial*		**lk**	Chalk, *Danien*		**tl**	Freshwater clay, *Late Glacial*
fi	Freshwater silt, *Postglacial*		**ll**	Fat clay, "Lillebælt clay", *Eocene*		**tp**	Freshwater gyttja, *Late Glacial*
fj	Ochre, *Postglacial*		**m**	Mould, organic topsoil		**ts**	Freshwater sand, *Late Glacial*
fk	Tufa (chemical precipitated limestone)		**mg**	Moraine gravel, *Glacial*		**tt**	Freshwater peat, *Late Glacial*
fl	Freshwater clay, *Postglacial*		**mi**	Moraine silt, *Glacial*		**tv**	Alternating thin freshwater beds, *Late Glacial*
fp	Freshwater gyttja, *Postglacial*		**ml**	Moraine clay, *Glacial*		**u**	Clay, sand, gravel, *unspecified*
fs	Freshwater sand, *Postglacial*		**ms**	Moraine sand, *Glacial*		**v**	Alternating thin beds, *unspecified*
ft	Freshwater peat, *Postglacial*		**mv**	Alternating thin moraine, *Glacial*		**vl**	Clay, *Early or Middle Oligocene*
fv	Alternating thin freshwater beds, *Postglacial*		**mz**	Moraine stone, *Glacial*		**x**	Unknown bed, no information
g	Gravel / Sand and gravel, *unspecified*		**o**	Fill (man made deposits)		**xl**	Clay, *Middle or Late Oligocene*
gc	Coal from *Late Tertiary*		**oi**	Silt from *Oligocene, unspecified*		**yg**	Marine gravel, *Late Glacial*
gi	Mica silt from *Late Tertiary*		**ol**	Clay from *Oligocene, unspecified*		**yi**	Marine silt , *Late Glacial*
gl	Mica clay from *Late Tertiary*		**oq**	Sandstone from *Oligocene*		**yl**	Marine clay, *Late Glacial*
gp	Gyttja or coal, *Late Tertiary*		**os**	Sand, from *Oligocene, unspecified*		**yp**	Marine gyttja, *Late Glacial*
gs	Mica sand from *Late Tertiary*		**p**	Gyttja, organic mud, *unspecifined*		**ys**	Marine sand, *Late Glacial*
gv	Alternation beds with mica, *Late Tertiary*		**pi**	Silt, *Paleocene*		**yt**	Marine peat, *Late Glacial*
hg	Marine gravel, *Postglacial*		**pj**	Claystone / siltstone, *Selandien*		**yv**	Alternating thin marine beds, *Late Glacial*
hi	Marine silt , *Postglacial*		**pk**	Limestone / glauconitic limestone, *Paleocene*		**z**	Stone, flint, *unspecified*
hl	Marine clay, *Postglacial*		**pl**	Clay or marl, *Selandien*		**zi**	Downflow silt, *Late or Postglacial*
hp	Marine gyttja, *Postglacial*		**pq**	Glauconitic limesandstone, *Paleocene*		**zk**	Limestone / flint, *Danien*
hs	Marine sand, *Postglacial*		**pr**	Shale, *Paleocene*		**zl**	Downflow clay, *Late or Postglacial*
ht	Marine peat, *Postglacial*		**ps**	Glauconitic limesand, *Paleocene*		**zs**	Downflow sand, *Late or Postglacial*
hv	Alternating thin marine beds, *Postglacial*						

Two letter symbol indicate that soil sample was described by a geologist. One letter symbol indicate that only the drillers description is available

Figure 9. Rock symbol letters.

3. Alternative Jupiter Access.

Danish well database Jupiter is available at Internet from various links. From all links you can zoom in to have maps showing the registered boreholes from a given area – and by clicking the borehole number you can view the well profile.

One of the links, however, give the possibility to view different geological background maps, and among these especial the geological surface maps (in Danish named “Jordarts-kort”) is very useful for geotechnical interpretation together with the well profiles.

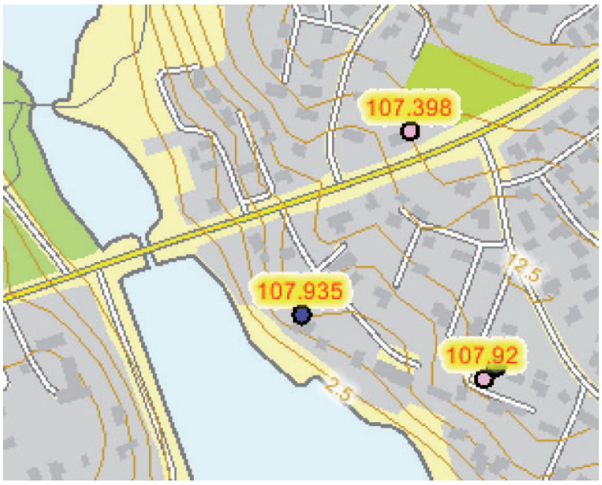
Link to database Jupiter with different background maps is

http://arcims.mim.dk/website/geus/dk/ms/JUPITER_2v1/viewer.htm.

The link will give you a map of Denmark, from where you can zoom in to your actual area.

In the left side of the screen you will see the field, where you can mark the box “Boringer” **1**. You only have to click the main field – then all types of wells will be selected. Now go to the bottom of the dialogue box and click ”Udfør søgningen” **2**.

Location of registered wells in the area will now appear on the screen together with the well numbers.



Now select the tool  (on the menu bar in the top left corner) and click on a borehole number - and the well profile will appear on the screen.

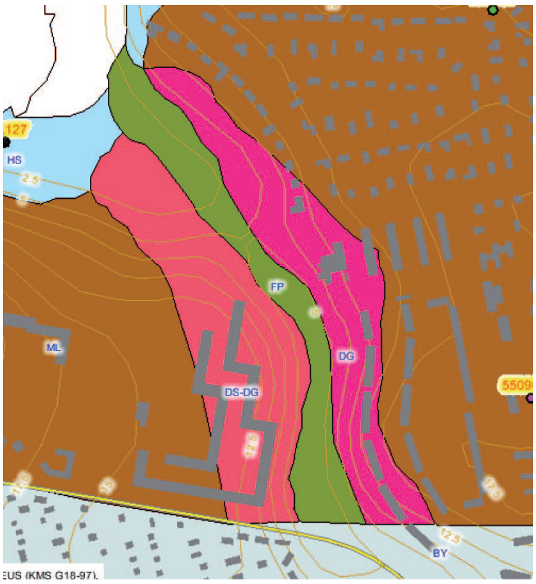
All information on the borehole is in Danish – but a general translation of the form and type of information is seen in Appendix 2. Translation of rock symbols are given in Figure 9. The rock symbols has been prepared, and is available in Fronter.

The geological background maps can be seen in the scroll menu placed at the top middle part of the screen:

Default background map is “Topografisk kort”. Contour lines will be seen, when the zoom level is below a certain limit

You can choose background maps from the list shown below:

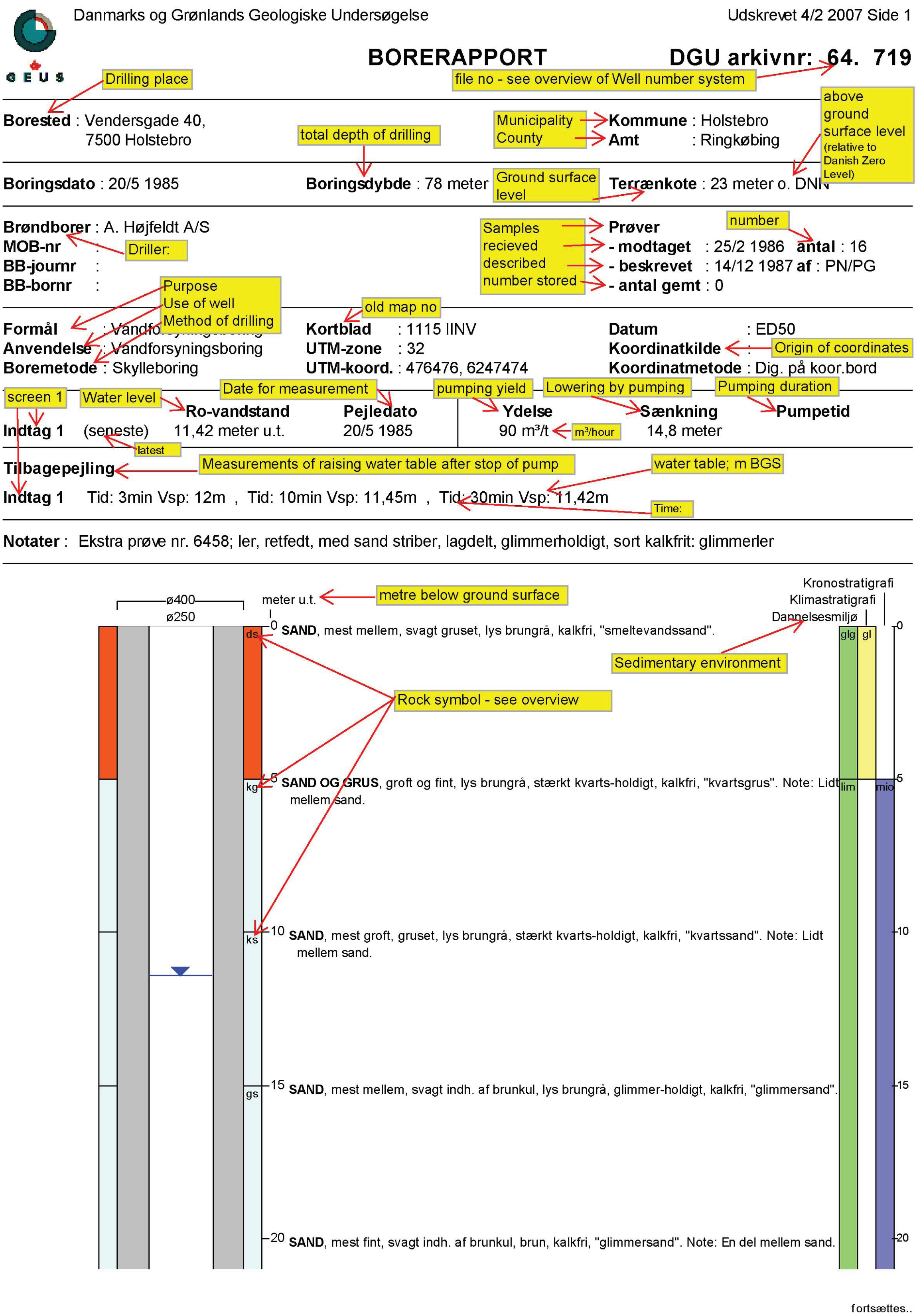
When you select “Jordarter” from the list, you will see a map of the same type as shown below:



This map shows the dominating rock type (type of soil) in the upper 1 metre below ground surface. Grey areas are towns or areas where no detailed mapping data is available.

Legends for colours and rock type symbols (DG, ML, FP ect.) can be seen in Appendix 3.

Appendix 2



Danmarks og Grønlands Geologiske Undersøgelse — Udskrevet 4/2 2007 Side 1

GEUS

BORERAPPORT — **DGU arkivnr: 64. 719**

Borested : Vendersgade 40, 7500 Holstebro

Kommune : Holstebro
Amt : Ringkøbing

Boringsdato : 20/5 1985
Boringsdybde : 78 meter
Terrænkote : 23 meter o. DNN

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

Prøver
- modtaget : 25/2 1986 **antal** : 16
- beskrevet : 14/12 1987 **af** : PN/PG
- antal gemt : 0

Formål : Vandforsyningsboring
Anvendelse : Vandforsyningsboring
Boremetode : Skylleboring

Kortblad : 1115 IINV
UTM-zone : 32
UTM-koord. : 476476, 6247474

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

	Ro-vandstand	**Pejledato**	**Ydelse**	**Sænkning**	**Pumpetid**
Indtag 1 (seneste)	11,42 meter u.t.	20/5 1985	90 m³/t	14,8 meter	

Tilbagepejling
Indtag 1 Tid: 3min Vsp: 12m , Tid: 10min Vsp: 11,45m , Tid: 30min Vsp: 11,42m

Notater : Ekstra prøve nr. 6458; ler, retfedt, med sand striber, lagdelt, glimmerholdigt, sort kalkfrit: glimmerler

ø400
ø250
meter u.t.

0 ds **SAND**, mest mellem, svagt gruset, lys brungrå, kalkfri, "smeltevandssand".

5 kg **SAND OG GRUS**, groft og fint, lys brungrå, stærkt kvarts-holdigt, kalkfri, "kvartsgrus". Note: Lidt mellem sand.

10 ks **SAND**, mest groft, gruset, lys brungrå, stærkt kvarts-holdigt, kalkfri, "kvartssand". Note: Lidt mellem sand.

15 gs **SAND**, mest mellem, svagt indh. af brunkul, lys brungrå, glimmer-holdigt, kalkfri, "glimmersand".

20 **SAND**, mest fint, svagt indh. af brunkul, brun, kalkfri, "glimmersand". Note: En del mellem sand.

Kronostratigrafi
Klimastratigrafi
Dannelsesmiljø
glg gl lim mio

fortsættes..

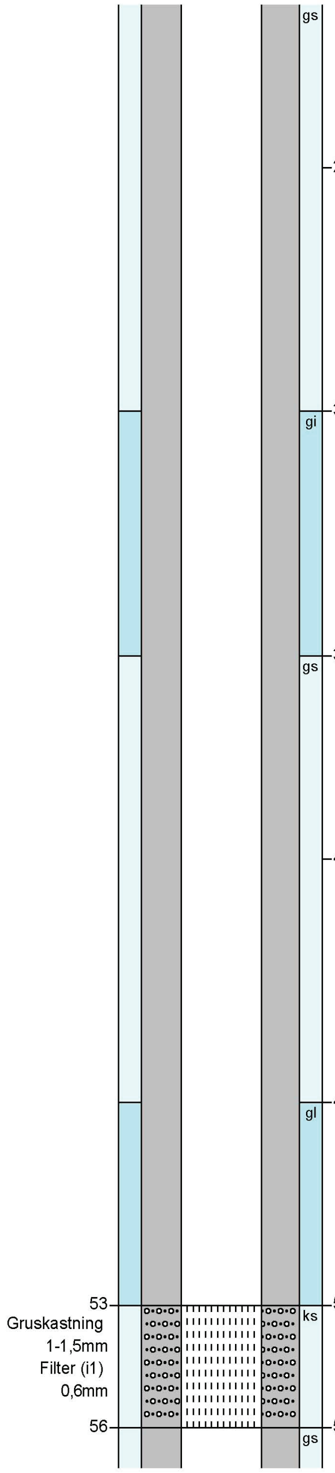
Danmarks og Grønlands Geologiske Undersøgelse

Udskrevet 4/2 2007 Side 2

BORERAPPORT

DGU arkivnr: 64. 719

meter u.t.



25 **SAND**, mest fint, mange klumper af silt, horisontal lagdeling, brun, glimmer-holdigt, kalkfri, "glimmersand". Note: Mange klumper af leret, lagdelt glimmersilt.

31 **SILT**, svagt leret, slirer af ler, horisontal lagdeling, mørk gråbrun, glimmer-holdigt, kalkfri, "glimmersilt".

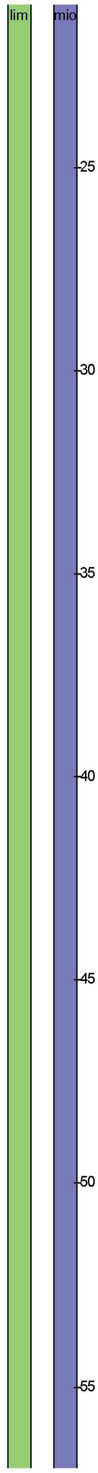
37 **SAND**, mest mellem, svagt gruset, brun, glimmer-holdigt, kalkfri, "glimmersand". Note: Med kvartsgrus.

42 **SAND**, mest fint, brun, glimmer-holdigt, kalkfri, "glimmersand".

48 **LER**, ret fedt, slirer af sand, horisontal lagdeling, mørk gråbrun, kalkfri, "glimmerler".

53 **SAND**, mest groft, gråbrun, stærkt kvarts-holdigt, kalkfri, "kvartssand".

56 **SAND**, fint og mellem, svagt gruset, mange klumper af silt, svagt indh. af brunkul, gråbrun, glimmer-holdigt, kalkfri, "glimmersand". Note: Med kvartsgrus.



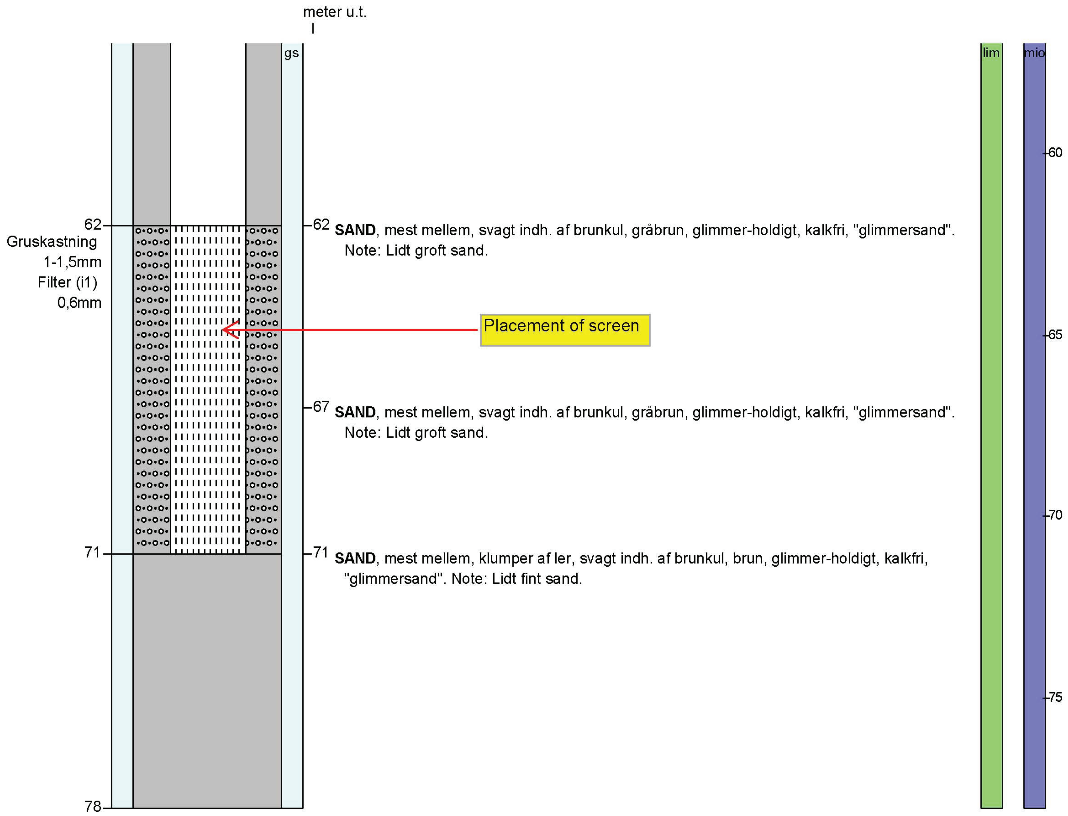
fortsættes..

Danmarks og Grønlands Geologiske Undersøgelse

Udskrevet 4/2 2007 Side 3

BORERAPPORT

DGU arkivnr: 64. 719



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

meter u.t.	
0 - 5	glacigen - glacial
5 - 78	limnisk - miocæn

Geological age

Sedimentary environment

Appendix 3

Colours and abbreviations used in geological surface maps.

Geological surface maps
Abbreviations for rock types in the upper 1 metre.

Geological age	Colour		
POSTGLACIAL		FG - Ferskvandsgrus	Freshwater gravel
		FS - Ferskvandssand	Freshwater sand
		FI - Ferskvandssilt	Freshwater silt
		FL - Ferskvandsler	Freshwater clay
		FP - Ferskvandsgytje	Freshwater gyttja
		FT - Ferskvandstørv	Freshwater peat
		FV - Vekslende tynde ferskvandslag	Alternating thin freshwater beds
		FK - Kildekalk, mose- og søkalk	Tufa / Travertine (precipitated limestone)
		FJ - Okker og myremalm	Ochre and bog ore
		HG - Saltvandsgrus	Marine gravel
		HS - Saltvandssand	Marine sand
		HI - Saltvandssilt	Marine silt
		HL - Saltvandsler	Marine clay
		HP - Saltvandsgytje	Marine gyttja
		HT - Saltvandstørv	Marine peat
		HV - Vekslende tynde saltvandslag, marsk	Alternating thin marine beds, march
		EK - Klitsand	Sand in dunes
		ES - Flyvesand	Eolian sand
		EI - Løss	Loess (Eolian silt)
LATE GLACIAL		TG - Ferskvandsgrus	Freshwater gravel
		TS - Ferskvandssand	Freshwater sand
		TI - Ferskvandssilt	Freshwater silt
		TL - Ferskvandsler	Freshwater clay
		TP - Ferskvandsgytje	Freshwater gyttja
		TT - Ferskvandstørv	Freshwater peat
		TV - Vekslende tynde ferskvandslag	Alternating thin freshwater beds
		YG - Saltvandsgrus	Marine gravel
		YS - Saltvandssand	Marine sand
		YI - Saltvandssilt	Marine silt
		YL - Saltvandsler	Marine clay
		YP - Saltvandsgytje	Marine gyttja
		YT - Saltvandstørv	Marine peat
		YV - Vekslende tynde saltvandslag	Alternating thin marine beds, march
GLACIAL MARGINAL		ZG - Issøgrus	Ice marginal gravel
		ZS - Issøsand	Ice marginal sand
		ZI - Issøsilt	Ice marginal silt
		ZL - Issøler	Ice marginal clay
		ZV - Vekslende lag af issøsedimenter	Alternating ice marginal beds
GLACIAL		DG - Smeltevandsgrus	Meltwater gravel
		DS - Smeltevandssand	Meltwater sand
		DI - Smeltevandssilt	Meltwater silt
		DL - Smeltevandsler	Meltwater clay
		DV - Vekslende tynde smeltevandslag	Alternating thin meltwater beds
		MG - Morænegrus	Moraine gravel
		MS - Morænesand	Moraine sand
		MI - Morænesilt	Moraine silt
		ML - Moræneler	Moraine clay
		MV - Vekslende tynde morænelag	Alternating thin moraine beds
		KMG - Kalkmorænegrus	Limestone moraine gravel
		KMS - Kalkmorænesand	Limestone moraine sand
		KML - Kalkmoræneler	Limestone moraine clay

Geological surface maps
Abbreviations for rock types in the upper 1 metre.

Geological age	Colour		
INTERGLACIAL		IG - Ferskvandsgrus	Freshwater gravel
		IS - Ferskvandssand	Freshwater sand
		II - Ferskvandssilt	Freshwater silt
		IL - Ferksvandsler	Freshwater clay
		IV - Vekslende tynde ferskvandslag	Alternating thin freshwater beds
		IP - Ferskvandsgytje	Freshwater gyttja
		IT - Ferskvandstørv	Freshwater peat
		ID - Ferskvandsgytje, kiselgur	Freshwater gyttja, Diatomite
		IJ - Okker	Ochre
		QG - Saltvandsgrus	Marine gravel
		QS - Saltvandssand	Marine sand
		QI - Saltvandssilt	Marine silt
		QL - Saltvandsler	Marine clay
		QP - Saltvandsgytje	Marine gyttja
		QT - Saltvandstørv	Marine peat
		QV - Vekslende tynde saltvandslag	Alternating thin marine beds
TOPOGRAPHIC INFORMATION		BY - Byområde	Urban area
		SØ - Sø	Lake
		HAV - Havområde	Marine area
		TA - Teknisk anlæg	Technical construction
		RÅ - Råstofgrav	Excavation for natural resource
		LRÅ - Lukket råstofgrav	Closed excavation
		LSL - Jordskred	Landslide
		O - Fyld	Fill
		X - Ukendt lag, oplysninger mangler	Unknown bed, no information
PRE-QUATERNARY		BK - Danien bryozokalk, koralkalk	Bryozoan limestone
		ED - Eocæn moler	Eocene moler clay (diatomaceous)
		EE - Eocæn vulkansk aske	Eocene volcanic ash beds
		G - Grus / sand og grus	Gravel/Sand and gravel
		GC - Oligocæn/miocæn/pliocæn brunkul	Lignite from Late Tertiary
		GL - Oligocæn/miocæn/pliocæn glimmerler	Mica clay from Late Tertiary
		GS - Oligocæn/miocæn/pliocæn glimmersand	Mica sand from Late Tertiary
		K - Kalk, kridt og kalksten	Limestone, chalk and limestone
		KS - Miocæn kvartssand	Quartz sand from Miocene
		LL - Eocæn ler, plastisk ler	Eocene clay, fat clay
		OL - Oligocæn ler	Clay from Oligocene
		PKV - Prækvartært lag	Prequaternary bed
		PL - Selandien ler, palæocæn ler	Selandien clay, Paleocene clay
		PS - Selandien sand, palæocæn grønsand	Selandien sand, Paleocene sand
		RL - Eocæn Røsnæs ler	Eocene Røsnæs clay
		S - Sand	Sand
		SK - Campanien-maastrichtien skrivekridt	White chalk from Late Cretacious
		SL - Eocæn Søvind mergel	Eocene Søvind marl
		ZK - Danien kalk / kalk og flint	Danien limestone/limestone and chert
		L - Ler	Clay
		I - Silt	Silt
		GI -	Mica silt
		GV - Vekslende glimmerholdige lag	Alternating beds with mica components
		C - Brunkul	Lignite (coal)

Colours and abbreviations used in geological surface maps.
1:25.000 version 2.0. GEUS, 10. november, 2000. *Translated by Inga Sørensen, 2008.*