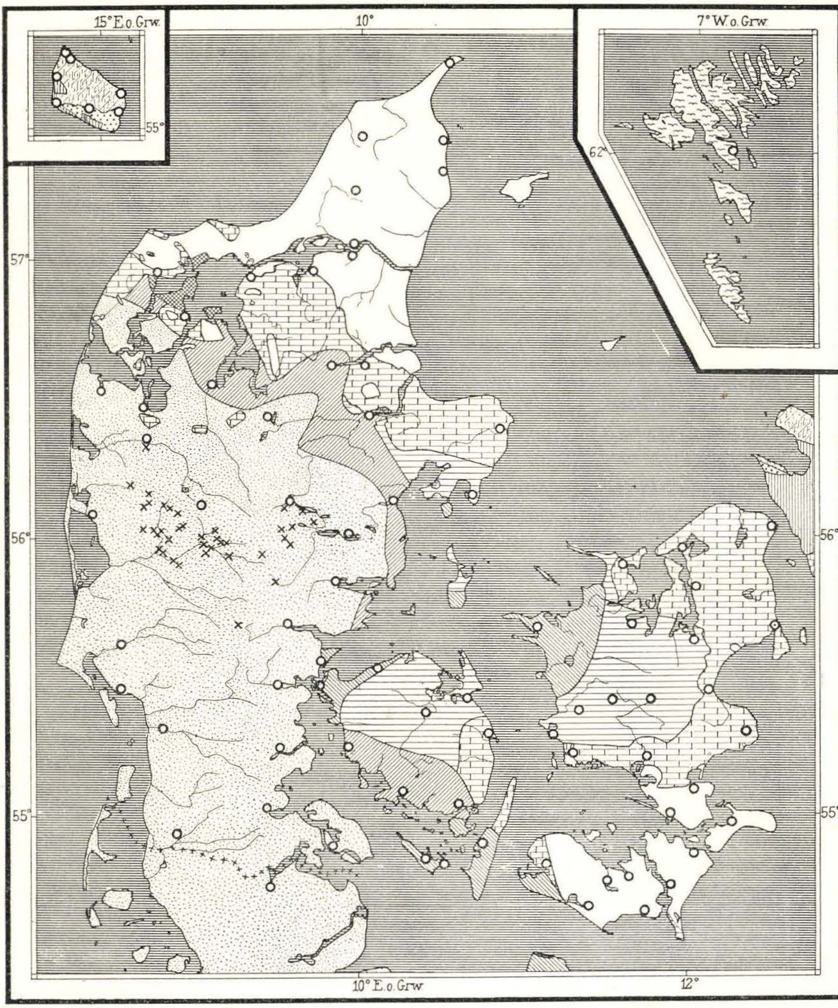
Danmarks geologiske Undersøgelse

V. Række. Nr. 4.

# SUMMARY

OF

# THE GEOLOGY OF DENMARK




Bornholm. The rest of Denmark and the Faroe islands.

- Granite.
- Cambrian. Ordovician. Gothlandian.
- Triass. Jurass. Cretaceous.
- Upper Senonian.
- Danian.
- Paleocene.
- Eocene. Plastic Clay.
- Eocene. Moler.
- Oligocene.
- Miocene.
- Basalt.
- × Brown Coal.

## Map of Denmark's Prequartary.

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# Summary
of
# The Geology of Denmark

With Contributions by

Johs. Andersen, O. B. Bøggild, Karen Callisen, Axel Jessen, Knud Jessen, Victor Madsen, Ellen Louise Mertz, V. Milthers, V. Nordmann, J. P. J. Ravn, Hilmar Ødum.

Edited by

V. Nordmann.

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Victor Madsen.

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# Preface.

Eighteen years have passed away since N. V. USSING in 1910, in the year before his death, published a Summary of the Geology of Denmark in the Handbuch der regionalen Geologie, issued by G. STEINMANN and O. WILCKENS. Since that time Danish geological research has made such great progress that USSING's work, excellent in its time, has become quite antiquated.

At the moment there are 37 completely surveyed geological map sheets on a scale of 1 : 100000 of the 70 which Denmark comprises. A geological map of the Prequartary deposits of Denmark, on a scale of 1 : 500000, has been published; it was drawn up by J. P. J. RAVN, for the most part based upon the numerous results of borings which are preserved in the archives of Denmark's Geological Survey and the Mineralogical-Geological Museum of the University of Copenhagen. The papers published by Denmark's Geological Survey have attained a total of 112. Of the "Meddelelser" of the Danish Geological Society six and a half volumes have been published.

As to Bornholm, we now have the geological map of Bornholm, on a scale of 1 : 100000, with description, published by KARL A. GRÖNWALL and V. MILTHERS, and V. MILTHERS' "Bornholm's Geology." Miss KAREN CALLISEN has made a deep study of the Archæan of Bornholm, CHR. POULSEN of the Olenus Stage and the Dictyograptus shale, HERMAN FUNKQUIST and E. M. NÖRREGAARD of the Asaphus region, ASSAR HADDING of the Middle Dicellograptus shale and TH. BIERRING PEDERSEN of the Rastrites shale, all works which have extended our knowledge of these subdivisions and their fauna very considerably. With regard to Bornholm's Jura there are C. MALLING's comprehensive collections, which have enabled him to draw up an age grouping of the complicated deposits of this System. J. P. J. RAVN's important studies of the Cretaceous System of Bornholm have shown that, besides the Westphalicus Zone of the Senonian, there occur not only Turonian and Cenomanian but also Albian (concretions in the Cenomanian).

Concerning the Cretaceous deposits of the remainder of Denmark, our knowledge of the Danian especially has made great progress. A division of this stage into four zones has been worked out. The conditions at its upper and lower boundaries have been made clear; it has been possible to give a satisfactory explanation of the formation of the "Cerithium Limestone" in Stevns Klint. To the old familiar localities have been added many new ones and our knowledge of the fauna is extended very considerably. This is particularly due to the investigations made by H. ØDUM, K. BRÜNNICH NIELSEN and A. ROSENKRANTZ.

The main outlines of our knowledge of the Tertiary had already been drawn up prior to 1910, but the subsequent works have widened our acquaintance with the subdivisions and fauna of the Tertiary to a considerable extent, as for instance POUL HARDER's studies of the Oligocene at Aarhus, E. M. NÖRREGAARD's studies of the Middle Miocene boulders at Esbjerg, O. B. BÖGGILD's of the volcanic tuffs in the Moler, POUL HARDER's and A. ROSENKRANTZ's of the Palaeocene, and KAI L. HENRIKSEN's of the Danish Eocene insects.

Progress has been greatest, however, in our knowledge of our complicated Quartary. Our present views of these deposits, which are of such great interest and of such importance to a correct valuation of many circumstances to-day, have been built up out of an intimate collaboration between the geologists who are or have been appointed to Denmark's Geological Survey, so that it is often difficult to determine how much is due to each one of them. The division of Denmark's Quartary into three glacial periods and two interglacial periods, which I drew up in 1895, marked the fundamental principles of our present views. The investigations made since then have provided a multitude of new facts which have thrown more light upon the details but have not altered the fundamental view. We have now advanced so far that it is possible to give, for the first time in a book on the geology of Denmark, a detailed chronological description of the "Ice Age." This is particularly a result of AXEL JESSEN's, V. MILTHERS' and my own studies of the glacigenous deposits and their terrain forms, of V. MILTHERS' studies of the boulders and of the "stone counts" I have made in the moraines, of V. NORDMANN's faunistic and KNUD JESSEN's floristic works, in which pollen studies have given such important results, as well as of AXEL JESSEN's investigations into the stratigraphy and extent of the marine deposits.

Denmark's Geological Survey has decided to issue this book for the purpose of remedying the existing need of a summary of the geology of Denmark in which the results of the comprehensive work of late years were included. We have considered it best that each chapter be written by the geologists who were most familiar with the particular subjects. It has been possible to complete this work not only because of the splendid co-operation of the eleven who are named as the authors, but also because of the great support rendered by the other officers, particularly Mr. SIGURD HANSEN and Mr. J. LUNDBERG.

*Victor Madsen.*

# Contents.

# Introduction.

Between the North Sea and the Baltic Sea lie a peninsula and a number of islands which, from early times, have been the home of the Danes. On a globe these lands appear as a tiny patch, even if their situation is sharply defined and easily found, and in fact on a map of Europe their extent is only small, and yet, for more than a thousand years they have formed an independent state, Denmark.

There are few countries to whom the sea has been of greater significance than it has been to this one, and few peoples have felt themselves more closely connected with the sea than the Danes. Whereas elsewhere the sea is more nearly a dividing factor, to Denmark it has been that which united the islands and the peninsula into one whole; it formed the high-roads round which the Danish realm grew up at the close of antiquity. It is the geological structure of this country that will be briefly sketched in this work.

Denmark lies between lat. 54° 34′ N. (Gedser Odde) and lat. 57° 45′ N. (Skagens Odde), between long. 8° 5′ E. of Greenwich (Blaavandshuk) and long. 15° 12′ E. (Christiansö). Its land area is 42,314 sq.km. This figure, however, does not include the areas occupied by streams or lakes (if these are counted in, the total area becomes 42,927 sq.km.), nor fiords, coves, sounds and belts, nor the maritime territory. In reality Denmark, with her peninsula and her 97 inhabited and about 430 uninhabited islands or groups of islets, occupies a greater part of the earth's surface than the figure would indicate. Altogether the coast-lines of Denmark have a length of 7,438 km.

Denmark consists of the peninsula Jylland (29,556 sq.km), the islands lying between it and Sweden, of which Sjælland (7,014 sq.km), Fyn (2,975 sq.km), Lolland (1,233 sq.km) and Falster (514 sq.km) are the largest, and also some smaller islands in the North Sea off the southern part of the west coast of Jylland, as well the island of Bornholm (588 sq.km) in the Baltic, to the south of Sweden. To Denmark also belongs the little group of islands, the Faroes (1,399 sq.km), whose geological structure, differing greatly as it does from that of Denmark, will be treated in a separate chapter.

That Denmark consists of a number of islands and a peninsula is not reflected in the country's geological structure and is only of slight morphological importance. There is no essential difference in the surface forms of the Jutlandic peninsula, the islands and the sea-floor, and we meet the same geological development everywhere, Bornholm excepted. At the close of the Tertiary period the whole of this area formed one continuous land mass, the surface of which was, in the Quartary period, denuded and eroded by the inland ice and its melt-water and covered with Quartary deposits; in the interglacial periods and the late-glacial period, it is true, the sea here and there inundated certain parts of the country; but it was not until the postglacial submergence that the sea divided it up into the many islands and the Jylland peninsula and caused in the main the present distribution of land and sea. On the other hand Denmark is divided by a large fault, which in no way follows with the Danish coasts, into two parts, very different geologically and morphologically, viz. the island of Bornholm and the rest of the country.

Bornholm lies in that zone, interspersed with faults, which borders upon the Scandinavian shield to the SW and which is called the Fennoscandian border zone (Fig. 1). In this section of the earth's crust the Quartary deposits are on an average of slight thickness; over wide stretches various Pre-Cambrian, Palaeozoic and Mesozoic Systems appear at the surface or at any rate reach just below, bounded by faults. As far as the two-thirds in the north are concerned, Bornholm consists of a large granite horst, the highest point of which, about the middle of the island, is Rytterknægten (162 m), whereas the lowland south and southwest of this is formed of Cambro-Silurian and Mesozoic deposits.

The other Danish islands, separated and much indented by the sea, as well as Jylland, are on the other hand closely related to the North-German lowland, of which they form a continuation and, like the latter, Denmark lies

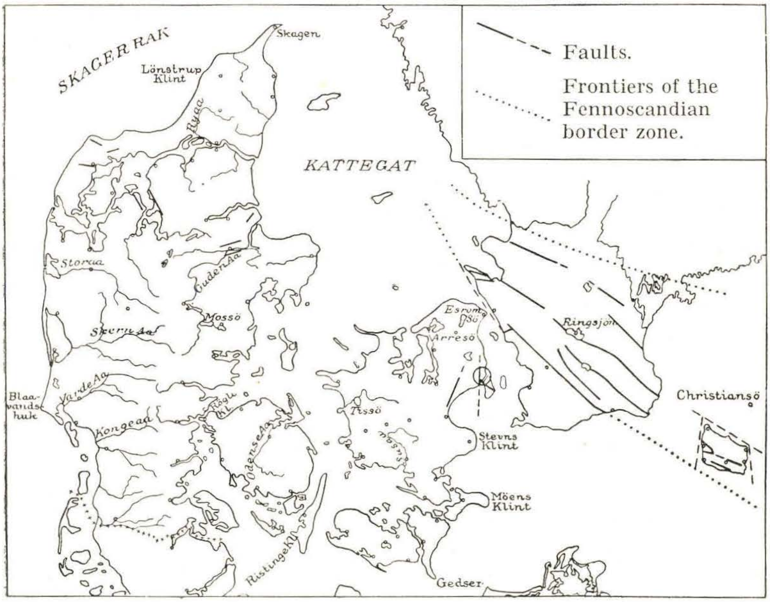


Fig. 1. Sketch-map of Denmark and its neighbouring countries.

in the great geosynclinal between the Scandinavian mountain country and the mountains in Central Germany. The boundary of the Fennoscandian border zone is looked upon as being the great fault, with several km of fault throw, which runs along the west coast of Sweden and continues some way into the Øresund, whence it turns sharply into Skåne, the south-westerly part of which is thereby cut off from the remainder of Sweden and, in a geological sense, is connected with the Danish islands. It should, however, be observed that this fault is not the most westerly one known in this region. In København and in North-east Sjælland faults occur which must be presumed to have come into existence in the Danian period, while in Jylland, between Djursland and the Nibe district, especially around Randers Fjord, as well as in the country round the western parts of Limfjorden, faults of larger or smaller extent have been found in the Cretaceous System. The dislocation phenomena which are visible in several cliffs (Møen, Ristinge, Røgle, Lønstrup, etc.) and which appear as overthrust series of strata, some of which consist of White Chalk, others of larger or smaller series of Quartary deposits, are regarded by some geologists as being tectonic disturbances (in the wider sense), by others as the effects of the pressure of the inland ice, and again by others as possibly due to both causes.

In Jylland and the Danish islands lying between that peninsula and Sweden, the Quartary is of comparatively considerable thickness. It can attain to 200 m (at Frederikshavn); on an average it may be estimated at 50 m. It overlies Tertiary and Cretaceous deposits, the surface of which on the whole seems to be fairly even; in some places, however, it has been shown that the interior of the hills consists of White Chalk to a height of 60—70 m above the sea. No deposits older than Senonian have been proved in Denmark, Bornholm excluded. The highest point of the Quartary land surface in Denmark is Ejer Bavnehøj, north of Horsens (172 m); several other hills in that district reach up over 160 m. One might also mention in Jylland Himmelbjerg, SE of Silkeborg (Kollen 147 m, NE of Himmelbjerg Gaard 157 m), Vonge Bavnehøj and Tranebjerg (138 m), Agri Bavnehøj in Mols (137 m), Møllebjerg, W of Vejle (137 m), Knøsen, between Aalborg and Sæby (136 m) and Lysnet, SW of Randers (131 m). Fyn's highest point, Frøbjerg Bavnehøj, is also 131 m, whereas Sjælland only attains to 126 m at Gyldenløves Høj, between Roskilde and Ringsted; Aborrebjerg on Møen is 143 m high. The average height of the whole country may be estimated at about 30 m.

Denmark is rich in running water, streams and rivers, of which the longest are, in Jylland, Gudenaa (158 km with a drainage basin of 2643 sq.km), Storaa (104 km and 1100 sq.km), Varde Aa (99 km and 1088 sq.km) and Skern

Aa (94 km and 2338 sq.km), in Sjælland Susaa (83 km and 835 sq.km). Of other rivers there are Kongeaa (58 km and 453 sq.km) and Ryaa (60 km and 500 sq.km) in Jylland, and Odense Aa (53 km and 784 sq.km) in Fyn.

There is also a rather considerable number of lakes, but most of them are small; among the largest there are, on Sjælland, Arresø (40.6 sq.km), Esrom Sø (17.4 sq.km) and Tissø (13.3 sq.km), in Jylland Mossø (16.9 sq.km). The lakes are very unevenly distributed, most of them being in the young Quartary in East Jylland and on the Islands. Of the various parts of the country Sjælland has comparatively the greatest (168.5 sq.km) and Bornholm the smallest total lake area (2.1 sq.km), the next smallest being in Fyn (21.0 sq.km).

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Of the Systems which compose the earth's crust, nine are represented in Denmark; these however are very unequally distributed over the country. The Pre-Cambrian, Cambrian, Ordovician, Gothlandian, Triassic and Jurassic Systems have only been found *in situ* on Bornholm. Most of the Cretaceous subdivisions (from and including Wealden to and including Lower Senonian) too, are only known *in situ* on this island, whereas on the other hand Middle and Upper Senonian and the Tertiary are only known in the remainder of Denmark. The Devonian, Carboniferous and Permian Systems, as well as some of the subdivisions of the Triassic, Jurassic and Cretaceous Systems have not yet been ascertained in Denmark, whereas of course the deposits of the Quartary occur over the whole area. Boulders from the Kelloway, Kimmeridge-Portland, Neocomian and Albian[1,2] have however been found in the Quartary deposits, and, as these boulders mostly occur in two regions, some on Lolland, Langeland, Ærø and South Fyn, and others at Hirshals on the NW coast of Jylland, this might be an indication that these deposits are in situ on the floor of the Baltic and also in the Skagerrack.

*Victor Madsen.*

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# Pre-Cambrian.

The Pre-Cambrian of Bornholm occupies an area of about 400 sq.km, or two-thirds of the whole island. It has a mean height above sea level of slightly over 100 m and to the north and east stretches to the sea; a continuation in a NE direction is indicated by the small, isolated rock islands of Ertholmene (Christiansø). The Pre-Cambrian consists of a number of granite varieties (fig. 2) from the salic, markedly potassic granites on Hammeren and in Almindingen (Bjergbakke) to the syenitic Rønne granite which is rich in hornblende. In habitus, structure and chemical differentiation they are most closely related to the Urgranite group (gneiss-granites) and must, therefore, be regarded as a continuation of the older Archean of Sweden.

The main constituents of the rocks are quartz, microcline, plagioclase and biotite, in addition to which hornblende occurs in some varieties. Only rarely, and quite locally, is orthoclase present instead of microcline. The hornblende is characterised by a blue-green absorption colour $\gamma$, a rather small optic axial angle and a high FeO content. Titaniferous magnetite, titanite (often in a corona around the magnetite), apatite and zircon, more rarely pyrite, orthite and fluorite are found accessorily.

The greater part of Bornholm's Pre-Cambrian consists of the so-called Striated granite, a more or less distinctly schistose, medium to fine grained and often porphyritic rock of grey colour which, close to the surface, usually becomes reddish. The striation is due to a more or less pronounced arrangement of dark and light components in alternate thin layers; it often has almost the same direction over large areas and usually only forms small angles to the horizontal. The granite

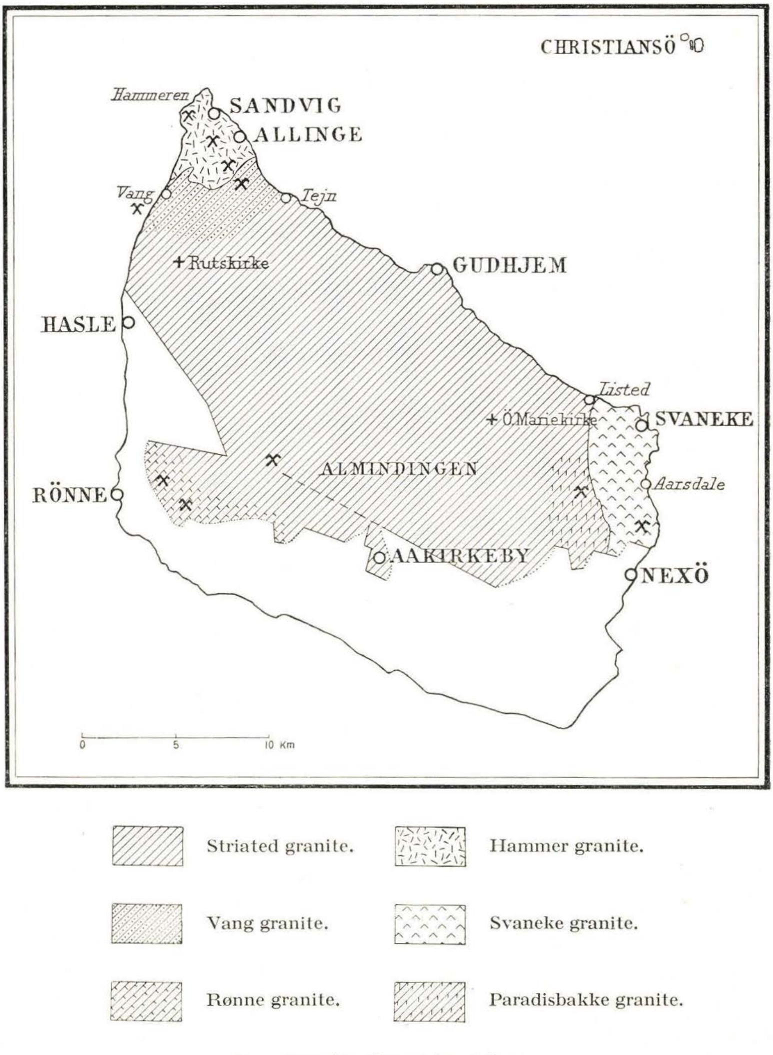


Fig. 2. The extent of the different varieties of granite on Bornholm.

in the environs of Gudhjem is the most schistose, and a rather similar kind forms a wide belt along the NE coast almost from Østermarie to Rutskirke, and is found also more to the south in the granite terrain. The predominant felspar is microcline, while plagioclase is abundant locally. The plagioclase occurs as larger oligoclase individuals with a size of grain of about 5 mm and as minute crystals of a more acid composition. The content of dark-coloured minerals varies somewhat, hornblende is subordinate and may be missing in places. Towards the N this variety passes gradually into the Vang granite which is richer in hornblende and in which the content of plagioclase is considerable as a rule. The Vang granite forms a belt across the island between the fishing hamlets Vang and Tejn. It is not so markedly schistose and, S of Vang, is even quite massive (type "Klondyke"). The dark-coloured constituents are collected in characteristic spots. To the SE, too, the Striated granite evenly changes character and is connected by a gradual transition with the fine-grained, dark-grey and white-streaky Paradisbakke granite, the light components of which are mostly collected in aplitic bands; the dark portions have a very fine-grained ground-mass with phenocrysts of plagioclase; hornblende is present in abundance. Rønne granite, along the SW edge of the granite terrain, is very similar in composition to the two latter varieties but has a larger quantity of plagioclase and hornblende. The plagioclase is surrounded by microcline in parallel intergrowth, a structural feature which, though less pronounced, is traceable in nearly all Bornholm granite varieties. Rønne granite is dark grey, medium grained and entirely without parallel structure. Through a striated, porphyritic border-zone, where the plagioclase forms the phenocrysts, and where the hornblende content decreases, it passes into the grey, striated granite with a small amount of hornblende. The granite within the central part of the region, Alminding granite, is light, reddish-grey, medium grained, and in places the striation is only slightly marked, as in the old quarry at Bjergbakke. The quantity of dark minerals is much less than in the foregoing varieties and hornblende is very sparse. In several places in the area between Hasle and Gudhjem there are found small, restricted occurrences of a light, red, aplitic granite of more or less pronounced schistosity. Light varieties that are not at all schistose occur in the east as Svaneke granite and in the north as Hammer granite. The latter is a light, red-grey, medium grained rock in which dark minerals, mostly consisting of biotite, play a very small role. To the Vang granite it has a narrow, aplitic border zone. The Svaneke granite, in the area between Svaneke and Nexø, is coarsely grained and light grey in the northern part, more red nearest Nexø. Biotite is the most important of the dark minerals, titanite relatively abundant, almost in the same quantities as hornblende. Svaneke granite locally crumbles very easily, as for instance at Listed and Aarsdale.

Pegmatite dykes of irregular course are common everywhere in the Granite terrain. The thickness varies greatly from one or two centimetres to several metres. The main constituent is always potassic feldspar, graphic granite is frequently met with, and in places quartz is very prominent, as for instance in Hvidehald at Aakirkeby. White, acid plagioclase and biotite are subordinate, and more rarely magnetite, titanite, molybdenite and fluorite. Beryl is stated to have been found at Skovgaard. Larger pegmatite masses occur in Vestermarie Højlyng, where feldspar quarrying was formerly carried on, in Baunklint, at Skovgaard in Bodilsker, in Hvidehald, at Nørrevig N of Svaneke and other places.

Aplite dykes are by no means so common as pegmatite; only in the Vang granite do they occur extremely numerously.

Basic segregations, in which the dark minerals of the granite are very abundant, are commonly met with in Rønne, Vang and Svaneke granite.

The following table gives the chemical analyses of the more important granite varieties.*)

*) The analyses of Nos. 2, 5, 6 and 7 according to G. KALB[3]. For No. 7 KALB uses the objectionable name "Knudsbakke-Granite," which was previously used by COHEN & DEECKE[4], but in Bornholm there is no locality of that name.

Anal. Nos. 1, 3, 4, 8 and 9, cf. KAREN CALLISEN.[5]

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ ............ | 75,38 | 73,77 | 72,82 | 69,95 | 66,99 | 65,40 | 64,49 | 65,39 | 63,60 |
| $TiO_2$ ............ | 0,38 | 0,32 | 0,63 | 0,75 | 0,71 | 1,01 | 1,22 | 0,28 | 1,41 |
| $Al_2O_3$ ........... | 12,57 | 11,97 | 13,42 | 13,48 | 13,00 | 14,73 | 13,67 | 14,32 | 13,51 |
| $Fe_2O_3$ ........... | 1,06 | 1,84 | 2,33 | 2,36 | 2,98 | 1,14 | 1,63 | 7,85 | 7,43 |
| FeO ............ | 0,95 | 0,78 | — | 2,31 | 2,23 | 2,92 | 4,42 | — | — |
| MnO ............ | trace | — | 0,24 | trace | 0,11 | 0,06 | 0,14 | 0,00 | 0,25 |
| MgO ............ | 0,21 | 0,23 | 0,13 | 1,00 | 0,65 | 1,02 | 1,38 | 1,12 | 1,18 |
| CaO ............ | 1,97 | 1,10 | 1,61 | 2,36 | 2,64 | 2,78 | 3,12 | 3,53 | 3,30 |
| $Na_2O$ ........... | 1,92 | 2,75 | 3,25 | 2,72 | 3,28 | 3,54 | 3,57 | 3,64 | 3,40 |
| $K_2O$ ............ | 4,60 | 5,61 | 5,47 | 3,62 | 4,39 | 4,31 | 4,40 | 4,40 | 6,30 |
| $P_2O_5$ ............ | trace | — | — | 0,34 | 0,57 | 0,19 | 0,58 | — | — |
| $CO_2$ ............. | 0,30 | — | — | 0,25 | — | 0,68 | — | — | — |
| S ............... | 0,00 | — | — | 0,10 | — | — | — | — | — |
| $H_2O$ above 110° . | 0,38 | 0,49 | — | 0,48 | 0,70 | 1,58 | 1,11 | — | — |
| $H_2O$ below 110° . | 0,00 | 0,65 | — | 0,00 | 0,78 | 0,55 | 0,46 | — | — |
| Ignition loss .... | — | — | 0,21 | — | — | — | — | 0,13 | 0,19 |
| per cent. | 99,72 | 99,51 | 100,11 | 99,72 | 99,03 | 99,91 | 100,19 | 100,66 | 100,57 |

No. 1. Almindingen, Bjergbakke. Anal K. Thaulow.
- 2. Hammer granite. Anal. M. Dittrich.
- 3. Hammer granite, Hammeren. Anal. C. Detlefsen.
- 4. Svaneke granite, Ibskirke. Anal. K. Thaulow.
- 5. Vang granite, "Klondyke," S of Vang. Anal. M. Dittrich.
- 6. Paradisbakke granite. Anal. M. Dittrich.
- 7. Rønne granite. Anal. M. Dittrich.
- 8. Rønne granite, Klippegaard. Anal. C. Detlefsen.
- 9. Rønne granite, border rock, St. Almegaard. Anal. C. Detlefsen.

The differences in the composition of the Bornholm granites may be attributed to chemical differentiation in an originally homogeneous magma. Where difference of age between the rocks can be stated, the more basic granites are older than the salic ones; Hammer granite has for instance consolidated later than the bordering Vang granite, and Svaneke granite is younger than the Striated granite to the west of it. In Svaneke granite enclosed fragments of striated granite, which consolidated immediately prior to it, are often found; the smaller pieces are rounded, the larger are irregular in shape.

**Diabase dykes** occur in large numbers. The diabase cuts the granite as regular, vertical dykes of varying breadth, although the majority are scarcely more than about two metres wide. The strike is as a rule NNO—SSW. The rock is olivindiabase, in many cases well preserved but in several dykes very altered. The composition varies a little according to the relative amounts of olivine and monoclinic pyroxene; in some dykes hypersthene is present subordinately. The structure is often ophitic, in some dykes it is porphyritic, and some dykes contain an amygdaloidal diabase. At the contact, where the diabase has cooled rapidly against the cold country rock, it is usually very fine-grained or quite aphanitic, in the middle of the bigger dykes it is medium grained and, in the great dyke of Kjeldseaa, even very coarse. The biggest dykes are at Listed (31 m wide), at Kaas (40 m), and the dyke of Kjeldseaa measures at Saltuna 57 m in width. The strike of the latter, which can be followed about 6 km through the valley, is NE—SW and, in opposition to the other dykes, it has exercised a powerful contact-effect upon the country rock whereby a granite-porphyritic, hybrid rock has been formed. Diabase dykes have only been found in the granite terrain, not in the Bornholm sediments, and may therefore be regarded as Pre-Cambrian. Probably they are of post-Archæan age; in favour of this hypothesis is the great conformity between these diabases and those in Western Blekinge and Skåne described by Moberg.[6]

**Sandstone dykes** occur in several places in the Granite terrain. They also cut through the diabase; the material presumably originated from Cambrian or, possibly, Mesozoic sand deposits.

**Kaolin.** East of Rønne a kaolin bed, 2—300 m wide and about 4 km long, stretches directly alongside the granite edge. The kaolin is found in its original place, formed out of Rønne granite, of which more or less completely altered lumps are met with in the kaolin now and then. Pegmatite dykes often appear distinctly in the kaolin mass. In several places there have been found decomposed diabase dykes whose original structure, fine grained at the contact and coarser in the central portions can often be recognised. Whilst the bulk of the raw kaolin is an incoherent, grey-white mass which to the hand feels rather sharp on account of its quartz content, the diabase has supplied a soft, clayey product with a faint grey-green, light yellow or reddish colour. The kaolin is overlain by beds of the Mesozoic formation. Its depth is not known. Boreholes have established that the thickness and purity increase as one moves from the granite, and at the same time the cover over it becomes thicker.

Different theories have been advanced as to the origin of this kaolin bed. FORCHHAMMER[7] assumed that the kaolin was produced by the effects of overheated vapour upon the feldspar. USSING[8], on the other hand, that it was due to disintegration caused by percolating water and that the present bed is only a small remnant of a very large layer of kaolin which covered the whole of Bornholm at the end of the Triassic period. GRÖNWALL[9] advocates the view that the kaolinisation is the result of influences from the interior of the earth. With our present knowledge of the occurrences of kaolin, USSING's theory of a continuous kaolin layer over the whole of Bornholm must be assumed to be untenable. The formation of the kaolin must be regarded as a local phenomenon. STAHL[10] presumes that the kaolin is formed in the same manner as numerous German kaolin beds by the action of marsh-water carrying dissolved carbon dioxide and humus which, from overlying bogs or coal strata has made its way down into the substratum. In the clay and sand strata which cover the kaolin, fragments of coal and vegetable remnants have been found in several places. In a large number of boreholes, however, it is simply indicated[9] that above the kaolin was found sand and, above the sand, green clay; in two boreholes green clay is shown directly over the kaolin, and in both these boreholes the clay is of great thickness; the thickest layer is 15.7 m and, below this, 47.1 m were bored through white kaolin. These circumstances tend to disprove the above assumption, for according to STAHL's[10] investigations into German kaolin beds, it is constantly found that where the kaolin is overlain by autochthonous coal layers, only thin interlayers of incoherent sand, more rarely of sandy clay, are found, in other words only such layers as have not been able to prevent the action of the marsh water on the solid rock. Furthermore, the great thickness of the kaolin can only with difficulty be explained alone by the action of percolating water; it must undoubtedly be put in connection with the situation of the bed just over the fault-fissure which divides the granite terrain from the sediments to the west. Along such a fissure the alteration would certainly extend further down into the substratum than in the cup-shaped depressions usually found under marshes. But as the kaolin formation, as already stated, cannot be satisfactorily connected with the Rhætic-Liassic coal strata, I will point out another possibility, viz. that the kaolinisation has taken place from the fault-fissure itself and caused by ascending water rich in carbon dioxide or thermal-water. Presumably this fault is part of the large post-Silurian system of faults which penetrates the Cambro-Silurian of Bornholm and Skåne and in which, in several places on Bornholm and in Skåne, there are segregations of fluorite and sulphidic ores which with great certainty can be connected with the contemporaneous diabase intrusions in Skåne.[11]

## Joint Zones.

As a general whole the surface of the granite terrain is rounded and smooth in form, but in reality the granite has been subjected to a widespread jointing, which is displayed by the sharp, jagged forms in the rocky walls along the coasts where deep crevices, numerous jutting peninsulas, small fiords and reefs present an illustration of skerries in miniature. In greater measure the occurrence of joints is visible in the numerous joint-valleys, often several kilometres long, one of which, Ekkodal-Kjeldseaa valley, can even be followed for twelve kilometres. The directions of the joint-valleys are for the most part NE—SW and N—S, i. e. essentially the same as those of the diabase dykes. In the Paradisbakker there is another system having a direction WNW—ESE, which is parallel to the direction of the sandstone dykes in this area. Among the widest joint-valleys are Dynddal (about 80 m), Ekkodal (about 60 m) and Døvredal (about 50 m) but otherwise the valleys are rather narrow.

*Karen Callisen.*

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## Abbreviations:

D. G. U. = Danmarks Geologiske Undersøgelse.
S. G. U. = Sveriges Geologiska Undersökning.

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# Palaeozoic.

## Cambrian.

To the south the granite terrain of Bornholm is bounded by sedimentary, Cambro-Silurian rocks, deposited in front of a granite coast, and on the whole dipping towards the south. For the most part these deposits lie in their original undisturbed position, unaffected by such tectonic movements as the Mesozoic deposits along the south-west coast of Bornholm have been subjected to. In some less extensive areas, however, the palaeozoic strata are thickly interspersed with faults, along which subsidence has taken place. In this manner the strata have been preserved and are now visible in sections along the rivers of the southern part of the island. Their extent is shown by the map, fig. 3.

### Nexø Sandstone.

The oldest division of the Cambrian System is the Nexø Sandstone. It is a coast deposit of the weathering products of the granite which, in Algonkian times, prior to the Palaeozoic sea-transgression, had lain as dry land. The direct superposition of the Nexø sandstone on the granite can be seen at some places, but for the most part the boundary is formed by faults, along which the granite rises here and there in "cliffs" beside the adjacent, slightly dipping sandstone strata.

The lowest layer of the Nexø Sandstone is an arkose and consists of small, often unassorted, edged pieces of quartz and feldspar, which are cemented together with a brownish, clayey cement. The sandstone gradually changes character

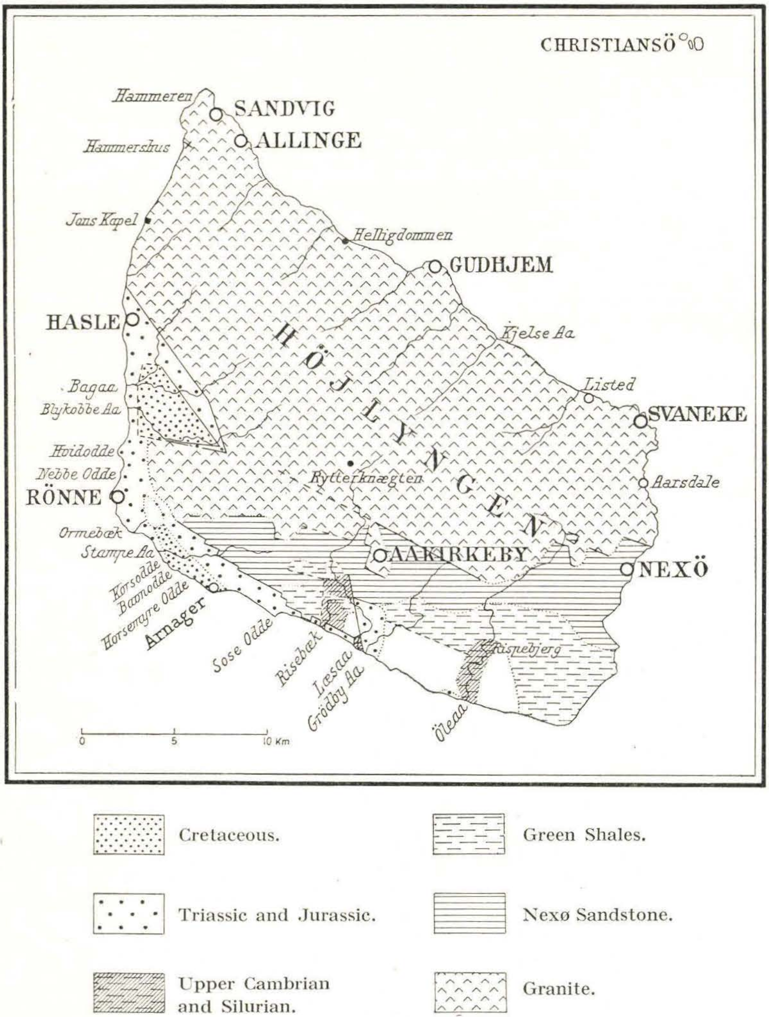


Fig. 3. Geological map of Bornholm (GRÖNWALL and MILTHERS).

as it passes upwards. The grains become more rounded and the larger grains are collected into separate layers; the quantity of feldspar diminishes at the same time as the size of grain on the whole decreases. Kaolin and silica occur in the cement and the colour becomes lighter. The sandstone becomes regularly stratified and lies in the form of beds which, north of Nexø, in exceptional places attain a thickness of up to 75 cm, but as a rule are much thinner. In the uppermost layer the hardness increases, the cement being mostly silica; the rock approaches quartzite and lies in the form of quite thin beds.

The Nexø Sandstone's character of a coast deposit appears from the ripple marks, which are to be found right up in the uppermost part of the series. No certain fossils have been found in it, but what are possibly vestiges of animals. In some places there occur conical formations of uncertain origin; they lie apex downwards. The Nexø Sandstone is regarded as being of the same type as the Hardeberga Sandstone in Skåne; it forms the older part of Lower Cambrian. Its total thickness is considered to be about 60 m.

## Green Shales.

The younger division of Lower Cambrian is formed of the Green Shales which concordantly overlie the sandstone. They are for the greater part dark, greenish, sandy shales (greywacke-shales), passing in places into fine-grained sandstone. Here and there the shales occur in alternate beddings with beds of sandstone, while conversely in the uppermost part of the Nexø sandstone thin layers of shales may occur. The shales are irregularly stratified; their greenish colour is due to glauconite, and the colour of the bedding planes is brownish as a result of the weathering of the glauconite. The total thickness of the series is reckoned at about 60 m.

Phosphorite nodules occur in certain places in the Green Shales, some sporadic, others more or less collected into layers. In connection with these occur fossils; G. HOLM[1] indicates the following: *Hyolithes Johnstrupi* HOLM, *H. Nathorsti* JOHNSTR., *H. lenticularis* HOLM and *Torellella laevigata* HOLM. J. MOBERG[2] puts the Green Shales at the Olenellus stage.

The Green Shales are overlain by a three metre thick, incoherent, speckled sandstone, Rispebjerg Sandstone, which is to be seen in the creeks of the river Læsaa at Kalby and in the river Øleaa at the farm Borregaard. Its uppermost four decimetres are impregnated with phosphorite and appear as a phosphorite sandstone.

## The Paradoxides Stage.

The rock which forms the main part of the succeeding Middle and Upper Cambrian is an alum shale, a black, bituminous shale with finely distributed pyrites and with subordinate layers and concretions of a more or less bituminous limestone. The lowest division of the alum shale, 2—3 m thick, the Paradoxides Stage, has been dealt with by GRÖNWALL[3]; the uppermost division, the Olenus Stage, which has a thickness of at least 21 m, has been dealt with by POULSEN[4]. These strata, as well as the younger Palaeozoic strata, are only visible on Bornholm in sections at the rivers Øleaa, Læsaa and Risebæk.

The Paradoxides Stage, in which more than 100 genera of fossils have been found, is divided by GRÖNWALL[5] into the following zones:

4. Zone of *Agnostus laevigatus* DALM.
3. » » *Paradoxides Forchhammeri* ANG.
2. » » » *Davidis* SALT.
1. » » » *Tessini* BRGN.
    - c. Sub-zone of *Conocoryphe aequalis* LNRS.
    - b. » » *Agnostus parvifrons* LNRS.
    - a. » » *Conocoryphe exsulans* LNRS.

The lowest sub-zone, which is best seen at Øleaa, here consists of a compact, grey, 25 cm thick limestone, the Exsulans Limestone, which in its lowest part contains nodules of the underlying phosphorite sandstone. The nodules of phosphorite are considered by GRÖNWALL to show that there is a lacuna in the Bornholm series of strata compared with the series in Skåne. The next two sub-zones consist of alum shale, at Øleaa with a good deal of anthraconite containing fossils belonging to sub-zone b. At Læsaa, fossils are only found in the upper part of the shale; it belongs to sub-zone c. Over the alum shale lies a bed of limestone, consisting at the bottom of anthraconite with concretions of phosphorite at the base. A very rich fauna has been found in the anthraconite, belonging to the Davidis Zone. The upper part of the limestone is a dark-grey limestone, the Andrarum Lime-

| System | Rocks | | m | Fossils, characterizing the Zones |
|---|---|---|---|---|
| Ordovician | Trinucleus Shale | | 3 | *Trinucleus Wahlenbergi* |
| Ordovician | Dicellograptus Shale | | 9,5 | *Climacograptus styloideus*<br>*Dicranograptus Clingani*<br>*Amplexograptus Vasae*<br>*Climacograptus rugosus* |
| Ordovician | Shale without fossils | | 1.5 | |
| Ordovician | Orthoceratite Limestone | | 5 | *Megalaspis limbata* |
| Ordovician | Dictyograptus Shale | Alum Shale | 2,5 | *Clonograptus tenellus*<br>*Dictyograptus flabelliformis* |
| Middle and Upper Cambrian | Olenus-Stage | Alum Shale | 21 | *Parabolina acanthura*<br>*Parabolina longicornis*<br>*Peltura scarabaeoides*<br>*Ctenopyge tumida*<br>*Ctenopyge flagellifera*<br>*Eurycare*<br>*Parabolina spinulosa*<br>*Olenus*<br>*Agnostus pisiformis* |
| Middle and Upper Cambrian | Paradoxides-Stage | Alum Shale | 2 | *Agnostus laevigatus* |
| Middle and Upper Cambrian | Paradoxides-Stage | | 0,8 | *Paradoxides Forchhammeri* |
| Middle and Upper Cambrian | Paradoxides-Stage | | 1,4 | *Paradoxides Davidis*<br>*Paradoxides Tessini* |
| | Rispebjerg Sandstone | | | |

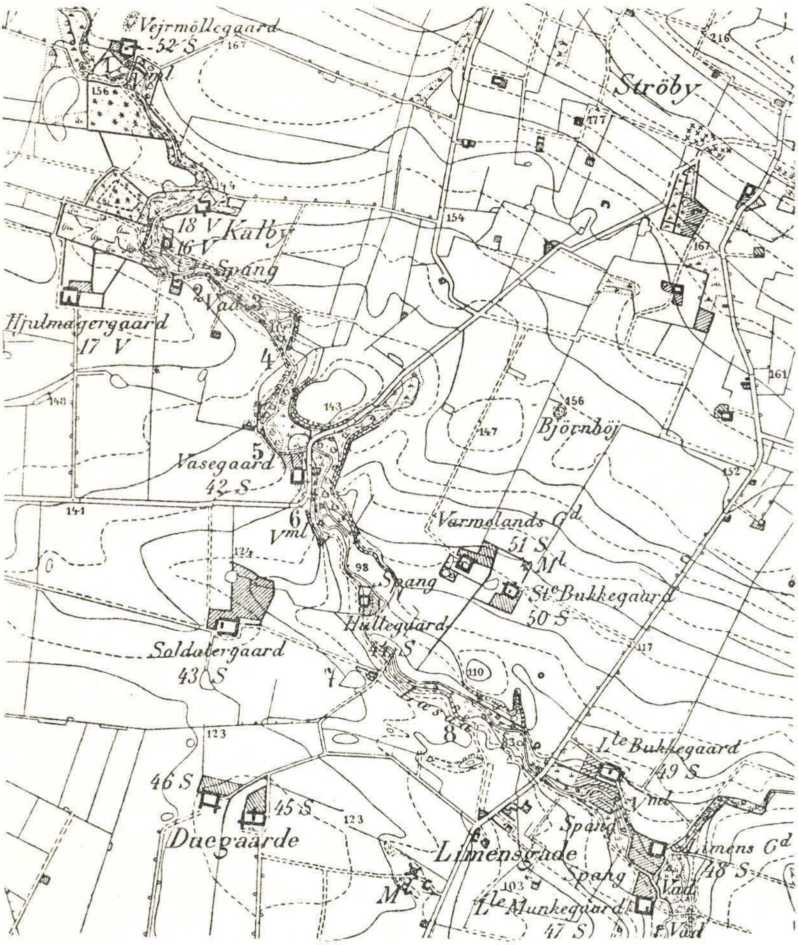


Fig. 4. Map of the localities for Cambrian and Ordovician along the river Læsaa.
Scale 1:20,000; equidistance 5 feet.

1. Locality of Hyolithes in the Green Shales near the farm Vejrmøllegaard. 2. Rispebjerg Sandstone. 3. Paradoxides deposits. 4. Section in the uppermost part of the Olenus Stage. 5. Dicellograptus Shale near the farm Vasegaard. 6. Trinucleus Shale near Vasegaard. 7. Quarry in the Orthoceratite Limestone. 8. Old quarries in Dictyograptus Shale and Orthoceratite Limestone near Limensgade.

stone, which is likewise very fossiliferous and belongs to the zone with *Paradoxides Forchhammeri*. Over the Andrarum Limestone follows a thick series of alum shale, the lowest portion of which belongs to the uppermost zone of the Paradoxides Stage, but has no fossils.

## The Olenus Stage.

The Olenus Stage on Bornholm consists exclusively of alum shale, in which there are anthraconite concretions arranged in rows. That part of the alum shale which belongs to the Olenus Stage is divided by POULSEN[4] into six zones, of which some may further be divided into several sub-zones closely conforming to the sequence in Sweden.

| | | |
|---|---|---|
| 6. Acerocare Zone | | Layer with *Parabolina acanthura* ANG. |
| 5. Peltura Zone. | 4. | Layer with *Parabolina longicornis* WGD. and *Peltura scarabaeoides* WBG. |
| | 3. | » » *Peltura scarabaeoides.* |
| | 2. | » » *Ctenopyge tumida* WGD. and *Sphaerophthalmus major* LAKE. |
| | 1. | » » *Ctenopyge flagellifera* ANG. |
| 4. Eurycare Zone. | 2. | Layer with *Eurycare angustatum* ANG. |
| | 1. | » « » *latum* BOECK. |
| 3. Orusia Zone. | | Layer with *Parabolina spinulosa* WBG. and *Orusia lenticularis* WBG. |
| 2. Olenus Zone. | | Layer with *Olenus* and *Agnostus pisiformis* L. |
| 1. Agnostus pisiformis Zone. | | Layer with *Agnostus pisiformis* L. |

The system is best seen in sections along the Læsaa (fig. 4), Zones 1—5 between Kalby and Vasegaard, Zone 6 at Limensgade. The lowest layers form a concordant continuation of layers of the Paradoxides Stage; Zones 3—5 are to be seen in a section, 60 m long and 10 m high, on the right bank of the stream, 300 m north of Vasegaard. There the alum shales dip slightly towards the south; the anthraconite concretions attain a length of 2—3 m and a thickness of 0.5—1.8 m. The bedding planes of the shale from Zone 3 upwards contain some small, fusiform pyrite bodies which have been determined by KAREN CALLISEN[6] as tung-spar crystals, the growth of which has continued with the formation of pyrites. The fossils in the alum shale are principally found in the lowest part of the various zones, whereas the upper parts do not reveal many, or are even unfossiliferous (POULSEN[7]). — At Øleaa, between Borregaard and Brogaard, the lower layer of the Olenus Stage is found as far as Zone 4.

## Ordovician (Lower Silurian).

### Dictyograptus Shale.

The boundary between Cambrian and Ordovician is placed at about 2.5 m under the upper edge of the alum shale where, above a quite unfossiliferous shale, *Dictyograptus flabelliformis* occurs in large quantities. This Graptolith, from which the Dictyograptus Shale has its name, only occurs in the lower, 2 metre thick, part of the zone; the upper part is characterised (POULSEN[7]) by *Clonograptus tenellus*. The Graptolith Shale also contains *Obolus* (*Bröggeria*) *Salteri* HOLL. and other Brachiopodes, like the underlying part of the alum shale; the abovementioned pyrite bodies also occur.

The principal localities of the Dictyograptus Shale are Limensgade by the Læsaa and Skelbro by the Risebæk; at both places it is overlain by Orthoceratite Limestone. At the boundary between the shale and the limestone there is a thin layer of phosphorite conglomerate which indicates the presence of a lacuna; this corresponds to a series of the Graptolith Shales of Skåne (See table page 33).

### Orthoceratite Limestone.

The Orthoceratite Limestone is a grey, argillaceous limestone, in the lower part of which there is much glauconite and rather irregular bedding planes. The limestone occurs in three areas, separated by faults: two at Læsaa, viz. north of Vasegaard and at Limensgade, and a third at Skelbro at Risebæk. It attains a thickness of 5—6 m; it contains rather a lot of fossils, but they are badly preserved. The commonest are *Megalaspis limbata* SARS & BOECK, *Ptychopyge applanata* DALM., besides species of *Orthoceras*, *Bellerophon* and *Euomphalus*. Thus contemporaneity with the lower part of the Orthoceratite Limestone of Sweden is indicated.

## Dicellograptus Shale.

Above the Orthoceratite Limestone follows an almost unfossiliferous shale, about $1\frac{1}{2}$ m thick, the lowest part being a phosphorite conglomerate, passing into phosphorite sandstone (FUNCKQUIST[8] and NØRREGAARD[9]). This layer is a basal conglomerate marking an interruption in the sedimentation which, however, did not extend to West Skåne where simultaneously a part of the lower Dicellograptus Shale was deposited. Above this follows the Dicellograptus Shale, a black or dark brown shale which at Læsaa, just north of Vasegaard, occurs in the form of a series, 9.5 m thick, overlain by Trinucleus Shale. HADDING[10] divides the series into four zones:

4. Zone with *Climacograptus styloideus* LAPW.
3. » » *Dicranograptus Clingani* CARR.
2. » » *Amplexograptus Vasae* TULLB.
1. » » *Climacograptus rugosus* TULLB.

Besides Graptoliths, the shale especially contains fossils of Brachiopodes; *Discina Portlocki* GEIN. is particularly common and is found throughout the whole series. HADDING, who considers the Graptolith Shale at Vasegaard to correspond completely with the Middle Dicellograptus Shale of Skåne, indicates 22 forms of Graptoliths besides other fossils.

Apart from the fine section at Vasegaard, the Dicellograptus Shale is to be found at Læsaa near Hullegaard, at Risebæk south of the lime quarry and just above the outlet of the stream.

## Trinucleus Shale.

The youngest known division of the Ordovician System in Bornholm is the Trinucleus Shale, a grey-brown, soft, argillaceous shale with uneven bedding planes. It occurs in situ at Læsaa in the section north of Vasegaard and also in the east bank of the river south-east of the farm. RAVN[11] indicates 22 trilobite species, among which are *Trinucleus Wahlenbergi* ROUALT, *Ampyx Portlocki* BARR., *Agnostus trinodus* SALT., *Asaphus* (*Ptychopyge*) *nobilis* BARR., *Phillipsia* *parabola* Barr., and several species of *Illaenus*. Grönwall[12] also indicates *Staurocephalus clavifrons* Ang. The strata correspond entirely to the Scanian Trinucleus Shale.

The youngest layer of the Ordovician, corresponding to the Brachipod Shale of Skåne, is not known in Bornholm, although they may perhaps be concealed under the Quartary.

## Gothlandian (Upper Silurian).

### Rastrites and Cyrtograptus Shales.

Of deposits belonging to the Gothlandian, we know on Bornholm the two divisions of Graptolith Shales, the Rastrites and the Cyrtograptus Shales. They occur in two isolated areas, by the lowest part of Øleaa and the lowest part of Læsaa. Both divisions are found at Øleaa, but only the Cyrtograptus Shale at Læsaa. Of the 7 zones of the Rastrites Shale which are known elsewhere, Bjerring Pedersen[13] has proved the occurrence on Bornholm of the five uppermost, characterised by the following fossils, reckoned from below: *Monograptus acinaces* Tornq., *M. gregarius* Lapw., *M. convolutus* His., *M. Sedgwicki* Portl., and *M. turriculatus* Barr. In all, 55 species have been found. This dark grey shale dips slightly to the south. In the lowest layers furthest to the north at a turn of the Øleaa, south-west of Billegrav, may be seen several thick layers, up to 20 cm, of grey limestone, alternating with the shale-strata.

Without interruption in the series the Cyrtograptus Shale follows above the Rastrites Shale. Of the 7 zones known in Skåne it may be taken that the five lowest are represented on Bornholm. Among the fossils may be mentioned *Monograptus priodon* Bronn., *Cyrtograptus Lapworthi* Tbg., *C. Murchisoni* Lapw., and *Retiolites Geinitzianus* Barr. The Cyrtograptus Shale has a rather irregular dip. In some places there occur in the shale lime-concretions, in the interior of which are radial fissures, and which contain small, clear quartz crystals, the so-called "Bornholm diamonds".

In consideration of the great faciel conformity between the Cambrian and Silurian deposits of Skåne and Bornholm, there is reason to presume that the Palaeozoic Systems of Bornholm have originally had a similar completion to those of Skåne. After the Cyrtograptus Shale there follows in Skåne still another shale, the Colonus Shale, and the System concludes with a sandstone, the Öved-Ramsåsa Sandstone. The Palaeozoic series which was commenced with a sea transgression, thus ended with a regression, after which a continental period set in and lasted throughout the latter part of the Palaeozoic and far into the Mesozoic period.

| | Series in Skåne | Bornholm | | | |
|---|---|---|---|---|---|
| | | Øleaa | Læsaa | Risebæk | |
| Gothlandian | Öved-Ramsåsa Sandstone.... | .... | .... | .... | Missing on Bornholm. |
| | Colonus Shale............... | .... | .... | .... | Not laid bare. |
| | Cyrtograptus Shale.......... | + | + | .... | |
| | Rastrites Shale.............. | + | .... | .... | |
| Ordovician | Brachiopod Shale............ | .... | .... | .... | Not laid bare. |
| | Trinucleus Shale............ | .... | + | + | |
| | Middl. Dicellograptus Shale .. | .... | + | + | |
| | Lower Dicellograptus Shale .. | .... | (+) | .... | Gap on Bornholm and in Eastern Skåne. |
| | Upper Didymograptus Shale . | .... | .... | .... | |
| | Orthoceratite Limestone..... | .... | + | + | |
| | Lower Didymograptus Shale . | .... | .... | .... | Gap on Bornholm. |
| | Ceratopyge Limestone....... | .... | .... | .... | |
| | Dictyograptus Shale......... | .... | + | + | |
| Cambrian | Olenus Shale, upper......... | .... | + | .... | |
| | — , middle........ | .... | + | .... | |
| | — , lower.......... | + | + | .... | |
| | Paradoxides beds........... | + | + | .... | Gap on Bornholm. |
| | Olenellus beds (Green Shales). | + | + | .... | |
| | — (Nexø Sandstone)....... | + | + | .... | |

*V. Milthers.*

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## Abbreviations:

Dansk geol. Foren. = Meddelelser fra Dansk geologisk Forening. København.
D. G. U. = Danmarks geologiske Undersøgelse.
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# Triassic and Jurassic.

The continental period which was commenced at the end of Gothlandian brought with it an interruption in the sedimentation on Bornholm which lasted until the latter part of the Triassic period. Until then the country lay exposed to weathering and denudation, as is expressed in the nature of the overlying Rhætic and Jurassic sediments. Prominent among these are quartz sand, ferruginous sandstones and partly refractory clays rich in kaolin, as well as concretions and beds of clay-ironstone. There is a remnant of the weathering products of the continental period, lying in situ, in the form of the kaolin east of Rønne. It lies upon granite and to some extent is overlain by Mesozoic beds. The Mesozoic deposits are otherwise separated from the older systems by faults. The strata themselves have been extensively subjected to faults and thrusts, and in many places they dip considerably, even vertically with varying directions of strike. Some of the deposits are marine, others limnian and estuarine, in many areas with seams of coal.

The area comprised by the Rhætic-Jurassic beds stretches along the west and south-west coast of Bornholm from Hasle to Øleaa, in addition to which there is a small area on the north-east coast, viz. in the bay west of Gudhjem. On account of the irregular positions of the strata and the lack of sufficient guide-fossils it is difficult to obtain a satisfactory basis for a classification into ages. The safest hold is the marine series of the deposits, whose beds and fauna have been surveyed by Jespersen, Lundgren, Moberg, Grönwall and Malling. Starting with this series, Malling[1] separates the limnian and estuarine beds in an older group (Rhæt—Lower Lias) and a younger group (Middle Lias—Wealden).

The oldest part must be taken to be the deposits in an area by the south coast from the river Grødby Aa to Arnager Bay and from there to the north-west to Robbedale, south-east of Rønne. These are beds of very diverse natures: various sandstones and conglomerates, fine and coarse sands, variegated clays and coal seams. Besides being separated from the adjoining Palaeozoic systems by faults, the beds individually occur in the form of isolated, small areas separated by faults. The dips are rather irregular, but slight on the whole. The direction of the dip lies between SSW and WSW except in an area between Grødby Aa and Limensgade at Læsaa, where it is south-easterly. On a stretch between Arnager Bay and Robbedale the beds are unconformably overlain by Cenomanian greensand (Arnager Greensand) and its basal conglomerate with older phosphorite concretions. The slight unconformability here—representing the period from Middle Lias to Cenomanian—together with the comparatively small dips of the Rhætic-Liassic beds, shows that these beds have not been exposed to great disturbances beyond the faults, by which they have subsided in relation to the Palaeozoic strata and the isolated areas are separated from each other.

If we disregard the coal seams which belong to the series and which are principally known from the sea-floor of Boderne and the cove Sose Vig, it is only at a few places that we know of beds containing plant fossils. One is at Munkerup, east of Risebæk, from which GRÖNWALL[2] according to BARTHOLIN's determination indicates *Gutbiera angustiloba* PRESL. and *Podozamites Agardhianus* BRONGN. The most fossiliferous area is Vellengsbygaard, south-east of Robbedale. There HJORT[3] and MÖLLER[4] have described thirty-six genera of plant fossils, among which especially the genera *Dictyophyllum* and *Podozamites* are prominent. Among the fossils may be mentioned *Dictyophyllum Münsteri* (GOEPP.) NATH., *D. Nilssoni* (BRONGN.) SCHENCK and *Podozamites lanceolatus* LINDB. & HUTT. Of conifers the genus *Pitiophyllum* is the most common. The flora is considered to be pronouncedly Rhætic, corresponding to the Rhætic beds in Skåne; and yet it has sixteen species in common with the much younger flora at Bagaa.

The Robbedale gravel is regarded as belonging to a rather younger subdivision of the Rhætic, but the series within the whole of this area must be considered as having once stretched right up to Middle Lias when the transgression of the sea occurred. In ironstone west of Sose Odde (Homandshald) an ammonite fragment has been found which MOBERG[5] regards as belonging to Middle Lias, like the marine series along the west coast, between the river Stampe Aa and Hasle.

There is, however, an area that is much more closely connected with the marine Lias series; it stretches from the bay at Pythus, two kilometres south of Rønne, to a little way past Nebbe Odde, north of Rønne. The rocks are mostly clay and sand, in many places with coal seams. At Pythus there is a series of twelve seams, north of Ormebæk a series with four seams. Coal seams have also been found in Rønne harbour, in the most westerly brick-works' pits at Rønne and north of Nebbe Odde. In Hasle harbour and just north of the town there are beds with coal seams which perhaps may be correlated with these. In Nebbe Odde there are clay and sand with strata of clay-ironstone.

The strata along the coast south of Rønne harbour to Ormebæk all dip to the west. In a more easterly belt, represented by Nebbe Odde, the clay pits of Rønne Brick-Works, and the coal area at Pythus, the strata have an easterly dip which increases eastwards. In the Pythus area, where the strike is about NNW—SSE, the dip increases from 23° to 70° on a stretch of about 700 metres from W to E., and the strata in the clay-pits at Rønne dip even more. In the area Ormebæk—Pythus and at Nebbe Odde (Galge Odde) there have been found a number of plant remains almost exclusively of Rhaetic forms. We may name *Gutbiera angustiloba* PRESL., *Podozamites lanceolatus f. intermedia* HEER, *Nilssonia acuminata* (PRESL.) GOEPP. and *Palissya Brauni* ENDL.

MALLING (see table on page 40) considers the strata at Galgeløkken (with *Cardinia Follini*) to be younger than the strata in Nebbe Odde (with *Cyrena Menkei*), but older than the strata in the clay-pits of Rønne Brick-Works and in the Pythus area. Until there is more material to support this classification, it ought not, however, to be regarded as definite. The strata at Nebbe Odde, Rønne Brick-Works and Pythus, having the same stratigraphical position as the more easterly marine series are more probably of the same age. Whether a fault runs between the coast strata at Galgeløkken and the strata at Rønne Brick-Works, as GRÖNWALL[2] assumes, or whether the strata form an anticlinal, must likewise be looked upon as being uncertain.

The marine Lias-series occurs south of Hasle and on a narrow stretch from Blykobbe Aa, east about Rønne to the mouth of Stampe Aa. To this series belongs the Hasle Sandstone, a greenish sandstone with a few fossiliferous beds of clay-ironstone, appearing just south of Hasle. The sandstone has a slight southerly dip and is overlain by the strata with coal seams at Løvka. Of fossils, MALLING[6] has determined 38 genera, including *Arietites cfr. falcaries* QUENST., and has therefore grouped the sandstone in the Bucklandi zone, the top zone but one in Lower Lias. In the table on page 40 MALLING[1], however, places it in the lowest part of Middle Lias.

From the mouth of Blykobbe Aa and southwards, over Hvidodde, just east about Rønne (the new clay-pit of Rønne Pottery Works) to the mouth of Stampe (Vellengs) Aa, we find the principal occurrences of the marine Lias series. From the finding place at the outlet of Stampe Aa, GRÖNWALL and MALLING[7] have described a fauna of 46 classified forms. Among the more important are *Aegoceras centaurus* D'ORB. *var. bornholmiensis* and, of new forms, *Myoconcha stampensis*, after which the strata has been given the name of the Myoconcha bed. The strata is placed to the Centaurus zone, the next lowest zone in Middle Lias. From the new clay-pit of Rønne Pottery Works, from Hvidodde, and from the beach at the mouth of Rosmannebæk three kilometres north of Rønne, MALLING[8] mentions finds of rich faunas belonging to the two lowest zones in Middle Lias: the Jamesoni and Centaurus zones. The marine strata referred to here all have an easterly dip like the older, limnian and estuarine strata to the west.

After the marine series again follow sands and clays with plant remains and coal seams. To these belong the most extensive coal seams on Bornholm. In the most northerly

Table of the Jurassic Strata (according to MALLING[1]).

| Epoch | | | Marine Strata | Limnian and Estuarine Strata | Localities |
|---|---|---|---|---|---|
| **Wealden** (Lowest Cretaceous) | | | | Clay-ironstone | Rønne Pottery Works' old pit<br>Ellebygaard<br>Kyndegaard? |
| | | | | Sandstone (overl. kaolin) | Buskegaard<br>Rabekkegaard |
| Lacuna | | | | | |
| **Malm** (White Jura) | | | | Clay with plants of young Jurassic types | Holsterhus |
| **Dogger** (Brown Jura) | | | | Clay-ironstone bed<br>Clay and sand with coal seams<br>Flora of older character than at Holsterhus | Bagaa |
| **Lias** (Black Jura) | Upper | | | | Sorthat<br>Løvka<br>Onsbæk |
| | Middle | $\delta$ | | | |
| | | $\gamma$ | Ferruginous coarser and finer sandstone | | Stampen (Myoconcha bed)<br>Blykobbe Aa<br>Hvidodde-Rosmannebæk (the Jespersen bow-strata)<br>Rønne Pot. Works' new pit<br>Homandshald<br>Hasle (Hasle Sandstone) |
| | Lower | $\beta$ | | Clay and sand with coal seams | Rønne Brick-Works' clay-pit, Pythus, etc, |
| | | $\alpha$ | Clay and sand with *Cardinia Follini* (brackish water) | | Galgelökken |
| | | | | Clay and sand with *Cyrena Menkei* | Nebbe Odde |
| **Rhæt** | | | | Gravel | Robbedale |
| | | | | Clay with plants | Vellengsby |
| **Keuper?** | | | | Fresh-water(?)clay | Munkerup |

section, at Løvka, south of Hasle, the strata dip slightly to the south. The series has a thickness of about 200 m and comprises not less than 25 coal seams with thicknesses of 7 to 70 cm. — At Sorthat, more to the south, there is a similar series with coal seams several of which seem to be identical with those of the Løvka section. The dip is easterly, increasing towards the east to 70°, until 500 m inside the coast the series is broken by a narrow granite horst, running N—S, on the east side of which occurs greensand, belonging to the Cretaceous System.

Between the areas of the Løvka and the Sorthat sections there is a third section with coal seams at Bagaa which, through faults, has sunk in relation to the surroundings. The strata dip to the south-east. There is clay with a very rich flora which has been examined by BARTHOLIN[9] and MÖLLER[4], who have found 69 genera, principally ferns, cycads and conifers. According to MÖLLER, forms occur from the whole period between Rhæt and Oolite. The fossils were found in white, refractory clay (45 genera) and also in a yellow clay-ironstone (27 genera), but the two floras only have three genera in common. *Dicksonia lobifolia* (PHILT) RACIB., is particularly prominent in the clay, and in the clay-ironstone *Dicksonia Pingelii* (BRONGN.) BARTHOL. and *Chladophlebis Roesserti* (PRESL.) SAPORTA (MÖLLER).

Two hundred metres from the coast at Onsbæk there are steeply dipping argillaceous and arenaceous strata, which strike N 15° W and seem to follow immediately after the marine series, just as do the strata at Løvka and Sorthat.

The fresh-water series which occurs in the old clay-pits of the Rønne Pottery Works (the pit farthest to the north-east), is, on the other hand, regarded as being much younger; MALLING places it in the Wealden.

Near to these strata in point of age is an isolated section with fossiliferous clay at Holsterhus, west of the outlet of the Øleaa. BARTHOLIN[10] has found 24 forms here, of which most belong to Oolite and Wealden. In his table of the Bornholm Jurassic strata MALLING[1] classifies the Holsterhus strata to the youngest Dogger and to Malm.

*V. Milthers.*

# Literature.

## Abbreviations:

Dansk geol. Foren. = Meddelelser fra Dansk geologisk Forening. København.
D. G. U. = Danmarks Geologiske Undersøgelse.
S. G. U. = Sveriges Geologiska Undersökning.

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# Cretaceous.

The Cretaceous Deposits of Denmark are distributed as follows:

| | | | |
|---|---|---|---|
| Danian*) | Younger Danian (Zone C and D) | Coccolith Chalk, Bryozoan Limestone and Coral Limestone | Denmark, except Bornholm |
| | Older Danian (Zone A and B) | | |
| Senonian | Mucronata Chalk | White Chalk Grey Marl | do. do. |
| | Quadratus Chalk | Grey Marl | do. do. |
| | Granulutus Chalk | | |
| | Westfalicus Chalk | Bavnodde Greensand | On Bornholm only |
| Turonian | Upper | Arnager Limestone | do. |
| | Middle | | |
| | Lower | | |
| Cenomanian | Upper | | |
| | Middle | Arnager Greensand | do. |
| | Lower | | |
| Albian (Gault) | Albian | On secondary bed in Cenomanian | do. |
| Neocomian | Hils a. o. | | |
| | Wealden | Fresh-water deposits | do. |

*) Of late years Brünnich Nielsen and others have supported the view of Grossouvre that the Danian ought to be placed under Tertiary and not under the Cretaceous.[1,2]

On Bornholm the Cretaceous deposits occur in two areas: the Nyker area, NNE of Rønne, and the Arnager—Stampe area by the coast SE of Rønne. As the Cretaceous of the Nyker area is very little known, only the deposits within the Arnager—Stampe area will be dealt with in the following.

## Wealden.

Several authors indicate with more or less certainty the occurrence of Wealden deposits on Bornholm. In all cases these are sands and ironstones with remains of plants and freshwater molluscs.

MALLING[3] places to the Wealden the sandstone overlying the kaolin as well as beds of ironstone at Kyndegaard, Ellebygaard and in Rønne Pottery Works' old pit; the fauna at the latter locality is characterised by *Dreissenssia membranacea* DUNK., *Unio Menkei* DUNK., *Cyrena majuscula* RÖM., *C. solida* RÖM., *C. gibbosa* DUNK., *Paludina fluviorum* MANT. and others.

## Albian (Gault).

Deposits belonging to Albian are in Denmark only known to occur in secondary position in Cenomanian. They are particularly known through RAVN's investigations into the conglomerate at Madsegrav, east of Arnager.[4]

At the basis of the Cenomanian greensand (see below) there is a basal conglomerate, for the greater part consisting of nodules of phosphatic sandstone, of sizes up to 20 cm. These nodules are of heterogenous origin, they themselves having been formed by the disintegration of an older conglomerate bed. Thus the construction is: the oldest nodules —the primary nodules—are for the most part rolled pebbles of a glauconitic, rather coarse-grained phosphatic sandstone; in these is a separate fauna, the *Hoplites* fauna. To a great extent these primary nodules are, however, cemented together into new nodules—the secondary nodules—with a ground mass of a more fine-grained, brownish phosphatic sandstone; in these is found—besides the primary nodules—a younger fauna, the *Schloenbachia* fauna.

The Hoplites zone (the primary nodules) may be placed to

Lower Albian, the zone of *Hoplites tardefurcatus* and *H. regularis.* The Schloenbachia zone (secondary nodules) belongs to the transition between Albian and Cenomanian, more nearly the very youngest Albian.

## Cenomanian.

Cenomanian deposits have been found both at the eastern and the western boundary of the Arnager-Stampe area, at both places resting unconformably upon older Mesozoic formations.

These strata are best known in the cliff at Arnager (RAVN[5]) (fig. 5). Here the Cenomanian has developed as greensand, Arnager Greensand, which can be traced over a stretch of 800 m. Beginning in the east, at Madsegrav, the greensand

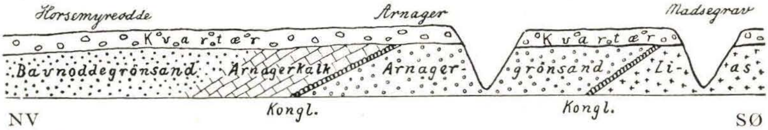


Fig. 5. Section in the cliffs on the SW.-Coast of Bornholm; eastward, at Madsegrav Lias is to be seen, and above that (to the west) follow successively Cenomanian (Arnager Greensand), Turonian (Arnager Limestone) and lower Senonian (Bavnodde Greensand). Two beds of conglomerate (Kongl): Cenomanian and Turonian, are to be seen. (after J. P. J. RAVN).

is found overlying various sand and clay strata; at its base is a conglomerate, with a maximum thickness of 50 cm, with rolled phosphatic sandstone pebbles of up to 20 cm in diameter (referred to above under Albian). The sand between the pebbles is fairly incoherent, but just above the conglomerate are two harder beds of greensand-stone. From there the greensand can be followed fairly unchanged to a little west of Arnager, where it is overlain by the Arnager Limestone. The greensand dips faintly to the west, whereafter its thickness is calculated at about 180 m.

The fauna described by RAVN originates chiefly from the lower strata of the greensand. Among the more frequent forms are *Inoceramus orbicularis* MÜNST., *Schloenbachia varians* SOW. and *Actinocamax plenus* BLAINV.; *Pecten dubrisiensis* WOODS, *Spondylus latus* SOW. and *Schloenbachia Coupei*

BRONGN. are also to be emphasised. The fauna as a whole may presumably be placed in Middle Cenomanian.

## Turonian.

Turonian is known on Bornholm as a pale limestone, Arnager Limestone, which may be seen in the cliff between the village Arnager and Horsemyre Odde, and also at the river Stampe Aa (RAVN[6]).

The Arnager Limestone overlies the above-mentioned Cenomanian Arnager Greensand. At its base is a conglomerate, about 18 cm thick, formed of nodules of phosphatic sandstone, very similar to those from the Cenomanian basal conglomerate, but only of a size up to 5 cm; they lie embedded in the limestone.

Over the basal conglomerate follows the typical Arnager Limestone, a white or light-grey, impure limestone, containing 40—50 per cent. clay, fine sand and silica; everywhere in the limestone can be seen cavities left by dissolved sponge spicules, but flint is only very rarely found. Further west, at Horsemyre Odde, where sections of the youngest Arnager Limestone are found (overlain by the Senonian Bavnodde Greensand) it appears in the form of a still more impure, blue-grey limestone, probably deposited in somewhat shallower water.

Of frequently occurring species in the Arnager Limestone may be mentioned *Lima Hoperi* MANT., *Pecten cretosus* DEFR., *Spondylus latus* SOW. and *Scaphites Geinitzi* D'ORB.; there does not seem to be any essential difference between the fauna collected at Arnager and that at Horsemyre Odde. Both fauna and stratigraphical position place the Arnager Limestone in Upper Turonian, the zone of *Holaster planus*.

## Senonian.

### Lower Senonian (Emscher).

Westfalicus Chalk.

Lower Senonian, Bavnodde Greensand, is only known on Bornholm, where it is to be seen in the coast cliffs west of

Arnager (fig. 5) and at Stampe Aa (Ravn[7]). The lower limit of the Bavnodde Greensand is found farthest to the east at Horsemyre Odde, where it may be seen on the beach resting upon the Arnager Limestone. The surface of the Arnager Limestone is rather uneven, the greensand fills small hollows in it, so that there has certainly been a break in the sedimentation.

In the cliffs, which are about 15 m high, the Bavnodde Greensand can be traced from Horsemyre Odde for two kilometres to the northwest to Korsodde. In the greensand—or the greensand marl—nodules and beds of hard grit occur here and there.

A fairly rich fauna is known from the Bavnodde Greensand, of which may be named: *Scaphites inflatus* Röm., *Actinocamax westfalicus* Schlüt. and *Mortoniceras pseudotexanum* Gros. On the whole the character of the fauna is Middle Senonian, whereas certain species decidedly indicate Lower Senonian. If all the greensand belongs to the same horizon, it must presumably lie at the very top of Lower Senonian, on the transition to Middle Senonian.

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The series of Cretaceous deposits on Bornholm provide information regarding a number of level changes, with the regressions and transgressions connected with them. The following summary is given, chiefly after Ravn[4]:

| Regression: | Transgression: |
|---|---|
| Wealden | |
| | Lower Albian |
| Middle—Upper Albian | |
| | Uppermost Albian |
| Lower Cenomanian | |
| | Middle Cenomanian |
| Upper Cenomanian—Middle Turonian | |
| | Upper Turonian |
| Lowest Senonian | |
| | End of Lower Senonian. |

## Middle and Upper Senonian.

Apart from Bornholm, Senonian deposits older than the Mucronata zone have only on two occasions been found in Denmark by means of deep borings: at Kasted near Aalborg (1872) and just south of Grøndals Aa, about 150 m west of "5. Juni Plads" at Frederiksberg, København (1894—1907). During the course of this latter boring ("The Carlsberg Fund's Deep Boring") the following series was found (according to RAVN and BØGGILD[8]):

| | | |
|---|---|---|
| 0—9.25 m: | Peat, clay, sand and gravel | = Quartary |
| 9.25—37.7 m: | Bryozoan limestone | = Danian |
| 37.7—290 m: | White Chalk with flints | = Upper Mucronata Chalk |
| 290—ca. 533 m: | White Chalk without flints | = Upper Mucronata Chalk |
| ca. 533—ca. 659 m: | Grey Marl | = Lower and Middle Mucronata Chalk |
| ca. 659—861 m: | Grey Marl | = Quadratus Chalk. |

### Quadratus Chalk and Lower and Middle Mucronata Chalk.

The deposit which is referred to these zones by RAVN is a coherent, only slightly shaly, marly limestone, very much stratified in thin, lighter and darker laminae. The lime content varies between 86.2 and 58.3 per cent. These figures apply to the total content in the samples; if the light and the dark laminae are analysed separately, the lime content may rise to 92.6 per cent. in the light ones and fall to 36.8 per cent. in the dark ones. At a depth of about 660 m fine sand occurs, consisting of quartz, calcareous grains, pyrites, etc. Upwards the marly limestone passes smoothly into the overlying, purer lime deposit, the clay content diminishing steadily about 533 m, and beds of pure limestone occur in the marl.

The following fossils have been determinable from the marly limestone:

533—659 m: *Metopaster tumidus radiatus* SP., *Pollicipes fallax* DARW., *Serpula undulata* HAG., *Metopaster undulatus* SP.

659—861 m: *Pollicipes fallax* DARW., *Crania antiqua* DEFR., *Belemnitella lanceolata* SCHLOTH.

## Upper Mucronata Chalk.

The Upper Mucronata chalk[9,10] has developed as White Chalk everywhere. Overlain by younger deposits, it is to be found at greater or smaller depths under the whole of Denmark except Bornholm. Only covered by the Quartary it occurs over the most of Lolland, Falster and Møen, the most southernly part of Sjælland (as well as smaller areas at Skelskør and Pilemølle by Køge Bugt); the north-eastern, northern and north-western parts of Jylland (Himmerland, Vendsyssel, Ø. and V. Hanherred and Thy). It is met with in Møens Klint, Stevns Klint, at Mariager Fjord and from there up to the area around Aalborg, the eastern part of Hanherred, north of Thisted and in Salling, as well as smaller areas on the isle of Mors and in western Himmerland.

The White Chalk occurs everywhere with almost the same character, subjected only to small variations in composition. The carbonate of lime content is on an average about 95 per cent., but may rise to higher than 99.5 per cent. It is thus an extraordinarily pure limestone, planktogenous in origin and with extremely little terrigenous material. Its principal component is extremely fine calcareous ooze, produced in all probability by chemical (perhaps chemico-bacteriological) precipitation in the surface layers of the sea. In this groundmass is a large contingent of coccoliths and a number of pelagic foraminifera; besides this, the fauna indicates that White Chalk must have been formed in not particularly deep water, and in fact the purely chemical sedimentation bears strong witness of this. The topmost strata of the White Chalk are often (Stevns, several localities in Jylland) very rich in bryozoa and other small forms, which indicate that this horizon was formed at a very slight depth.

Flint, coelestine, pyrite (as well as gypsum and limonite) are met with as concretions in the chalk. The flint occurs first and foremost in the form of irregular nodules, more or less continuous in rows and bands, parallel to the stratification, and also as infilling of thin fissures, tests of echinoidea and mollusc shells, etc.; the colour is very dark, often pure black, and the nodules are covered with a crust of white flint, as a rule only few millimetres thick.

Flint is not equally abundant in the chalk in all localities. As mentioned on p. 48, it is missing in the lower strata of the White Chalk in the Grøndals boring, and the same is the case with the chalk of Salling and around Aalborg. At this latter place there is an unusual number of well preserved siliceous sponges in the chalk, so that in this case the explanation is without doubt that the transformation of the silica—from the original state in sponges to flint nodules—for some reason or other has not taken place.

Of characteristic fossils in the White Chalk may be named: *Belemnitella mucronata* SCHLOTH., *Scaphites constrictus* SOW., *Baculites vertebralis* LAM., *Inoceramus tegulatus* HAG., *Trigonosema pulchellum* NILS., *Terebratulina gracilis* SCHLOTH., *Terebratula carnea* SOW., *Echinocorys ovatus* LESKE, *Tylocidaris baltica* SCHLÜT.; furthermore, several species of *Conulopsis*, *Terebratulina striata* WHLB., *Rhynchonella plicatilis* SOW., *Pecten pulchellus* NILS., *P. Puggaardi* RAVN., *P. Nilssoni* GOLDF. etc., *Vola striatocostata* GOLDF.; several species of *Lima*, *Spondylus*, *Gryphaea vesicularis* LAM. Of the aragonitic mollusca there is no trace as a rule, they have been completely dissolved; only where the uppermost layers of the White Chalk have, in places, been solidified at an early point of time, as for instance in Stevns Klint (as will be referred to later) have these forms been preserved as casts and moulds. Of higher animals, remains of fishes (including shark teeth and remains of *Myliobatis*) and teeth of *Mosasaurus* are known.

All the White Chalk which appears in our cliffs and lime pits belongs, as has been stated, to the Zone of *Belemnitella mucronata*. Within this the chalk in Stevns Klint and in the Aalborg-Mariager area is the youngest, whilst that in Møens Klint is a little older. Within the series in the Grøndal boring the oldest White Chalk is without flint, and it is quite possible that the White Chalk without flint in Salling is to be classified to the same older horizon; at both these places the poverty in silica seems to be original (in contrast to the Aalborg area).

## Danian.

Where the White Chalk does not form the substratum to the Quartary, it is normally overlain by the calcareous deposits of the Danian[9.10.11.12]; only in the extreme south, at Gedser, is the Danian missing, the Selandian (Paleocene) resting directly upon the White Chalk.

Covered only by Quartary, the Danian forms the underground in north-eastern, eastern and part of southern Sjælland, where it appears at Faxe, in Stevns, the area around Køge Bugt, København and on the isle of Saltholm; on Lolland it is known from a boring in the vicinity of Nakskov; furthermore, on Langeland and eastern Fyn; in Jylland—visible in many places—it occurs in the peninsula of Djursland, around the Randers and Mariager fiords, in Himmerland, Ø. and V. Hanherred, Thy and on Mors, as well as in smaller areas on Thyholm, in Salling (?), at Hjerm and Sevel (N and NE of Holstebro), Davbjerg-Mønsted (W of Viborg) and Nøvling (NW of Herning). By many borings Danian has likewise been found both in Jylland and on the islands, covered by Paleocene clay or greensand.

Whereas the White Chalk only exhibits comparatively slight variation in the different localities, it is otherwise with the Danian, its deposits varying rather considerably both from place to place and during the course of the Danian period. Nevertheless there are certain mutual features among the different calcareous rocks.

The precipitation of calcareous ooze which proceeded during the White Chalk Period was continued almost unchanged during the Danian period. The calcareous ooze, too, contained a large number of coccoliths, but as the coasts round the Danian sea consisted to a great extent of White Chalk, there has undoubtedly also been a not inconsiderable addition of terrigenous calcareous mud. In its typical form the rock which was thus produced occurs as a fairly soft Coccolith Chalk, differing from the White Chalk only in that it contains a large quantity of coarser particles of lime and crystalline calcite. The finest variations of the Danish Coccolith Chalk (for instance from Hjerm) often resemble White Chalk very much in appearance; but a microscopic examination at once discloses the difference referred to. Danian Coccolith Chalk is often called—in contradistinction to the White Chalk—"Blege" Chalk.*)

This calcareous ooze, which in its pure state occurs as Coccolith Chalk, also forms the groundmass in several differing rocks. In many cases the sea-bottom has been thickly covered with bryozoa and, if their branches became more or less dominating, the rock became a Bryozoan Limestone. Limestone which consists almost exclusively of bryozoa is also met with, but only rarely. As a rule the Bryozoan Limestone is rather porous, sometimes easily splitting, but is often very coherent too.**)

Less frequently the octocorals (*Moltkia*, *Isis*, *Gorgonella*) or hexacorals (*Dendrophyllia*, *Lobopsammia*) occur in such numbers that they have turned the limestone into Coral Limestone. Coral Limestone is the principal rock at Faxe (and has been found by borings west of Næstved); a Coral Limestone, in which, however, the hexacorals are in minority to the octocorals, has been met with at several places in Jylland as a subordinate bed.

On the whole it may be assumed that the Bryozoan Limestone was formed under conditions during which the sedimentation of the lime ooze was less rapid, i. e. farther from the coast and in deeper water (exceptions are, of course, met with); on the other hand, the Coccolith Chalk has undoubtedly been formed in shallower water, and every intermediate form of rock is met with from the fine grained Coccolith Chalk to the pure shallow-water formations such as lime sand and lime gravel.

Thin, quite subordinate beds of clay are met with throughout the Danian. Flints appear everywhere in the Danian limestones, though their quantity varies. In Faxe the Coral Limestone is almost devoid of flints, and on the other hand certain forms of Bryozoan Limestone are particularly rich

*) The name originates from the fact that harder parts of the Chalk are sometimes called "Bleger."

**) A coherent, rather soft Bryozoan Limestone, is sometimes called "Limsten."

in flints. In the Bryozoan Limestone in Stevns Klint the flint layers often are only about a metre apart, and each layer may be 20 to 30 cm thick. Flint is also found in the Coccolith Chalk to a great extent; but, in addition, the flint occurs here in the form of individual, irregular, round nodules, sometimes measuring several decimetres in diameter. Whereas White Chalk flints are almost pure black, Danian flints are more impure, grey-black—grey—white, sometimes yellow in colour, and, moreover, the white crust on the nodules is much thicker and the nodules themselves are much more irregular, pitted, "corroded" and porous.

Finally, the limestones of the Danian may have been hardened to different degrees. Derived from an originally uniform sediment the rock sometimes appears as an almost unchanged, incoherent calcareous powder, sometimes as a hard limestone in which all the pores are infilled with crystalline calcite.*)

Compared with Senonian, the Danian is characterised by the fact that a number of genera have disappeared: *Scaphites*, *Baculites* (all Ammonites), *Belemnitella*, *Inoceramus*; the same applies to a large number of species. It is, however, true of some typical Senonian species that they are still met with as "relics" in the basal deposits of Danian (Zone A), but not else in Danian. On the other hand, a large number of species are common to both Senonian and Danian; of these may be mentioned: *Terebratulina striata* WHLB., *Gryphaea vesicularis* LAM., *Exogyra canaliculata* SOW., several asteroidea, many bryozoa, etc.

Of new species, occurring through the whole of Danian, may be mentioned: *Echinocorys sulcatus* GOLDF., *Bourgueticrinus danicus* BR.N., *Pecten tesselatus* HNG., *Dromiopsis rugosa* SCHLOTH., *Pentacrinus paucicirrhus* BR.N., *Tylocidaris vexillifera* SCHLÜT., *Argiope faxensis* POSS., *A. dorsata* BR.N. In the Danian lime deposits too, the aragonite-shelled mollusca have

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*) The name "Saltholm limestone" (which by the way has been used in a number of different senses) is now principally used as the name of such very hard, Danian limestone, regardless of its composition or age.

normally dissolved without leaving any trace. Only under special conditions have they left casts, as for instance in the Coral Limestone in Faxe (locally in the Coral Limestone aragonite shells are found preserved as pseudomorphs in calcite), in hardened beds of Coccolith Chalk in Zone A, in BRÜNNICH NIELSEN's "Crab bed" in the Bryozoan Limestone of Zone B, and elsewhere. Of vertebrates a large number of fish teeth are known (*Lamna*, *Carcharodon*, *Cestracion*, *Myliobatis* and many others), and also remains of turtles (*Allopleuron*, *Trionyx*).

The Danian is divided into Older Danian (Zones A and B) and Younger Danian (Zones C and D); cf. Table p. 63.

## Older Danian.

### Zone A.

The oldest Danian bed appears—wherever it has so far been found—as a deposit of Coccolith Chalk with a thickness of only few metres. It is called Zone A. Fig. 6 gives a schematic view of some characteristic sections.

At Voxlev (east of Nibe) there is a sharp limit between the Coccolith Chalk and the White Chalk, and the deposition of the former commenced with the formation of a thin layer of clay. The Coccolith Chalk is overlain by Bryozoan Limestone.

At Bøgelund (just west of the cement works on the south side of Mariager Fjord) a similar series is met with, but here the clay layer at the base of the Coccolith Chalk has developed into a distinct basal conglomerate, with large pebbles of White Chalk. The upper part of the Coccolith Chalk is very hard and fissured and contains, among others, the casts of aragonite-shelled mollusca. Against the overlying Bryozoan Limestone the Coccolith Chalk is sharply delimited by a plane of abrasion and the Bryozoan Limestone fills up the pits and holes in the hardened Coccolith Chalk.

A similar consolidation of this bed is met with at Nystrup (west of Thisted). Here, however, there is no clay layer at the base of the bed, whereas a clay bed, developed as a conglomerate, lies at the base of the Bryozoan Limestone, at the top of the Coccolith Chalk; thus here, too, the Coccolith Chalk bed is delimited upwards by a plane of abrasion.

At Eerslev, on the Isle of Mors, there is a sharp limit between the Coccolith Chalk and the White Chalk, and the upper horizon of the latter is very hard and fissured and also contains casts of aragonite shells; this hardened horizon passes insensibly downwards into the ordinary, soft White Chalk.

The explanation of these sections is, that there has been a regression followed by a transgression both before and after the deposition of the Coccolith Chalk of Zone A. The first of these regressions concluded the formation of the White Chalk and caused the consolidation of the uppermost chalk at Eerslev; with the transgression, which introduced the deposition of the Coccolith Chalk, the clay bed and the basal conglomerate at Voxlev and Bøgelund were formed. The last regression cut short the formation of the Coccolith Chalk and caused its hardening at Bøgelund and Nystrup; by the following transgression, during which the deposition of the Bryozoan Limestone (Zone B) commenced, occurred the abrasion which formed the conglomeratic clay bed at Nystrup.

These conditions are still more clearly illustrated by the exposure of Stevns Klint (figs. 6 and 7). According to ROSENKRANTZ,[13] the Coccolith Chalk of Zone A is here deposited in shallow basins in the surface of the White Chalk. The deposition of the chalk ceased with the first regression, and the shallow pits, in which the Coccolith Chalk was deposited during the subsequent transgression, were presumably formed by abrasion. The deposition of the Coccolith Chalk was commenced with the formation of a clay bed (the "Fish Clay"), which is often developed as a conglomerate, containing pebbles of White Chalk; the clay passes insensibly upwards into the Coccolith Chalk ("Cerithium" or "Cyclaster Limestone"). The deposition of the Coccolith Chalk was cut short by the last regression and an abrasion occurred which affected both the White Chalk and the Coccolith Chalk, so that of the latter there only remained the thin stratum which lay at the bottom of the shallow basins. Simultaneously there was a rapid consolidation of the lime strata which formed the sea-floor, both the Coccolith Chalk in the basins and the White Chalk between these. And during a new transgression the Bryozoan Limestone was deposited above the plane of abrasion, in such a manner that at one place it rests upon the hardened White Chalk, at another

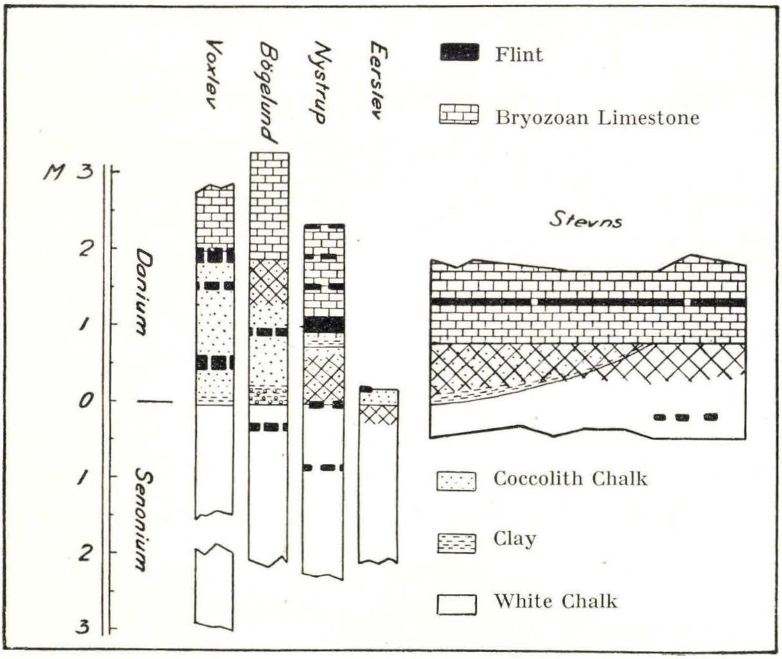


Fig. 6. Sections throueh the limit between Senonian and Danian. The cross hatching indicates a hardened horizon.

upon the similarly hardened Coccolith Chalk. As a consequence of the hardening both these rocks now appear as very hard, but greatly fissured limestone, full of cavities from dissolved organisms and with casts of the aragonite-shelled mollusca which have otherwise disappeared from the non-consolidated rocks without leaving any trace.

As the consolidated horizon in Stevns Klint is very conspicuous, underlying the Bryozoan Limestone throughout the whole length of the cliff, it may easily be taken for a homogeneous stratum; but, as shown above, it passes through very different strata, and the fauna of the Coccolith Chalk is very different to the fauna of the hardened White Chalk.*)

Zone A of the Danian is known in the following localities:
Sjælland: Stevns Klint.
Jylland: Bøgelund (Mariager Fjord), Gravlev (between Ho-

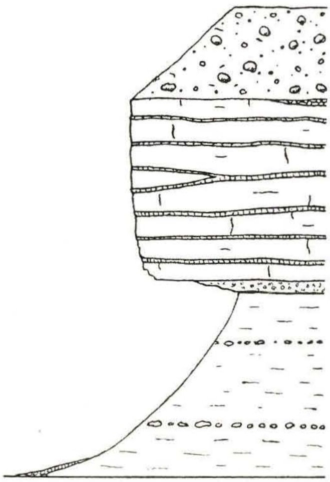


Fig. 7. Transverse section of Stevns Klint, right-angled on the shore.

*) As in the course of time this has given rise to a good deal of confusion, there may be reason for pointing out the lines in the historical development.

FORCHHAMMER gave to this Coccolith Chalk the name of "Cerithium Limestone," and under this name he, as well as JOHNSTRUP, only refers to the Coccolith Chalk *in* the shallow basins. The fact that JOHNSTRUP nevertheless maintains that the "Cerithium Limestone" contains ammonites is due to a confusion with fossils collected in the hardened White Chalk, which resembles "Cerithium Limestone", the fossils from this having been mingled with those from the real "Cerithium Limestone." RAVN[9] considered the whole of the hardened horizon to be a homogeneous stratum, and the fauna lists from "Cerithium Limestone" which he as well as GRÖNWALL and HENNIG operated with, contain a mixture of forms from the two different strata. ROSENKRANTZ[13] separated the Coccolith Chalk in the basins ("The Brissopneustes bed" or, as the stratum is now most frequently called, the "Cyclaster Limestone") from the hardened White Chalk in the intervals between these and pointed out that the fauna in them is different.

bro and Aalborg), Voxlev (east of Nibe), Kjølby Gaard (near Hunstrup Station), Nye Kløv (south of Hunstrup St.), Hov (at Lønnerup Fjord), Nystrup (northwest of Thisted), Eerslev and Øxendal (Isle of Mors).

Zone A is characterised by containing a purely Danian fauna, of which *Cylaster Brünnichi* RAVN is especially prominent, and side by side with it some Senonian species as "relics"; of these *Echinocorys ovatus* LESKE seems to be the most frequently occurring.

## Zone B.

Wherever the stratigraphical position has been observable, the Coccolith Chalk of Zone A has been seen to be overlain by Bryozoan Limestone which (as far as is known) reaches a thickness of 30—40 m. Other rocks than the Bryozoan Limestone have not been observed and this always occurs in typical form, with a very large number of Bryozoa embedded in a fine groundmass. Often the lime and flint layers are arched, in large banks, resting unconformably upon each other, presumably in consequence of irregular deposition on the sea-floor. The deposition of Zone B's Bryozoan Limestone probably represent the maximum of the Danian submersion.

Of typical occurrences of the Bryozoan Limestone of Zone B may be mentioned the "Limsten" in Stevns Klint and at Kagstrup, Sjælland; Sangstrup and Karlby cliffs and Bulbjerg in Jylland; it is also met with in a large number of Jylland lime quarries, as at Tinbæk Mølle (between Hobro and Aalborg), Munksjørup and Løgsted (south of Løgstør), Aggersborg, at Klim and Torup Station and in many other places.

As to the fauna the deposits of this zone seem likewise to be very homogeneous in the various localities. The Senonian relics have quite disappeared, several Danian have appeared and in every place one finds an almost stereotype company, of which the following may be named: *Metopaster mammilatus*

Gabb. *typ.*, *Terebratula fallax tenuis* Br.N., *Epitrochus vermiformis*, Br.N., *Tylocidaris vexillifera* Schlüt. *α* (and *γ*), *Brissopneustes danicus* Schlüt., *Serpula distincta* Br.N., *S. erecta* Br.N., *Rhynchonella incurva fax.* Poss. On the whole the fauna is fairly poor in species.

## Younger Danian.

### Zone C.

In contrast to Zone B, Zone C varies greatly in its rocks from place to place. Where the zone has developed as Bryozoan Limestone it displays greater variation, and furthermore, Coccolith Chalk and Coral Limestone occur to a great extent. Coccolith Chalk and Bryozoan Limestone are as a rule stratified and filled with layers and seams of flint.

Localities with Coccolith Chalk: North of Bjerregrav St. (by Skovvad Bro). Skillingbro, where the Chalk overlies Zone B's Bryozoan Limestone. Tved (north of Hunstrup St.). Legind (at the north end of Ove Lake, Thy). Eerslev (Isle of Mors). Helligkilde (Thyholm); the Coccolith Chalk which here appears in large quarries, containing subordinate layers of Bryozoan Limestone rich in Corals, must probably be placed in Zone C. Thisted (east of the town); here the Coccolith Chalk is to be seen partly in the cliff of Østerodde, partly in the big quarry by the slaughtery (with subordinate beds of Bryozoan Limestone).

Localities with Bryozoan Limestone: A part of Faxe Limestone Quarry. Lendrup Strand by Løgstør Canal; the whole canal is cut through limestone, mostly Bryozoan Limestone, but with smaller quantities of Coccolith Chalk. Aggersborg Gaard (a small quarry west of the farm); here the limestone must more nearly be characterised as Bryozoan Limestone, but with a great Octocoral content (*Moltkia Isis* Stp. and others) and Hexacorals (*Dendrophyllia candelabrum* Hng.). Hansted (Hanstholm). Hjardemaal. Dollerup (west of Thisted).

Localities with Coral Limestone: The typical Coral Limestone has been found by two borings at Spjellerup (southwest of Næstved), but is only exposed in the famous Faxe Limestone Quarry. Here the limestone rises to a height of 70 m above sea-level and forms a hill with an area of half a square kilometre, in which it is broken in a large, open quarry. The hill must be regarded as a Coral bank, formed at some depth. The Coral Limestone itself appears as an unstratified mass of interwoven branches of Hexacorals (*Dendrophyllia candelabrum* HNG., *Lobopsammia faxensis* BECK), to a smaller extent Octocorals (*Moltkia Isis* STP.), the interstices of which are infilled with hardened calcareous mud. Surrounding the Coral bank (and to some extent alternating in layers with the Coral Limestone) occurs the Bryozoan Limestone. The Coral bank has been the scene of a very rich animal life: sharks, crabs (*Dromiopsis rugosa* SCHLOTH.), nautili (*Nautilus danicus* SCHLOTH., *N. fricator* BECK, *N. Bellerophon* LDGR.), a number of snails and mussels (*Pleurotomaria niloticiformis* SCHLOTH., several species of *Cerithium*, *Cypraea* and *Tritonium*; *Modiola Cottae* RÖM., *Arca* and *Cucullaea*, *Crassatella faxensis* RAVN, *Isocardia faxensis* LUNDGR.), a number of brachipods (*Rhynchonella flustracea* SCHLOTH., echinoderms (including *Cyathidium Holopus* STP., *Temnocidaris danica* DESOR.), and so on.

As to the fauna, Zone C is characterised by the presence of a number of newly appearing typical fossils of Younger Danian (Zones C—D): *Terebratula lens* NILS., *Tylocidaris vexillifera* SCHLÜT. f. $\beta$, *Ceratotrochus saltholmensis* BR.N., *Isis vertebralis* HNG., *Brissopneustes suecicus* SCHLÜT., *Serpula dentata* BR.N., *S. undulifera* BR.N., *Ditrupa Schlotheimi* RSKR., *Rhynchonella incurva* SCHLOTH. *typ.*, *Scalpellum Steenstrupi* BR.N. Together with these the following species from Zone B are still present: *Terebratula fallax tenuis* BR.N., *Metopaster mammilatus* GABB. *typ.*, *Brissopneustes danicus* SCHLÜT., *Serpula distincta* BR.N., *S. erecta* BR.N., *Rhynchonella incurva fax.* POSS.

On the whole, the fauna is much more rich than that of Zone B.

### Zone D.

The deposits from Zone D also vary greatly, a circumstance which to a great extent is due to the fact that the uprising of the sea-floor, which was already commenced at the transition from Older to Younger Danian, is now more effective, so that at least the deposits in East Sjælland are partly formed in very shallow water (calcareous sand and gravel); otherwise both Coccolith Chalk and Bryozoan Limestone occur as in the previous zone.

In Jylland, Coccolith Chalk is the principal rock in Zone D, and the greater part of the exposures of this rock in that part of the country belong to it. Of typical localities may be mentioned: Bredstrup Klint at Grenaa; occurrences in the district around Klavsholm (southeast of Randers) and close to Bjerregrav Station; at Mariager Fjord; Roldtved (in Rold Forest) and several other places in Himmerland; Thisted (west of the town); Frøslevvang on the isle of Mors; Hjerm, Sevel, Davbjerg and Mønsted. Overlain by the clay deposits of Paleocene (Selandian) the Coccolith Chalk of Zone D has been met with at Hvalløse and Svejstrup in the environs of Randers and by several borings; in a boring at Skive Zone D seems to have developed as Bryozoan Limestone, whereas Bryozoan Limestone in Zone D in Jylland otherwise only occurs as quite subordinate layers.

On Fyn and Langeland the Danian has in general developed as Bryozoan Limestone, but in several cases as Coccolith Chalk too. The limestone is exposed (possibly not in situ) at Rejstrup and several other places in the neigbourhood of Nyborg and has also been found in many borings, partly overlain by Selandian. Only Zone D has hitherto been ascertained on Fyn and Langeland.

On Lolland the Danian has been found by a boring at Branderslev (north of Nakskov), here, too, as Bryozoan Limestone which may be placed under Zone D.

On Sjælland a number of occurrences may be placed under this zone. At Herføgle, Bryozoan Limestone has been found overlain by a rather coarse lime gravel, both belonging to Zone D, and the same applies to a part of the Bryozoan Limestone of Faxe. Excavations in the port of København have exposed the youngest Danian stratum (partly overlain by the clay and greensand deposits of Selandian), here developed as calcareous sand and on the isle of Saltholm shallow water deposits are likewise met with in various developments.

The conditions at several of these localities show that

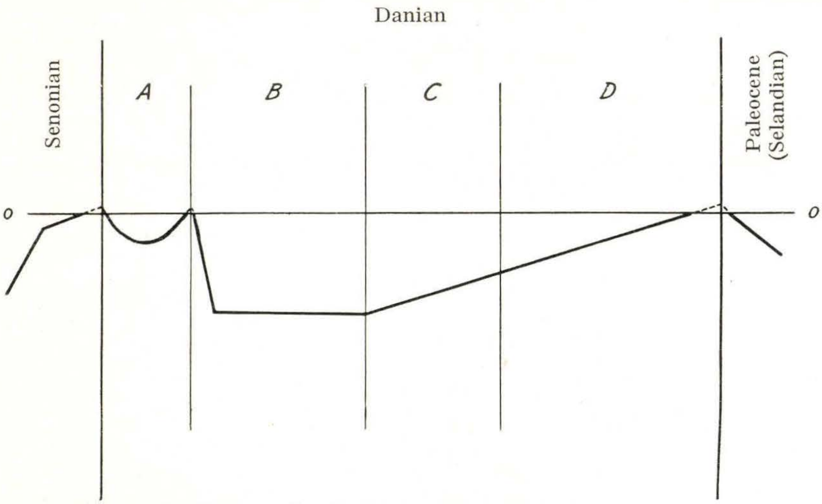


Fig. 8. Diagram showing the emergences and submergences during the Danian time.

the lime deposits in question must have been formed in the immediate vicinity of a coast which must have consisted of Danian lime. ROSENKRANTZ[14] explains this by presuming the formation of big faults in these areas during the close of the Danian period.

As to fauna, Zone D is characterised by the fact that a number of the species known from Zone C (*Terebratula fallax tenuis*, *Metopaster mammilatus typ.* etc.) have disappeared, and at the same time a number of new species have appeared: *Crania tuberculata* NILS. *typ.*, *Argiope scabricula* KOEN., *A. Johnstrupi* POSS., *A. Cimbrorum* BR.N., *Graphularia Grönwalli* BR.N., *Serpula Hisingeri* LUNDGR., *Terebratula fallax*

LUNDGR. *typ.*, *Lima testis* GRW., *L. bisulcata* RAVN., *Plicatula Ravni* RSKR.

Zone D almost corresponds to GRÖNWALL's "Zone of *Crania tuberculata*" (to which GRÖNWALL[16], however, also counted the deposits which have now been placed under Selandian) and ROSENKRANTZ's "Lower Crania Limestone".

The Danian period was introduced with a transgression of rather short duration, during which Zone A was deposited, again interrupted by an regression. This, however, was only brief, and the maximum of the Danian depression probably occurred during the deposition of the Bryozoan Limestone of Zone B. With the formation of Zone C the commencement of a rising is traceable, culminating with the close of Danian. Cf. fig. 8.

Paleocene.
(Selandian)

<table>
<tr><td rowspan="4">Danian</td><td rowspan="2">Younger</td><td>D</td><td>Calcareous sand and gravel<br>Coccolith Chalk<br>Bryozoan Limestone</td><td>Crania tuberculata typ.<br>Argiope scabricula-Group</td><td rowspan="2">Terebratula lens<br>and<br>Tylocidaris vexillifera<br>β</td><td>Dromiopsis rugosa</td></tr>
<tr><td>C</td><td>Coccolith Chalk<br>Bryozoan Limestone<br>Coral Limestone</td><td>Terebratula fallax tenuis<br>Metopaster mammilatus typ.</td><td>Pecten tesselatus</td></tr>
<tr><td rowspan="2">Older</td><td>B</td><td>Bryozoan Limestone</td><td>Terebratula fallax tenuis<br>Metopaster mammilatus typ.</td><td rowspan="2">Tylocidaris vexillifera<br>α & γ<br>and<br>Cyclaster Brünnichi</td><td>Bourgueticrinus danicus</td></tr>
<tr><td>A</td><td>Coccolith Chalk</td><td>Metopaster mammilatus typ.<br>Echinocorys ovatus</td><td>Echinocorys sulcatus</td></tr>
</table>

Senonian

Zone A only attains slight thickness (the greatest thickness observed is 6 m); Zone B attains a thickness of between 30 and 40 m. The total thickness of Danian would on an average seem to be between 100 and 200 m, of which the greater part thus belongs to Younger Danian, Zones C+D.

*Hilmar Ødum.*

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### Abbreviations:

Dansk geol. Foren. = Meddelelser fra Dansk geologisk Forening. København.
D. G. U. = Danmarks Geologiske Undersøgelse.
S. G. U. = Sveriges Geologiska Undersökning.
Vid. Selsk. Skr. = Det Kongelige Danske Videnskabernes Selskabs Skrifter.

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# Tertiary.

The deposits of the Tertiary period are widely distributed in Denmark, occupying more than half of the country's area, viz. Mid and West Sjælland, the south point of Falster and the southwest corner of Lolland, the whole of the Funen island group (excepting North Langeland and an area round Nyborg), as well as that part of Jylland lying south of a rather wavy line from the shores of the Kattegat a little south of Grenaa to the shores of the North Sea somewhat north of the western outlet of Limfjord. These deposits, however, are practically everywhere overlain by more or less thick Quartary deposits, so that they are only accessible in a number of cliffs and in large and small pits where marl has been taken for agriculture or clay for the brick and cement industries. The Tertiary has also been met with at well-diggings and especially through numerous borings, the latter having to a very great extent increased our knowledge of these deposits.

The nature of the deposits varies greatly. They are almost exclusively terrigenous sediments, pure, or almost pure limestones—in contrast to what is the case in our Senonian and Danian—being extremely rare. The main mass is formed of marl and clay, partly with glauconite or mica and most frequently with varying quantities of quartz grains. More or less pure sand deposits, sometimes transformed into sandstones, likewise are of importance, especially within the younger part of the series. Lignite and diatomaceous earth also occur as subordinate strata. In the latter are layers of tuffs, the only volcanic products known from Denmark if we disregard Bornholm and the Faroe Islands, as well as boulders found in our Quartary deposits.

Observations from natural profiles and especially from borings seem to show that the position of the Tertiary strata on the whole is the original one. And yet rather extensive disturbances are frequently seen, in most cases due to glacial action during the Ice Age, but may also have occurred through slides in more recent times. A contributory cause of these disturbances may presumably be found in the beds of rich clay which are found at various levels in our Tertiary.

Stratigraphic investigations have shown that marine deposits are by far the most important, but they are, at any rate at two (or three) different levels, interrupted by lacunas which, however, are wholly or partly infilled with limnian deposits. All the stages of the Tertiary system occur in Denmark; yet the occurrence of the uppermost stage, the Pliocene, is rather doubtful. According to our present knowledge we may divide our Tertiary as shown by the following tabular summary.*)

Denmark's Tertiary Deposits.

| | | |
|---|---|---|
| Pliocene | limnian | ?More or less coarse-grained sand with small Silurian pebbles in the area round Vejle. |
| Upper Miocene | marine | Dark, sandy Mica Clay (Astarte Clay) in West Jylland. |
| Middle Miocene | marine | Mica Sand and Clay at Skyum in Thy. Skive, Mariager Fjord etc. and in borings at Varde, Viborg etc. |
| Lower Miocene | limnian | Mica Sand and Clay with lignite in Central Jylland.<br>?Mica Sand and Clay at Vejle, Fredericia etc. |

*) The extent of the subdivisions of the various stages is not yet established. The subdivisions are therefore not shown on the map (Pl. I).

Of late some authors have in Denmark commenced to place the Plastic Clay to the Paleocene, because in England and France strata of equal ages are generally placed to this stage. As will be seen later, there is, however, some reason for supposing that the uppermost part

| | | |
|---|---|---|
| Upper Oligocene | marine | Black, rich Mica Clay at Vildsund, SSW of Thisted.<br>Dark-green, glauconitic clay at Mariager Fjord, Aarhus, Albækhoved near the mouth of Vejlefjord and Hindsgavl in Fyn. |
| Middle Oligocene | marine | Grey Septaria Clay at Branden in Jylland, Skive, lower Gudenaa valley, Faarup NW of Randers, Mariager Fjord, etc.<br>Sandy clay at Aarhus and Odder NE of Horsens. |
| Lower Oligocene | limnian | Only known as boulders at Katholm south of Grenaa. |
| Upper Eocene | | Missing? |
| Middle Eocene | marine | ?Grey, Plastic Clay at Little Belt ("Rösnæs Clay," "Little Belt Clay"). |
| Lower Eocene | marine | Red (and grey?) Plastic Clay ("Røsnæs Clay," "Little Belt Clay") and Mo Clay with tuffs in Thy, on Mors, at Mariager Fjord, Røgle Klint on Fyn, Fredericia, Røsnæs on Sjælland, South Langeland, Lolland, etc. |
| Upper Paleocene | marine | ?Grey non-calcareous clay of Klitgaard (Mors), Rugaard and numerous borings in NW Sjælland, Fyn and Jylland. |
| Middle Paleocene | marine | ?Light-grey marl ("Kerteminde marl") on Sjælland and Fyn and at Rugaard (Jylland). |
| Lower Paleocene | marine | Glauconite marl in København, at Hvalløse SE of Randers and in Djursland.<br>Greensand Limestone at Lellinge west of Køge (Sjælland).<br>Greensand conglomerate ("Upper Crania Limestone", "Echinodermata-conglomerate"). |

of our Plastic Clay must be grouped with deposits which in England and France are placed to Eocene. As, however, the Plastic Clay in the petrographic sense forms a unity and no definite boundary can be indicated between its two subdivisions, it will be proper to place it in its entirety to one and the same stage, as has most often been done hitherto, both in Denmark and in Germany.

## Paleocene.

Where there have been opportunities of examining the boundary between Danian and Tertiary in Denmark, it has always proved to be sharply defined. The lowest phase of the Tertiary belongs to the Paleocene ("Selandian") and as a general rule it overlies Danian; in a few borings, however, the substratum would seem to be White Chalk, according to Bøggild's[1] investigations. Only a few borings have gone right through the Paleocene, the thickness of which here is from 28 to 60 m; but in other borings a much greater thickness has been found (up to at least 112 m). There is reason for believing that this rather thick deposit belongs to no single subdivision of the Paleocene, but that it represents this stage in its full extent. For it is certain that in the glauconite marl at Vestre Gas Works in København we have the Older Paleocene, whereas the grey, non-calcareous clay at Hanklit on Mors seems to pass insensibly into the very oldest Eocene and therefore cannot well be very much older than that. The tripartition of our Paleocene which is used throughout in the following is particularly based upon the petrographic structures, although as regards the first two subdivisions on the palaeontological content too. However, as pointed out by Bøggild, there is a possibility that the difference between the three subdivisions is due to difference in facies. A definite answer to this question must be left to future research.

The Lower Paleocene most often begins (port of København, Hvalløse at Randers) with a basal conglomerate ("Upper Crania Limestone"), which to a great extent consists of more or less rolled fragments of Danian fossils together with unrolled shells of Paleocene molluscs.[2·3·26·4] Then follow glauconite sand and arenaceous, grey-green marl; the latter, especially at the Vestre Gas Works of København, contains a very rich fauna, described by Mørch[5] and von Koenen[6], with *Corbula cfr. regulbiensis* Morr., *Dentalium rugiferum* v. K., *Turritella nana* v. K., *Scalaria Johnstrupi* Mørch, *Natica detrita* v. K., and *N. detracta* v. K., *Aporrhais gracilis* v. K., *Voluta nodifera* v. K. and so on. A similarly rich fauna is also found at Sundkrogen (the north harbour of København);[7,27] and it is also known from Lellinge at Køge, Hvalløse at Randers, Korup in Djursland and from numerous boulders.[8,9]

To Middle Paleocene may well be placed deposits which extend widely in Mid and West Sjælland, on Fyn (the cliff at Kerteminde) and in East Jylland (Jensgaard, Rugaard); they have in particular been found by numerous borings. They consist of almost non-arenaceous, grey marl with subordinate, hornstony beds and usually pass under the name of "Kerteminde Marl". The content of calcium-carbonate is rather variable; on an average it may be put at about 50 per cent. In the marl, sponge-spicula and foraminifera, as well as diatoms, are often met with; the shells of the latter are transformed into pyrite. Macroscopic fossils are rare as a rule, but from Rugaard, in particular, a rather rich mollusc fauna is known, which, besides numerous species from Lower Paleocene (especially *Lima testis* GRÖNW. (= *L. Geinitzi* v. HAG.) and *Pecten sericeus* GRÖNW.), contains *Discohelix Pingelii* MØRCH *sp.* and *Fusus cimbricus* GRÖNW.[10]

By means of many borings in Northwest Sjælland, on Fyn and in Jylland, there have been found above the Kerteminde Marl fairly thick deposits of grey, non-calcareous clay without fossils, and similar deposits appear on the north coast of Mors and at Rugaard south of Grenaa. They are overlain by the clay deposits with volcanic debris mentioned in the following. With some reserve they have been placed by USSING[11] to the Upper Paleocene; but, according to BØGGILD's[1] investigations, there is some possibility that this is a non-calcareous facies of the Kerteminde Marl.

## Eocene.

To this stage is placed Plastic Clay, with the appertinent "Mo Clay formation" and layers of tuffs. The total thickness varies somewhat (from 34 to over 165 m). It is not known how the boundary is between Paleocene and Eocene; but at Klitgaard on Mors there seems to be a smooth transition between the two stages.[1] By means of borings it has been proved that as a rule Eocene begins with a series of tuff layers alternating with clay layers; this subdivision of the Eocene is, however, best known from dislocated outcrops where the clay is substituted with diatom earth (Moler = Mo Clay). This deposit, which from early days has passed under the name of "the Moler formation", occurs fairly widely in the west Limfjord areas (Thy, Mors, Fur, Ertbølle) and has also been found at Mariager Fjord and Little Belt (Røgle Klint) and on Røsnæs (NW-Sjælland). At these places it has been subjected to great glacial disturbances and it is probable that it has nowhere retained its original position, but that —at any rate locally—it has been pushed by the ice up over Quartary deposits in the marginal moraines.[11]

The Mo Clay is a laminated deposit of white or light grey, rather argillaceous, diatomaceous earth with numerous beds of tuffs and volcanic sand, and concretions and beds of an impure, grey limestone ("cement stone"). Besides a few molluscs (*Cassidaria sp.*, *Valvatina raphistoma* Stolley) and a number of hitherto undescribed remains of Teleostei and some leaves (*Cocculites Kanei* Heer), this series contains a very rich flora of saltwater diatoms (species of *Coscinodiscus*, *Trinacria*, *Triceratium*, *Corinna*, etc.); remains of Dictyochids[12] are also found. In the Mo Clay itself the diatoms are more or less crushed, whereas they are particularly well-preserved in the cement stone. The volcanic beds have especially been examined by Ussing[11] and Bøggild[1]. They are formed partly of ash, partly of more or less firmly cemented tuffs. Most of the beds are basaltic and dark in colour; on the other hand some are andesitic or liparitic and light in colour. In each bed the size of grain decreases from the bottom upwards, from which it appears that each bed originates from a separate rain of ash, the grains of which, while sinking through the water, have been sorted according to size. The distance between the different beds varies greatly; in some cases double beds have been formed, two beds lying in direct contact with each other. By means of the varying thicknesses of the beds of ash, their mutual distance and petrographical structure, it has been possible to follow the different beds from one locality to another. It has furthermore been possible to divide the Mo Clay into two subdivisions, a lower, about 30 m thick, with 39 ash beds, which altogether only measure 0.62 m in thickness, and an upper one, about 27 m thick, with no fewer than 140 beds, the total thickness of which is 3.68 m. Volcanic tuffs, such as those found in the Mo Clay, are often met with in boulders here and there in Jylland and North Germany, and have also been found in numerous borings, some in Denmark (Skive, Wedellsborg in the western Fyn, etc.) and some in Holstein and North Hanover[28] as well as in outcrops in the environs of Hamburg and on Greifswalder Oie.[29] Strangely enough, not a trace of Mo Clay has been found in these borings, but it would seem as if this rock has there been replaced by Plastic Clay.

Above the Mo Clay follows a deposit of Plastic Clay, which in most instances is very red in colour. Like the younger grey Plastic Clay, it is extraordinarily rich and plastic and contains almost exclusively colloidal components; and yet the content of calcium-carbonate is oftenest greater than in the Younger Plastic Clay. In Plastic Clay on the whole ("Røsnæs Clay", "Little Belt Clay") concretions of clay-ironstone and barytes are not rare. Where this clay is exposed in cliffs, there are very often great slides (for instance in Røgle Klint). As long as it has not become dry it forms a fairly firm mass, and through drying it becomes almost as hard as stone. But if it again becomes moistened after drying, it readily softens into a more or less viscid porridge, absorbing water in great quantities. The fauna of the Plastic Clay is very sparse. In the lower, more frequently red subdivision, there have been found a number of hitherto unclassified foraminifera and a few brachiopods; but the most important is the discovery of a crab, *Plagiolophus Wetherelli* Bell, which indicates that this subdivision is contemporary with London Clay and must thus be placed to Lower Eocene.[13] This age-determination is proved to be correct by the rather richer fauna met with in similar deposits in North Hanover (near Hemmoor). Plastic Clay appears in cliffs particularly in Røsnæs and by the Little Belt. It has also been found by numerous borings in Northwest Sjælland, Southwest Lolland, the south Fyn islands, Northwest Fyn, East Jylland as well as at Frijsenborg (between Silkeborg and Randers) and Skive.

Borings have shown that the thickness of the Plastic Clay may be much more than 100 m. As the deposition of this extremely fine sediment must doubtless be taken as having proceeded at an exceedingly slow rate, it is justifiable to assume that the upper strata may be considerably younger than the lower ones. Unfortunately, the fauna, especially in the upper strata, is very poor and sheds only very little light upon the age. And yet the occurrence of an *Avicula*, which is presumably identical with the *A.* (*Aviculoperna*) *limaeformis* VINC. described from the Belgian Bruxellien, would seem to indicate that at any rate a part of the grey Plastic Clay which overlies the red may be placed to Middle Eocene. On account of the poverty of fossils it will certainly be very difficult to draw the boundary between this presumed Middle Eocene and the definitely determined Lower Eocene, nor is it possible at the moment to decide how great a part of Eocene is represented by the grey Plastic Clay. The marine deposit which, in this country, succeeds the Plastic Clay belongs to Middle Oligocene and, as Lower Oligocene must be taken to be represented by a lacuna, it is possible that this lacuna also comprises the upper part of the Eocene Stage.

## Oligocene.

Lower Oligocene deposits in situ are not known in Denmark. On the other hand a few boulders have been found at Katholm in Djursland, containing shells of *Melanopsis sp.* and *Cyrena* (*Corbicula*) *sp.*, but, in particular, numerous shells of *Paludina lenta* SOW.; on account of this fauna these boulders have by GOTTSCHE been classified as Lower Oligocene.[14] As the boulders must originate from a lacustrine deposit, there are grounds for supposing that during the transition from Eocene to Oligocene the marine series in Denmark has been interrupted by a regression, whereby at any rate a part of the country was raised above the sea.

To the Middle Oligocene may be placed a number of more or less arenaceous, oftenest rather micaceous and glauconitic clay deposits which are spread over a stretch from the environs of Aarhus to the northwest right up to Branden in North Salling (south of the Limfjord); on the east coast of Jylland they have been found locally northwards to Mariager Fjord and southwards to Odder. To the southeast (at Aarhus) these deposits are more sandy and are especially characterised by the occurrence of *Leda Deshayesiana* DUCH., which species becomes more and more rare towards the northwest (the valley of the river Gudenaa between Langaa and Bjerringbro) and finally (in Salling) completely disappears, while at the same time the deposits become less and less sandy and often contain calcareous concretions with an internal system of radiating cracks ("septaria"). On the whole our Middle Oligocene contains a rather rich fauna, which has been described by v. KOENEN,[15] RAVN[16] and HARDER;[17] in particular, a large number of molluscs have been found (*Nucula Chasteli* NYST, *Leda Deshayesiana* DUCH., *Cyprina rotundata* A. BRAUN, *Dentalium Kickxi* NYST, *Aporrhais speciosa* SCHLOTH. *sp.*, *Cassidaria nodosa* SOL., *Buccinopsis danica* v. K., *Fusus biformis* BEYR., *F. Waeli* NYST, *Pleurotoma Selysi* DE KON., *Surcula regularis* DE KON. *sp.* and so on). Of other animals may be mentioned a whale, *Squalodon* (*Microzeuglodon?*) *Wingei* RAVN.[18]

Upper Oligocene is represented by rich, glauconitic, dark clay deposits (Cilleborg and other localities at Mariager Fjord, Aarhus) and also by dark Mica Clay with spherical calcareous concretions (round Vildsund); it has also been found more sporadically on the east coast of Jylland south of Aarhus (Jensgaard south of Horsens Fjord, Albækhoved at Vejle Fjord). On Fyn it has been met with at Hindsgavl near Middelfart, and observations from borings seem to indicate that it has a rather wide extension in the southwest part of the island.[30] The fauna[16,17] is fairly rich in species, especially of molluscs (*Leda gracilis* DESH., *Limopsis Goldfussi* NYST *sp.*, *Meretrix splendida* MER. *sp.*, *Aporrhais speciosa* SCHLOTH. *sp.*, *Cassis Rondeleti* BAST., *Fusus Steenstrupi* RAVN, *Pleurotoma Selysi* DE KON. and *Pl. Duchasteli* NYST, *Surcula regularis* DE KON. and so on).

## Miocene.

In passing from Oligocene to Miocene the marine series is again interrupted, Lower Miocene only being known in a limnian facies. It occurs over the most of Mid-Jylland. There we have found alternating deposits of more or less Mica Clay and Sand which, unfortunately, seem to be quite devoid of fossils. Their thickness is often more than 30 m. In many places there are in these deposits found a small number (two to four) of Brown Coal seams and, in conjunction with these, the remains (leaves, fruits, etc.) of a rich flora. Particularly in mud-deposits, which directly underlie the Brown Coal seams, but also occurring elsewhere, these plant remains are met with, sometimes extremely well preserved and in great quantities (Silkeborg, Moselund). A number of years ago this flora was described by HARTZ;[19] besides numerous diatoms, it contains leaves and fruits of coniferous and foliferous trees (*Pinus Laricio Thomasiana* HEER, *Sequoia Langsdorfii* BRONG. *sp.*, *Hydrocharis tertiaria* HARTZ, *Laurus tristabiaefolia* WEB. etc.). The results of later, very comprehensive collections (especially at Moselund west of Silkeborg) have not yet been published. In several parts of Jylland (for instance by the Little Belt) deposits are met with which consist of ever-alternating, often laminated layers of more or less micaceous clay and sand, often with large quantities of bitumen or pieces of wood and sometimes accompanied by limonite layers, but without fossils. There is probably some reason for assuming that these are lacustrine or lagoon deposits and therefore they must really be placed under Lower Miocene.

With the Middle Miocene we again have our Tertiary developed in marine facies. These deposits consist of Mica Sand and Mica Clay, often in alternating beds. They are mostly and best known from various borings in Jylland (Viborg, Skive, Varde, Endrupholm etc.). Formerly they have been visible in the cliff at Skyum (Thy). On the other hand it is rather doubtful whether certain deposits occurring at Mariager Fjord and Ulstrup SW of Randers, of black, very sandy Mica Clay, may be placed to this group. It is especially from the boring in the market-place of Varde that the fauna of the Middle Miocene is known;[16] fifty-three molluscs were found (*Portlandia pygmaea* MÜNST. *sp.*, *Yoldia glaberrima* MÜNST. *sp.*, *Mactra trinacria* SEMP., *Dentalium mutabile* DOD., *Cerithium spina* PARTSCH, *Aporrhais speciosa* SCHLOTH. *sp.*, *Nassa cimbrica* RAVN, *Pleurotoma rotata* BROC. *sp.*, *Ringicula striata* PHIL., *Vaginella depressa* DAUD. etc.). Furthermore, the Middle Miocene is spread in the form of boulders over a large part of West Jylland; the localities of such boulders are, among others, Balling (in Salling), and Maade (at Esbjerg).[20] It remains to observe that GRIPP[22] and KAUTSKY[25] place some of the deposits here classified as Middle Miocene to Lower Miocene, but against this NØRREGAARD has raised objections.[24]

The marine facies is continued in Upper Miocene, which extends over West Jylland right from the environs of the Limfjord to the southern boundary of the country. Here we find deposits of greyish Mica Clay ("Astarte Clay") which at times is fairly rich, but most often rather sandy and often glauconitic. Round calcareous concretions, usually containing a crab shell, are frequently found in the clay. Fossils[16] often occur in large numbers (Skjærum Mølle near Vemb Station W of Holstebro, Esbjerg, Gram in North-Slesvig etc.). The most common form is *Astarte Reimersi* SEMP., but about fifty other molluscs have also been found (*Nucula Georgiana* SEMP., *Isocardia Forchhammeri* BECK, *Natica helicina* BROC., *Cassis saburon* BROC., *Fusus eximius* BEYR. and *F. distinctus* BEYR., *Dolichotoma cataphracta* BROC. *sp.*, *Pleurotoma turricula* BRUG. etc.). A few seal bones and a large number of whale bones have also been found; some of the latter have been classified by WINGE[21] as *Hoplocetus curvidens* GERV. and *Plesiocetus sp.* In conclusion may be mentioned carapace and bone remains of a large turtle of the family of *Sphargidae* (*Psephophorus sp.*).

## Pliocene.

With the Upper Miocene the marine Tertiary is brought to an end in Denmark. On the island of Sylt and several places in Holstein there have been found, over the Upper

Miocene Mica Clay, more or less kaolinitic sand with small pebbles which, by the fossils they contain, prove to have come from Silurian deposits. It is assumed that these pebbles have come from the Swedish Baltic area and that, in the Pliocene period, they have been brought to their present place by a river. WOLFF[23] has proved the presence of Silurian pebbles in similar sand deposits in Grejsdalen, near Vejle, which might indicate that these, too, are Pliocene river deposits. Nothing is known as to the further course of the river (or rivers) which has carried this material.

It is certain that the present surface of the Tertiary in Denmark is nowhere the original one. During the glacial period the ice planed off and removed the uppermost part of the Tertiary and this has frequently been exposed to pressures and overthrusts, so that the boundary plane between Tertiary and Quartary has often become most irregular. On looking at a geological map of the Prequartary of Denmark (see frontispice—Plate I) it will be noticed that—especially in Jylland—on proceeding southwest one meets on the whole younger and still younger deposits. The cause of this may be that the glacial erosion has been particularly severe towards the northwest and decreasing towards the southwest, and in that case there may, at the commencement of the Quartary period, have been a homogeneous covering of Tertiary deposits all over the country, possibly with marine Pliocene too. Various features seem to show, however, that there is another cause, viz. a gradually continued regression of the sea. This regression has at any rate begun before the end of the Cretaceous period and several times developed into temporary emersions, at least as regards some parts of the country. But it is perhaps not impossible that more profound, tectonic disturbances have been contributory.

*J. P. J. Ravn.*

# Literature.

## Abbreviations:

Dansk. geol. Foren. = Meddelelser fra Dansk geologisk Forening. København.
D. G. U. = Danmarks Geologiske Undersøgelse.
Vid. Medd. Naturh. Foren. = Videnskabelige Meddelelser fra Dansk naturhistorisk Forening i København.
Vid. Selsk. Skr. = Det kongelige danske Videnskabernes Selskabs Skrifter.

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# Quartary.

## Glacigenous Deposits.

The Glacigenous deposits consist of moraine deposits, accumulated by the inland ice itself, and of glaciofluvial deposits, accumulated by the meltwaters of the inland ice.

### Moraine Deposits.

**Moraine clay,** stony clay without stratification, is the glacigenous deposit that is of most importance. It occupies the greater part of the surface of the Danish islands, the eastern parts of Jylland south of Mariager Fjord and about the western parts of Limfjord, but is also to be found here and there in other places. In unweathered state it is as a rule blue-grey in colour. Its content of particles less than 0.002 mm (mostly argillaceous substance) is as a rule between 15 and 35 per cent.; occasionally it reaches up to 60 per cent. The remainder is mostly sand, gravel rarely forming more than four to eight per cent. The content of calcium-carbonate varies greatly, and is usually between 10 and 30 per cent. Of phosphoric acid there is about 0.1 per cent. The stones, boulders, in the moraine clay have their edges worn round, and their surface is scratched; the harder limestones especially, but also fine-grained granites, may have fine striæ. Through weathering the iron compounds of the moraine clay are oxydised, with the result that the colour first becomes yellowish, then reddish, the lime content dissolves and a part of the clay content is washed out so that the clay becomes more sandy. Under the influence of humic acids the moraine clay may become slightly podsolized.

**Moraine sand** has a clay content of less than 20 per cent.

It is sandy to the touch and so meagre that it is only very slightly plastic. In appearance it resembles moraine clay, from which it is not essentially different. Through weathering it becomes more podsolized than moraine clay, and the weathering goes much deeper than in the latter, but otherwise proceeds in the same manner. Moraine sand occurs particularly in West Jylland, in Vendsyssel and on Bornholm.

**Moraine gravel** contains so many stones that in all essentials it must be described as an accumulation of stones. The interstices between them are infilled with moraine clay or moraine sand. Moraine gravel only occurs here and there.

**Stony sand.** Fairly wide-spread over the surface occurs the so-called stony sand. As a rule it forms a cover, $\frac{1}{2}$ to $1\frac{1}{2}$ m thick, over other deposits. It lacks lime and most frequently clay too. There is no trace of stratification, but it contains scattered stones which, when the absence of limestones is disregarded, are of the same rocks as in the moraine clay; often, however, they are more rounded and sometimes appear to have been exposed to sanddrift. Stony sand occupies considerable stretches in West and North Jylland (Vendsyssel); on the islands it occurs more rarely.

Whilst moraine clay and moraine sand, and in many cases moraine gravel too, must be regarded as being the ground-moraine of the inland ice, the stony sand must be taken to be a surface-moraine; it is the quantities of sand, gravel and stones which have covered the surface of the inland ice close to the ice-margin. Whereas the ground moraine has been firmly compressed by the weight of the ice, the surface moraine is loose and incoherent; the finest components, clay and dust, have been washed away or blown away by the wind.

**Local moraines.** A moraine deposit may have developed in the form of a local moraine. In such cases it consists almost exclusively of older material, fragments of limestone, Tertiary clay or sand; local moraines of glaciofluvial gravel, sand or clay may occur too. In other cases it has appeared that the deposits under the ice have been folded or bent up into the overlying moraine, or that whole floes have been torn loose and carried away by the ice.

### Glaciofluvial Deposits.

Among the Quartary deposits, the glaciofluvial or meltwater deposits play an important part. They were deposited by the meltwater of the inland ice in under the ice-sheet, above the ice or on the land in front of the ice-margin. They consist principally of sand, to a much smaller extent of gravel or clay.

**Stratified sand and gravel.** In the gravel the stones are worn and rolled. It sometimes occurs as thick deposits of pebbles, but these are not frequently met with. In the sand are finer and coarser strata, usually with gravel beds between them, often deposited with false bedding. It plays a great part in the building up of the country and not uncommonly forms deposits of more than 30 m thick. In the eastern part of the country it is as a rule covered by moraines, in West Jylland it forms great heath-plains and occurs on the surface in many other places. Glaciofluvial sand and gravel are, in Danish geological literature, still often called Diluvialsand and Diluvialgrus (Diluvial gravel), which terms however are not applied to stratified sand and gravel deposited before the ice-edge in basins or in the form of heath-plains, these deposits being by some writers called lateglacial.

Where a mouldering of the dead vegetation is proceeding, the air having free access to it and bacteria and earthworms act upon it, the mould becomes rich in carbonic acid and this together with oxygen from the air penetrates with the percolating water down into the sand and has the effect that it weathers in the same manner as the moraine clay, but the weathering proceeds much deeper than in the latter. The colour becomes yellowish or brownish, the lime is washed out and the stratification disappears. At the boundary between the weathered and the unweathered sand there are irregular, wavy, narrow, brown stripes, formed by a slight quantity of mould and ferruginous matter deposited by the water. This is the common appearance of the sand below cultivated fields.

Conditions are otherwise in areas where the air only has little access to the dead vegetation, for instance in sandy districts with dense heather growth or in places where sun and wind have dried up the soil so that earth-worms cannot live and the earth does not become aired through their holes. In these areas a peaty bed of plant-remains, called »Mor«, accumulates. It hinders the passage of the air and the vegetation cannot moulder but is simply turned peaty, i. e. it is partly transformed into humic acids. These are carried down by the percolating water and dissolve all soluble matter in the sand under the Mor-bed, so that a typical Podsol formation results. The sand becomes a barren quartz-sand which, with a little intermixed humus, assumes a lead-grey colour, the so-called "Blegsand" (pale sand); it is most often about a quarter metre thick. The lowest portion of the Blegsand is often especially rich in precipitated Mor-particles and may thus become quite black, the so-called "Törveal" (peat hard-pan). The real hard-pan, "the brown hard-pan", which is found under the Blegsand, consists of sand which has been cemented by humus substances into a poorly cohering sandstone. When it is excavated and exposed to the air it quickly crumbles. It is often 1—2 dm thick, although sometimes it may attain to 1 m. At the top the hard-pan has a fairly horizontal plane against the Blegsand, whilst below it is less coherent and ramifies into the underlying sand. The hard-pan formation begins as a fine, brown skin, which deposits itself about the single grains of sand. The interstices between the grains are gradually infilled so that an almost compact mass is formed. Of the substances which the percolating water dissolves in the Blegsand, the iron compounds are again precipitated in the hard-pan and therefore this is usually ferruginous. In fact it is no rare occurrence that iron compounds form one of its principal components so that there arises a ferruginous sandstone which does not crumble in the air. As a rule it does not form strata, but nodules or cakes in ordinary hard-pan.

**Meltwater clay** is free of stones and, unweathered, it is blue-grey; through weathering it becomes yellowish. It weathers in the same manner as moraine clay. It always contains fine sand which is often deposited in thin layers, whereby the clay has assumed a handsome stratified appearance. The size of the sand grains rarely reaches 0.5 mm. Meltwater clay's content of particles of less than 0.002 mm (principally clay substance) as a rule exceeds 40 per cent. and does reach up to 60 per cent. in places. The content of calcium-carbonate is usually between 20 and 50 per cent. It often occurs in the form of fragment-clay, i. e. composed of small, angular clay fragments, of sizes between a nut and a hand, bounded by slickensides. Each clay fragment is stratified, but the stratification in the various fragments runs in quite different directions. Meltwater clay occurs in many places in the country, but mostly in small areas, which shows that it has been deposited in small lakes, to which the meltwater streams from the ice ran. In many places the meltwater clay occurs overlain by moraine clay or sand, in others it forms the surface and in such cases it is often possible to define the shores of the one-time lake in which it was deposited. Sometimes a part of the rim of the basin is missing; the lake has then been dammed by the inland ice or "dead" ice. Where the whole of the basin rim is missing, so that the meltwater clay occurs as a plateau, forming an isolated bank, this shows that the meltwater clay was originally deposited in a hollow in the surface of the inland ice itself or in "dead" masses of ice. The objectionable term "Diluvialler" (Diluvial clay) is still generally used in the Danish geological literature for meltwater clay.

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**Flow-earth.** In countries where the mean temperature for the year is below 0°, the earth remains frozen some distance down; it forms what the Norwegians call "tæle," or the Swedes "Käle" or "Tjäle." Even with a mean temperature of a few degrees of frost the tæle extends to a considerable depth, 150—300 m. In summer, only the uppermost 1—5 m thaw out. Where there is a tæle there is no ground water at all, and there are no springs. Rain and meltwater have to ooze away above the tæle. As a consequence of this and of the fact that the upper part of the tæle thaws, the earth over the tæle becomes quite saturated with water and the clay in it assumes a fluid consistence. If the terrain slopes, the earth moves slowly from the higher parts down into the lower ones; alternate freezing and thawing contribute to this.

That we have had tæle in Denmark in the glacial periods is not to be doubted. Earth-flow must have taken place to no small extent; but how is flow-earth recognised? By the survey of the interglacial Brørup bogs (p. 104) it was found that the peat strata in these are overlain by flow-earth, and thus an opportunity was given of studying it.

It was found that there was no sharp boundary between the underlying peat and the overlying flow-earth, but an insensible transition between mud with sand stripes, or muddy sand, and loamy, slightly muddy sand to moraine sand with scattered stones; or the peat might be rather pressed up, or occur like a breccia or form smears in the overlying clay and sand masses. The flow-earth itself is a sandy, moraine-like mass with scattered stones, locally argillaceous, at other places consisting of sharp sand, passing downwards into muddy sand. Beyond the hollow it passes into sand with very few stones, to finally—farthest out—become free of stones, stratified, distinctly water-sorted sand. The stones in the flow-earth increase in number inwards towards the edge of the hollow and up towards the surface. They may reach a size of up to 20 cm, indeed one quartzite measured 35 cm; but most of them are on an average no bigger than eggs or nuts. In most there is flint; it is sometimes sand-polished.

Flow-earth does not occur upon hill tops, but on slopes and in hollows. On the whole it resembles moraine sand, but can be distinguished from this by the fact that the scattered stones are not evenly distributed, but more numerous in towards the edge and up towards the surface. If there is a freshwater deposit under the flow-earth, there is as a rule a transition between them.

## First Glacial Period.

In Denmark it has so far only been possible to prove three glacial periods, corresponding to the last three of the four Alpine glacial periods. During the first two of these, the whole of Denmark was covered by ice; during the last one the inland ice only extended over the islands and the northern and eastern parts of Jylland.

Moraine clay (Moraine A) from the first of the Danish glacial periods, the Mindel Glacial Period (PENCK and BRÜCKNER), the Milazzian Glacial Period (DEPÉRET), the Saxonian Glacial Period (JAMES GEIKIE), sometimes occurs as "lower" moraine in West Jylland. This moraine clay has been definitely proved at Esbjerg as the substratum of the Yoldia Clay which occurs there and which was deposited in the beginning of the first of the two Danish interglacial periods, and at Tvile, Kalsgaarde and several places on the map-sheet Varde as the substratum of a thick deposit of meltwater clay which is widely spread in Southwest Jylland and which was deposited in the same period as the Yoldia Clay at Esbjerg. This moraine clay is described by AXEL JESSEN[1] as dark grey, very hard and sandy and containing fewer large stones, but much more small stones and fine gravel than moraine clay in general. The content of calcium-carbonate is less than 10 per cent. In situ in the moraine clay, underlying the Yoldia Clay at Esbjerg, a rhombporphyry has been found. It is the only indicator-boulder taken in situ in this moraine.

As an objective method of separating the various moraine deposits, stone-counts[2] have for a number of years been employed by Denmark's Geological Survey. Ten kilogrammes of air-dried moraine clay are washed through a sieve with quadratic meshes, the sides of which are 6 mm. Of the stones which remain in the sieve, the few which are greater than a hen's egg are removed. The remainder are weighed, determined, counted, and the percentage of the various rocks is calculated. Then the coefficient of the stone-count is worked out, this being the number of flints divided by the number of eruptives + crystalline schists. This coefficient has proved to be approximately the same for stone-counts made in the same moraine clay deposit in the same area. From the stone-count coefficients is worked out the mean number and the probable mean error of this. This gives a figure which characterises the particular moraine in the area concerned.

By applying this method to Moraine A at Esbjerg and at

Tvile, 0.55 was found as the mean number of seven stone-count coefficients; the probable mean error of this figure is 0.035.

Moraine A has also been found in Røgle Klint, at Strib in Fyn (see pag. 97). In this dislocated cliff, which is very important in a geological sense, the series is as follows:

10. Moraine D.
9. Glaciofluvial strata.
8. Moraine C.
7. Moraine B.
6. Glaciofluvial strata.
5. Tellina clay.
4. Glaciofluvial strata.
3. Moraine A.
2. Upper Oligocene Mica Clay and Mica Sand.
1. Eocene Plastic Clay (Little Belt Clay).

Here the Moraine A has a thickness of 5—6 m. It is blue-black or black-brown in colour and in places contains numerous sand smears. 0.36 was found as the mean number of eight stone-count coefficients; the probable mean error of this figure is 0.044.

There is not sufficient material as yet in Denmark to judge of the directions of the ice movement in the First Glacial Period; but, in the countries south and southwest of Denmark, this can be cleared up. It must be regarded as being established, especially by the comprehensive studies of V. Milthers[3.4.5] of the occurrence of the various indicator-boulders, both in these countries and in Denmark, that Denmark was first covered by ice from East Norway and West Sweden and then by ice from the Baltic.

*Victor Madsen.*

## First Interglacial Period.

The few marine and freshwater deposits which we can with certainty place to the First Interglacial Period (Mindel-Riss Interglacial, Penck & Brückner, Tyrrhénian Interglacial, DEPÉRET) give us only little knowledge of the distribution of sea and land in this period and practically no information as to the terrain forms.

## Marine Deposits.

To this interglacial period belong, first and foremost, the so-called Esbjerg Yoldia Clay and the Tellina Clay in Røgle Klint, and also the marine deposits at Vognsbøl near Esbjerg and a few other places in Southwest Jutland.

Between Esbjerg and the village of Maade, $2\frac{1}{2}$ km east of Esbjerg, there occurs a marine clay[1] in its original position; its full thickness is not known, but it is at any rate over 12 m, decreasing in thickness towards the sides. It has been given the name of "Esbjerg Yoldia Clay," which is not very apt, as *Portlandia (Yoldia) arctica* only occurs in the lowest part of the deposit. The lowest part of the clay is rich in mica and also contains a number of sand layers; higher up the sand layers become more subordinate and the various clay layers thicker; but at the top the clay again becomes more arenaceous and passes into a deposit of dark, argillaceous marine sand. The marine deposits contain only few stones. In the western sections the deposits are to be seen overlying moraine clay, with the surface of which the sand layers are conformable. The moraine clay, which especially in its lower part is very much mixed with mica clay, overlies Miocene Mica Clay which, both to the west, in Esbjerg, and to the east, at Maade, reaches up over the sea. The stratification of the marine clay and the sand layers dip to the east in the western part of the area, to the south in the middle of the area (at Gammelby) and, in the Brickworks' pits out by the shore between Gammelby and Maade, to the west. It is not known with certainty how far the deposits extend, but at any rate they continue some way in under the edge of the high land to the west and north and, to some extent, to the east. The borings so far made in Esbjerg town have not definitely proved the "Yoldia Clay," but, in a boring made in 1927 at the Esbjerg Cooperative Pig Slaughteries, there were found, below 20 m of glaciofluvial sand, marine clay and sand layers with a few shells to a depth of about 67 m, resting on moraine sand and, below that, mica clay. This series shows that we have here to deal with the Esbjerg Yoldia Clay. Over a large part of the area the marine deposits lie so to say exposed, or they are simply covered by marsh and freshwater alluvium; but a part is also covered with a real glacigenous deposit: glaciofluvial sand with more or less folded strata, argillaceous, in places with a moraine character or containing large boulders. As the inland ice did not stretch so far to the west during the last glacial period, this glaciofluvial deposit overlying the marine deposits must be placed to the last but one (the second) glacial period.

Scattered about in the marine clay, and locally in the marine sand, shells have been found of in all 12 species of molluscs.[6] As the shells, though crushed, have all their pieces lying in situ, and as the mussels have their shells closed, the animals must have lived on the spot. Fairly evenly distributed in the deposits are *Tellina calcarea*, *Saxicava arctica* (in its arctic, thick-shelled form) and *Mya truncata*; *Leda pernula* and *Astarte Banksii* with *var. Warhami* are also common, although these two species are principally limited to definite, not very thick zones in the clay. In the lower part of the clay there occurs the stenothermous, high-arctic mussel *Portlandia* (*Yoldia*) *arctica*, whilst at the top of the clay and in the overlying sand are shells of *Mytilus edulis* and *Modiola modiolus*, which cannot live in high-arctic seas. These facts show that the temperature of the water during the deposition of the marine deposits must have changed from pronouncedly arctic to boreoarctic, perhaps boreal, and that the marine deposits thus belong to the beginning of an interglacial period; certain features indicate that the originally upper part of the marine deposits has been removed by the inland ice which later on advanced over them.

The marine deposits which have been found by marl diggings northeast and east of this area have probably been formed in close connection with the Esbjerg Yoldia Clay; these are at Skads church, Smørpyt, Sadderup, Solbjerg and Sneum

Gaard;[1] a deposit of marine clay at Terpager east of Esbjerg, in which only the shells of *Nucula* have been found, probably belongs to this group too.

In several borings near to each other at Vognsbøl, 2 km northwest of Esbjerg, there have been found, under glaciofluvial deposits which cannot be younger than the last but one glacial period, marine clay and sand overlying a glacigenous deposit.[7] The stratigraphical position is, however, so irregular that the marine strata are scarcely in their original position; on the other hand the comparatively good state of preservation of the mollusc shells found in the strata indicates no long or violent transportation. Among the 35 species found are a number of arctic species which are widely spread under various conditions of temperature (but no really high-arctic species); but in particular the boreal and lusitanian forms must be emphasised: *Cyprina islandica, Zirphaea crispata, Aporrhais, Mactra elliptica, Anomia squamula, Litorina litorea, Cardium edule* and *Pholas candida*. There seems to have been a certain amount of sorting, the lusitanian species only appearing in the upper strata. Thus in a climatological sense the Vognsbøl fauna forms a continuation of the Esbjerg fauna, and therefore it may be that the dislocated deposits at Vognsbøl were originally formed in conjunction with and in continuation of the Esbjerg deposits.

On Indre Bjergum Bank, west of Ribe, two borings at a distance of 300 m from each other have revealed a marine formation about 26 to 66 m under the sea.[8] From only one horizon (about 52 m under the sea) have shells been collected: *Leda pernula, Limopsis sp., Mytilus edulis, Cardium fasciatum, Cyprina islandica, Mactra elliptica, Syndesmya alba,* and many others; in other words, a northern boreal fauna. It is true that it has not been established whether the deposit is in situ, or whether it is only a loose floe; but as it is separated by considerable deposits of moraine clay and glaciofluvial sand from the overlying Eem deposits from the last interglacial period, which deposit has conserved its original stratigraphical position, whereas on the other hand it lacks all traces of preglacial elements, it is reasonable to place this deep-set deposit to the First Interglacial Period; in that case it is, for the present, the only known place in Denmark with marine deposits from both interglacial periods.

The Tellina Clay in Røgle Klint occurs in the dislocated parts of the cliff among the other glacial deposits in such a manner that there is no doubt that its place in the Quartary series has been preserved. It is a rich, micaceous clay which, especially at the bottom, is so full of sand layers that there seems to be a smooth transition between the marine sediments and the underlying glaciofluvial sand and clay strata; these again rest conformably upon a meagre moraine which, both by its stone content (low stone-count coefficient) and its content of mica clay (Oligocene), very much resembles the moraine which lies under the Esbjerg Yoldia Clay, although this resemblance cannot be said to definitely determine its age.

Overlying the Tellina Clay are two moraines (B and C, see pp. 97 and 109), whose stone-count coefficients correspond so closely to those of the two surface moraines east and west of the last glaciation boundary in Jylland, that we may consider the Røgle moraines as being identical with these and thus each belonging to its own glacial period, the last but one and the last, regardless of the fact that no interglacial deposits have been found between them in Røgle Klint. Consequently, the Tellina Clay must be placed under the first interglacial period.

Mollusca have been found here and there in the clay of: *Tellina calcarea*, *Saxicava arctica*, *Mya truncata* and *Modiolaria laevigata*, an arctic fauna that is no doubt poor, but still of such a nature that it must be presumed that the sediment was deposited in an arctic fiord of considerable salinity, but also with an abundant supply of mud (Cf. the conditions at the bottom of Nordre Strømfiord in West Greenland, where it is exclusively the tremendous quantities of mud washed out by the meltwater rivers which have put an end to the development of animal life).[9,10]

Besides the deposits so far dealt with, there are, in many parts of the Pleistocene, marine sediments of greater or smaller extent and with more or less destroyed stratification.

The fauna is in part arctic and partly boreal, with a more or less strong lusitanian stamp. Some of these deposits in all probability have preserved their original stratigraphical position, for instance the marine deposit at Hostrup in Salling (NW Jylland);[26] others are undoubtedly isolated floes.

At Hostrup[26], under a 4—5 m thick bed of moraine clay, which must be regarded as belonging to the Last Glacial Period, there are two or three metres of marine sand, almost horizontally stratified, with shells of *Mytilus sp.*, *Leda pernula*, *Cyprina islandica*, *Axinus flexuosus*, *Tellina calcarea*, *Saxicava arctica*, *Mya truncata* and *Litorina litorea*; under this about 4½ m of indistinctly horizontally stratified marine clay with shells of *Astarte Banksii*, *Modiolaria discors*, *Tellina calcarea* and *Saxicava arctica*. The depth at which the clay strata must be considered as having been deposited has been calculated at 15—150 m; the sand strata have been formed in ground water. The temperature during the deposition of the clay strata is considered to have been between—2° and 6° C., and during the deposition of the sand between 0° and 10° C. The marine deposits lie conformably over Miocene Mica Clay, which must be regarded as being in situ. On account of the height of the deposits above sea-level (27 m) and because they lie higher than large parts of the heath-plains from the Last Glacial Period, it is assumed that the Hostrup strata must be very old in comparison with the greater part of the Pleistocene in Denmark.

*V. Nordmann.*

### Freshwater Deposits.

To the First Interglacial Period have been placed some interglacial lake deposits[11] which lie outside the Main Stationary-line of the last glaciation in Jylland and which are overlain by glacigenous formations of the Second Glaciation. These are particularly the occurrences of calcareous mud at Rind, south of Herning and at Harreskov, near to Kibæk Station. The lake deposits at Starup, east of Varde, most of them calcareous, likewise belong to this. These are overlain by late-

| Stages | Character of flora | | | Zones | Climatic conditions | Changes of level | | |
|---|---|---|---|---|---|---|---|---|
| **Second Glacial Period (Riss)** | | | | | | | | |
| | Lacuna | | | | | | | |
| III | Northern flora | | *Betula pubescens, Pinus silvestris* | k | Continental climate gradually cooler | Changes of level not particularly known in Denmark | in Holstein | Emergence? |
| II | Temperate flora, mostly | Coniferous forest | *Pinus silvestr.* predominating, 2. Maxim. of *Picea excelsa* *Betula pubescens* frequent | i | | | | |
| | | | *Pinus silvestr.* predominating, 1. Maxim. of *Picea excelsa*, mixed oak forest species disappearing | h | | | | |
| | | Woods of Foliferous trees | [*Carpinus betulus* Zone, not established] | [g] | Atlantic temperature optimum | | | Submergence? |
| | | | Oak mixed forest Zone *Pinus silvestris* and *Betula pubescens* in minimum | f | | | | |
| | | Coniferous forest | *Pinus* and *Betula* decreasing. *Ulmus*-maximum | e | Continental climate gradually milder | | | |
| | | | *Pinus* predominating, mixed oak forest species immigrate | d | | | | |
| | | | *Betula pubescens* predominating, *Pinus silvestris*, *Picea excelsa* traceable | c | | Emergence | Vognsbøl deposits | |
| I | [Subarctic and arctic flora, not established] | | | [a, b] | Melting | | Esbjerg Yoldia Clay | |
| **First Glacial Period (Mindel)** | | | | | | | | |

Table showing development of flora, climate and levels in Denmark during the First Interglacial Period.

glacial meltwater sand, but their age is determined by the fact that they overlie, without any intermediate lacuna, glaciofluvial clay whose position in the series must be assumed to be between the two ground moraines that are known from West Jylland.[1] Some peat strata, lying very deeply at Tirslund and Vejen between Esbjerg and Kolding, must also be assumed to originate from the First Interglacial Period. These deposits bear witness of a floral and climatic development very similar in nature to that which took place in the second stage of the Last Interglacial Period (see p. 105). The main points of this development have been drawn up in the table on p. 94.

Whilst the age of the aforementioned deposits is determined by their stratigraphical position, we are met, to the east of the extreme boundary of the last glaciation, by a number of fossiliferous, diluvial, lacustrine deposits which are overlain by or are interbedded in the youngest glacigenous deposits and whose age can therefore only exceptionally be established by their stratigraphical position. A group of these, which besides a pronounced mollusc fauna also contains Tertiary plants in certain cases, is undoubtedly older than the Last Interglacial Period, and has even been considered to be preglacial.[11,22,13] This particularly applies to the Amber-twig-beds (Rav-Pinde-Lag) at København. They occur as subordinate beds of only a few cm in thickness, in glaciofluvial sand and contain quantities of plant-remains washed together, such as charcoal, wood, fruits and seeds of about 60 different plant-species, among which, besides Tertiary species, are especially numerous pleistocene species, for instance *Brasenia*, *Carpinus*, *Stratiotes*, *Aldrovanda*[14] etc. The same age as the Amber-twig-beds is also ascribed to the deeply situated lacustrine deposit at Førslevgaard in South Sjælland, whereas some mud blocks enclosed in the moraine clay at København as well as the Nematurella Clay at Gudbjerg in SE-Fyn, more probably belong to the First Interglacial Period.[15] The fauna in the mud blocks, the deposit at Førslevgaard and the Nematurella Clay are characterised by the following old-diluvial forms: *Nematurella runtoniana* SANDB. *f. stenostoma* NORDM., *Corbicula fluminalis* MÜLL., and *Pisidium astartoides* SANDB.[16]

We have no means of more definitely determining the age of others among our interglacial, lacustrine deposits which are overlain by our youngest moraine. This applies to the technically exploited deposits of diatom earth at Hollerup SW of Randers, which rests upon calcareous mud, similar deposits at Hørup north of Viborg and Egtved SW of Vejle, the similarly exploited ochre bed at Løvskal W of Randers and the loose floes of diatom earth and calcareous mud at Fredericia.[17] The flora and fauna of these deposits exactly correspond with those known from the lacustrine deposits of the Last Interglacial Period.

*Knud Jessen.*

## Second Glacial Period.

Moraine clay and moraine sand (Moraine B) from the Second Glacial Period, the Riss Glacial Period (PENCK & BRÜCKNER), the Tyrrhenian Glacial Period (DEPÉRET), the Polandian Glacial Period (JAMES GEIKIE), occur in the surface of the hill-islands in West Jylland, and some of the "lower" moraines which are found in the area occupied by the inland ice in the Last Glacial Period in North and East Jylland and on the Islands, may be moraines from this glacial period.

The nature of the surface moraines of the hill-islands (see p. 154) may vary very much. Thus AXEL JESSEN,[1] on the moraine deposits in the area northeast of Esbjerg, says that they occur in all variations from meagre moraine sand to typical moraine clay and on through very rich, almost stoneless moraine clay to local moraines of stoneless clay. In the same clay wall may be seen both moraine clay and moraine sand, sometimes in alternating strata. Where the thickness of the moraine sand is great, it is, as a rule, distinctly bedded.

The surface moraines occur in a similar manner on the other hill-islands, but as a rule moraine sand and arenaceous moraine clay predominate over the normal moraine clay.

In an area along the west coast of Jylland between Esbjerg and Brøns, with a breadth of about 20 km, the moraine clay suddenly becomes rich in chalk and flints; sometimes it is closely spreckled with pieces of chalk. Presumably the cause is that a chalk horst projects here, up through the Tertiary deposits, as is the case north of Hemmingstedt in Holstein; otherwise it is difficult to understand where all the chalk found in the moraine clay here has come from. The 32 stone-counts made in this area have given 1.44 as the mean number of the stone-count coefficients, with a mean error of 0.103. The 92 stone-counts made outside this area in Moraine B, from the Danish frontiers northward to a line Varde—Grindsted, have resulted in a mean number of coefficients that is not a little lower, viz. 0.87, with the mean error 0.042. A rather lower mean number is arrived at when it is calculated solely upon the 32 stone-counts made on the map-sheets Varde and Bække, viz. 0.84, with mean error 0.057.

In Røgle Klint at Strib on Fyn, Moraine B attains a thickness of about 23 m. It consists at the bottom principally of grey-brown, arenaceous moraine clay; there are beds to which mica-clay has obviously supplied much material. In the upper part, Moraine B is sometimes blue-grey and much richer; it may contain beds and parts of stoneless clay, sand and gravel. The difference in consistence between the upper and the lower part of Moraine B is also reflected in the stone-count coefficients. In the lower part, $B_1$, 0.50 has been found as the mean number of 7 calculations, with a mean error of 0.049; in the upper part, $B_2$, 0.82 is the mean number of 30 calculations, with a mean error of 0.026.

The close conformity between the mean number for Moraine $B_2$ in Røgle Klint and that for Moraine B in West Jylland, especially on the map-sheets Varde and Bække, shows that these two moraines must be contemporaneous; the Tellina Clay in Røgle Klint must thus be contemporaneous with the Yoldia Clay at Esbjerg, and the moraine in Røgle Klint that is older than the Tellina Clay must be Moraine A.

On the most northerly hill-island, the big Skovbjerg hill-island, Milthers[3] has shown that the Norwegian indicator boulders which otherwise are almost the only ones occurring on the hill-island, suddenly decrease rapidly in number southwards at the line Fiskbæk—Finderup, NNE of Skjern. Southwest of this line, and southwards to the Danish frontier, there is an abundance of Baltic indicator-boulders on the moraine surfaces. This is also shown by AXEL JESSEN's, MILTHERS' and NORDMANN's researches on the geological map-sheets Varde, Bække, Ribe, Vamdrup and Tønder.

MILTHERS interprets this in this way: that the boundary between the occurrence of the Norwegian boulders in large numbers and the rather numerous occurrences of Baltic boulders is the limit of an ice-sheet which has advanced to this area from NNE over the line Holstebro—Herning, but not to the line Ringkøbing—Borris, and which has spread out over a moraine of Baltic origin. As in several places in West Jylland, under the Baltic moraine, there is glaciofluvial gravel the indicator-boulders of which are almost exclusively Norwegian, but hardly ever Baltic,[1] and as in Moraine B, which by the "gas-boring" on Skærumhede was found under the marine Skærumhede series (p. 101), there were only found Baltic boulders,[20] it must be concluded that, in the Second Glacial Period, ice from Norway and West Sweden first spread over Denmark, then ice from the Baltic advanced, bringing with it Baltic boulders and spreading them over the whole of Jylland, to the north over the whole of Vendsyssel as well and to the north-west over the whole of Thy; later on, ice again advanced from NNE, extending southwards to the aforementioned boundary at Skovbjerg hill-island. AXEL JESSEN,[1] however, has come to the conclusion that the ice from NNE reached still further south, because on the surface of the northern part of the Varde sheet the Norwegian boulders are present in greater numbers than the Baltic. A ridge at Thorlund, Krusbjerg Ridge NE of Varde,[1] and Horns Reef in the North Sea,[21] are interpreted by AXEL JESSEN as marginal moraines deposited by this ice-sheet.

*Victor Madsen.*

## Second Interglacial Period.

The Second (last) Danish Interglacial Period corresponds to the Riss-Würm Interglacial Period (PENCK & BRÜCKNER), the Monastirian-Interglacial Period (DEPÉRET). As regards this interglacial period, the many occurrences of marine deposits, especially the Eem deposits in Southern Denmark and the deposits of the Skærumhede series in Vendsyssel, the northern part of Jylland, give some idea of the distribution of sea and land, of the levels and of the changes in climatic conditions.

From the southerly part of the present North Sea area the waters of the Eem sea[22] made their way in over large parts of West Slesvig and, by means of several comparatively narrow straits, were connected with a large inland sea which on the whole occupied the position of the present Baltic Sea from East Slesvig to West and East Prussia. The rich fauna which has been found in the Eem deposits on the peninsula of Broager in East Slesvig indicates a relatively great salinity and it must therefore be presumed that the inland sea has had other connections with the ocean than the above named narrow straits between the hill-islands of West Slesvig.

During a rather later section of the interglacial period, North Jylland subsided and a part of Vendsyssel was covered by a sea which, at the beginning, was temperate but ended by becoming high-arctic.[20]

The occurrence of peat-bogs and other lacustrine deposits[11] give us some information as to the relief of the country, as also the West Jylland hill-islands and heath-plains show where there has been high land and where there have been depressions, even though the original terrain-forms of the hill-islands have, in the long period which has elapsed since their formation, become greatly changed as to details. But what is more, there is good ground for believing that the Jylland streams, which run into the North Sea, at any rate for the most part follow interglacial river beds; indeed, it may be that the situation of some of the tunnel-valleys formed during the last glacial period was determined by the interglacial streams, for instance the tunnel-valley which runs from Tørring, W of Horsens to the northwest and in which the rivers Skjern Aa and Gudenaa have their sources.[23]

## Marine Deposits.

Two important groups of marine deposits belong to the Second (last) Interglacial Period, viz. the Eem deposits and the Skærumhede series. The first group, the Eem deposits,[8,22] has the widest spread, its deposits occurring along the coast of Belgium, in Holland, on the Friesian Islands, in West and East Slesvig, in West and South Fyn and on the islands to the south of Fyn, as well as in West and East Prussia. In Denmark they occur undisturbed in West Slesvig, whereas in the other Danish localities they are more or less disturbed and appear now as more or less dislocated parts (Ristinge Klint at Langeland, the east of Ærø and the east coast of Broager, Slesvig), now as more or less detached floes or smears in the moraine, or they have been so much destroyed that only more or less rolled shell fragments are to be found, secondarily embedded in glaciofluvial sand and moraine clay (Sjælland, Fyn, the east coast of Slesvig).

The Eem strata are to be found completely developed and best preserved in the only slightly dislocated Gammelmark Klinter (Stensigmose)[22] on Broager: overlying a series of interglacial lacustrine strata (peat, sand and gravel, lacustrine clay), which are closely connected with the marine Eem deposits, there is first a brackish water zone with *Hydrobia ulvae*, thin-shelled *Cardium edule* and *Syndesmya* (*Lutricularia*) *ovata*, then a zone of muddy clay deposited in comparatively shallow water (Mytilus zone), then a deposit of pure clay from deeper water (Cyprina zone; the latter two zones were formerly together called Cyprina Clay), then a deposit of clay which becomes more and more sandy upwards, and finally a pure sand deposit (Tapes Sand) with a rich fauna, principally of shallow-water species.

Numerous borings in West Slesvig have shown that the Eem deposits occupy a level that is on an average 10 m below the sea, that they lie undisturbed upon moraine clay and glaciofluvial sand and that they are only overlain by glaciofluvial sand of the Last Glacial Period and by alluvial deposits. As a rule the Eem deposits begin at the bottom with gravel and sand, then become muddy or clayey, then clay and conclude—where the later erosion has not been too severe—with sand. Thus the Eem deposits were formed during the course of a submergence with subsequent emergence, but the fauna shows no sign of a change of temperature in all this time. The fauna is markedly lusitanian; the northern species which appear in it are such as have a wide diffusion. The fauna is partly characterised by a variety of the extinct *Tapes senescens*, which is generally diffused in these deposits, partly by a definite little company of southern species: *Lutricularia ovata*, *Gastrana fragilis*, *Mytilus lineatus*, *Lucina divaricata*, *Haminea navicula*; there are also numbers of other southern and boreal forms which occur in the recent North Sea or in the Cattegat.

The marine Skærumhede series[20] is known from a deep boring for natural gas at Skærumhede, about 10 km west of Frederikshavn in Vendsyssel. The boring was made in a valley and here, under 57 m of glaciofluvial deposits from the Last Glacial Period, were found marine deposits with a total thickness of 123 m, resting on moraine clay and glaciofluvial sand and gravel, with fragments of *Portlandia arctica* and other arctic molluscs. The marine series for the most part consists of clay; only in its upper part are there strata or irregular parts of sand and rolled gravel, which will be referred to later. The clay contains numbers of more or less well preserved shells of molluscs, of which 81 species could be identified. There were 36 arctic species, 22 boreal and 23 lusitanian, so distributed in the series that they reflected a climatic change from boreal, through boreoarctic to high-arctic conditions.

In the lowest part, the Turritella terebra zone, 74 m thick, were found 22 lusitanian, 18 boreal and 16 arctic species; among the most commonly occurring were: *Cardium fasciatum*, *C. echinatum*, *Leda pernula*, *L. minuta*, *Abra* (*Syndesmya*) *prismatica*, *A. alba*, *A. nitida*, *Mya truncata*, *Turritella terebra* and *Eulimella Scillae*. Among the species which characterise the temperature maximum were: *Nassa reticulata* and *Mangelia brachystoma*, which in the present time are not found further north than by the Norwegian west coast about Bergen. These species are neither found in the very lowest nor the uppermost strata of the zone, and thus the temperature maximum of the whole Skærumhede series is to be found some way up in the Turritella zone.

The next zone—the Abra nitida zone—only has a thickness of $8\frac{1}{2}$ m and contains 10 arctic and 3 boreal species, but no lusitanian; the fauna must therefore be described as boreoarctic. The most commonly occurring are: *Leda pernula*, *Mya truncata*, *Cardium fasciatum* and *Abra nitida*; the latter two are characteristic of the temperature conditions of the zone. *Cardium fasciatum* has its present northern boundary at North and East Iceland and the Murman coast, *Abra nitida* extends to East Iceland and Vadsø, in Norway.

The Abra nitida zone is connected, by a smooth transition, both downwards with the Turritella zone and upwards with the third zone, the Portlandia arctica zone. In this 40 m thick zone have been found 25 arctic and 2, possibly 4 boreal species, but no lusitanian. Among these species *Saxicava arctica*, *Mya truncata* and the high-arctic *Portlandia* (*Yoldia*) *arctica* are the most common; besides the latter, *Kennerleya glacialis*, *Cardium ciliatum*, *Lyonsia arenosa*, *Axinopsis orbiculata*, *Turritella erosa*, *Rissoa scrobiculata* and *R. Jan-Mayeni* determine the temperature conditions, which are purely arctic, in fact with a distinctly high-arctic stamp. This is determined by the fauna which actually belongs to the clay. But in the parts of sand and gravel referred to in the foregoing, quite another fauna is found with a distinct boreal character and characterized by *Zirphaea crispata*, *Mytilus edulis*, *Cyprina islandica* and *Bittium reticulatum*. This fauna obviously cannot have lived simultaneously, side by side with the arctic fauna just referred to, and therefore must be lying on a secondary position. The explanation must be that the sand and gravel with the boreal fauna are shore deposits corresponding to the more deeply situated deposits of the Abra and Turritella zone, shore deposits which have been disturbed by the advancing inland ice during the formation of the Portlandia zone and carried by icebergs farther out to sea.

The boreal species characteristic of all three zones: *Bela incisula*, which begins to appear a little above the middle of the Turritella zone and disappears in the lower part of the Portlandia zone, is worthy of special attention. It is a small gasteropod which has not been found as a fossil at any other place in Scandinavia; in the present time it is not known from

European waters, but only from the boreal and boreoarctic zone by the east coast of North America, from Rhode Island to Umanak in West Greenland, and from the Bering Sea. —Despite the peculiar circumstance, which has not yet had any satisfactory explanation, that the Skærumhede series at the bottom begins with a rather deep-water deposit (as both the sediment and the fauna show), with no transition to the underlying moraine clay in the form of sand or another shallow-water deposit, there is no sufficient reason for doubting that the whole of this thick deposit lies in its original position in the Quartary series.

Whereas the Skærumhede series as a whole is only known from this boring, its uppermost zone has long been known under the name of "Older Yoldia Clay." It has been found at several places in Vendsyssel[24,25] and may be seen in shore cliffs, in marl and brickworks' diggings, often as detached floes or fragments or rubbed out. Both at Hirshals north of Hjørring and in the lowland north of Frederikshavn it is found close to the surface, covered by the alluvial shore deposits of the Tapes Period. As not only the original covering of glacigenous formations, but also the uppermost parts of the Portlandia zone have been eroded away, the stones which were originally embedded in these strata are washed out and concentrated, often like a dense stone covering on the surface of the marine clay.

Embedded in or between the glacigenous deposits there are, in several places, remains of marine sediments which probably belong to the Last Interglacial Period, for instance the Tellina calcarea Clay at Høve, in Odsherred on Sjælland[27] (contains only *Tellina calcarea* and *Nucula tenuis* and is probably arctic) and the clay at Skambæk Mølle, Røsnæs on Sjælland (containing five species, all lusitanian).[22]

The detached floe of marine clay with boreal fauna, found in the moraine clay at Selbjerggaard,[20] Hanherred in the northern part of Jylland, undoubtedly belonged to the Abra or Turritella zone of the Skærumhede series; but whether the so-called "Cyprina Sand"[22] in Møens Klint is to be placed in the Skærumhede series or, perhaps rather in the Eemian, can scarcely be decided. The fauna contains boreal and lusitanian species, but none of those especially characteristic of the Eemian; the stratigraphical position, which is the original, shows, that the deposit belongs to the Last Interglacial Period.

*V. Nordmann.*

## Freshwater Deposits.

Numerous interglacial bog and lake deposits,[11] which were first discovered in the environs of Brørup station in South Jylland, west of the last glaciation boundary in Jylland, belong to the Last Interglacial Period.[13] They consist of peat, mud, clay and sand strata, in undisturbed stratigraphical position and overlain by washed out material and flow-earth (clay and sand with or without stones) from the Last Glacial Period, but never by glacigenous deposits.[28] The strata covering the bogs attain a thickness of from about two to about eight metres, whereas the interglacial series may have a thickness of more than 17 m. The subaerial denudation in the Last Glacial Period, which brought about a transportation of sand and clay from the higher terrain down over the bogs of the preceding interglacial period, did not as a rule quite succeed in filling up these basins, which still appear as faint depressions in the terrain, without outlet.

Thus the interglacial orography of West Jylland may still be traced to a certain degree in the present surface forms.

These interglacial fresh-water deposits west of the last glaciation boundary are divided according to their stratigraphical development into two groups, viz. deposits of the Brørup type, which only display one temperate horizon, and deposits of the Herning type, which comprise lake and bog deposits with two temperate horizons separated by a subarctic intermediate bed. The series of the Brørup bogs corresponds to the lower part of the Herning type's profile. This type has been established in the district at Herning and has later been found at Brørup Station, at Rodebæk (E of Varde) and at several other places; it illustrates the complete course of the Last Interglacial Period; cf. Table on p. 106.

Apart from these deposits west of the last glaciation boundary, certain fresh-water deposits which lie just to the east of it must also be placed to the last Interglacial Period. This is particularly true of the lacustrine deposits lying in their original stratigraphical position under late-glacial terrace-sand at Ejstrup Station, west of Kolding,[13] as well as a bog at Rostrup, west of Vejle.[29]

In the First Stage of the Last Interglacial Period, which is represented by various clay beds, there prevailed an arctic and subarctic flora. In the Second Stage the sedimentation in the lakes normally changed to mud-deposits, to be gradually superseded in the smaller basins by the formation of peat. Fir and birch remains characterise the oldest zones of this Second Stage (see Table), with which the fresh-water strata under the marine Eem-deposits are contemporaneous. In the oak mixed forest and hornbeam zones the temperature optimum of the Interglacial Period fell, presumably simultaneously with the maximum of the Eem-submergence; these zones are characterised by the following plants among others: *Brasenia purpurea*, *Dulichium spathaceum*, *Trapa natans*, *Aldrovanda vesiculosa*, *Stratiotes aloides*, *Najas marina*, *N*, *flexilis*, *Ilex aquifolium* and *Tilia platyphylla* as well as by the fallow deer (*Cervus dama*). While the succeeding Picea-and Pinus-zones were being formed, the temperature was gradually sinking, the thermophile water-plants and the foliferous forests succumbed, *Betula nana* appeared and, during the formation of the Middle Bed consisting of clay and sand, in the Third Stage a subarctic heath vegetation prevailed. Simultaneously with this, it must be assumed that the inland ice made an advance on the Scandinavian peninsula. It later retreated, and all the named thermophile species made their appearance again in Jylland, in the Fourth Stage, or the upper warm stratum, which consists of mud or peat. It may be divided into a lower zone rich in remains of foliferous trees, and an upper zone with mostly birch and conifer remains. This was again superseded in the Fifth Stage by a subarctic vegetation, whilst at the same time the sedimentation in the basins again changed to clay and

| Stages | Character of flora | | | | Zones | Climatic Conditions, Changes of level | |
|---|---|---|---|---|---|---|---|
| | | | **Third Glacial Period (Würm)** | | | | |
| V | Lacuna | | | | | Third Glaciation advancing | Skærumhede series |
| | Sub-arct. flora | | *Betula nana*-heaths, *Betula pubescens*. Sparse aquatic flora | | n | | |
| IV | Upper temperate flora | | *Betula pubescens, Pinus silvestris, Pic. excelsa, Bet. nana* | | m | Ice-edge retreating. Temperate climate in Jylland | |
| | | | Foliferous forest max. *Brasenia, Dulichium, Trapa* | | l | | |
| III | Middle Bed Subarct. flora | | *Betula nana* heaths and subarctic bogs. Northern, sparse aquatic flora | | k | Glaciation on Scandinavian peninsula. Subarctic climate in Jylland | |
| II | Lower temperate flora, mostly | Coniferous forest | *Pin. silv.*-Zone. *Picea excel., Betula pub., Populus tremula* | | i | Swamping of Bogs | |
| | | | *Picea excelsa*-Zone. *Dulichium* and *Brasenia* rare | | h | Climate of continental stamp, gradually cooler. Emergence | |
| | | Foliferous forest | *Carpinus betulus*-Zone. *Picea excelsa*. Oak mixed forest diminishing | | g | | |
| | | | Oak mixed forest Zone. *Pinus silvestris* rare. *Brasenia, Dulichium, Trapa, Aldrovanda* etc. No *Picea*. | | f | Eem-submergence. Atlantic climate. Temperature optimum | |
| | | Coniferous forest | *Betula pub. Pinus silv.*-Zone | *Ulmus* maximum | e | Cool, gradually milder, climate with continental stamp. | |
| | | | | Appearance of foliferous forest spec., *Picea* traced | d | | |
| | | | | unmixed | c | | |
| I | Subarct. flora Arctic flora | | *Betula nana, Salix phylicifolia* | | b | Melting period of the second glaciation | |
| | | | *Dryas octopetala, Salix reticulata, Salix herbacea* | | a | | |
| | | | **Second Glacial Period (Riss)** | | | | |

Table showing development of flora, climate and levels in Denmark during the Second Interglacial Period.

sand, both under the influence of the approaching Glacial Period. The formation of the subarctic Middle Bed, with a thickness of up to 9 metres and overlain and underlain by temperate zones, means a violent climatic oscillation in the Last Interglacial Period.

Besides the fallow deer referred to above, we also know from the Last Interglacial Period stag, elk, beaver and remains of an elephant, presumably a mammoth, which were found in the lacustrine deposit at Ejstrup, W of Kolding.[18]

Mention may also be made here of some finds of Pleistocene mammals, the age of which has not been definitely established. Teeth and bones of mammoth have been found at about fifty different places in moraine clay or glaciofluvial beds,[18] principally within the area of the last glaciation. The skull of a musk ox was found at Bannebjerg, NNW of Hillerød in Sjælland. Both animals had presumably disappeared prior to the maximum of the Last Glacial Period. The very rarely occurring remains of Irish elk (*Megaceros giganteus*) in Denmark undoubtedly belong to the Pleistocene too.

*Knud Jessen.*

## Third Glacial Period.

On the map of Jylland a line may be drawn which forms the shed between areas of widely different scenery, a line which on the whole may be said to form the boundary of the inland ice during the Third Glacial Period, the Würm Glacial Period (Penck and Brückner), the Monastirian Glacial Period (Depéret), the Mecklenburgian Glacial Period (James Geikie). From south of Bovbjerg on the west coast this line runs eastwards with a winding course to Dollerup, SW of Viborg at the end of the lake Hald Sø. There it turns in a southerly direction and continues, with smaller windings but on the whole maintaining this direction to the frontier between Denmark and Germany, which it passes at Padborg station.

There is a marked essential difference between the terrain-forms on the one side and on the other side of this boundary line. On the one side are the original glacial forms preserved in the young stage with steep hills, with hollows without outlets, with tunnel-valleys and with extramarginal valleys, formed under other draining circumstances than the present ones. On the other side of the boundary line are the great heath-plains and hill-islands of West Jylland. On these the original glacial forms have not been preserved. The terrain-forms have attained the maturity stage with levelled hills, without large hollows with no outlets, without the peculiar tunnel-valleys and extramarginal valleys, but with valleys formed by the present water-courses. This marked essential difference between the terrain-forms on the one side and on the other side of this boundary line is decisive proof that this line has, on the whole, been the boundary of the advance of the inland ice in Jylland during the Last Glacial Period.

It is not possible, however, to exactly determine the course of this boundary in all its details. The extreme traces of the advance of the ice may be buried under the sand of the heath-plains, and furthermore, the hollows (subsidence holes) which are to be found on the heath-plains WNW of Hygum, at Fole and north of Tislund East and Southeast of Ribe,[30] as well as the occurrence—shown by MILTHERS[29]—of a comparatively large number of basalt boulders on a stretch from Vork at Vejle Aa (5 km north of Egtved) over Bække, Københoved, Vester Lindet, Nustrup and Skrydstrup in North Slesvig, in the opinion of many prove that in places the inland ice has pushed itself some way over this boundary line, but only for such a short period and with such slight thickness that it did not succeed in altering the shape of the terrain-forms on those parts of the hill-islands over which it extended.

It is particularly in southern Jylland that the inland ice, many believe, for a time passed the said boundary line, its margin between Vandel (20 km west of Vejle) and Øster Løgum (9 km northwest of Aabenraa) forming a large curve which in the west reached Brørup, Foldingbro and almost to Hjortvad (10 km west of Rødding), and between Øster Løgum and Padborg another curve, which reached out almost to 5 km west of Tinglev station. On the map Pl. II the boundary of the extreme advance of the inland ice in Jylland during the Third Glacial Period is accordingly shown by Line C.

The moraine which the inland ice deposited during this glacial period, Moraine C, varies in nature. In Vendsyssel it is, according to AXEL JESSEN,[31] in the central and northern parts rather arenaceous and, in most places, must be described as moraine sand; to the south and west it is on the whole much more argillaceous and occurs oftenest as typical moraine clay. In the geologically mapped portions of southeast Jylland Moraine C as a rule occurs as moraine clay, al though moraine sand is found here and there.

Among the indicator boulders in Vendsyssel the Norwegian are in overwhelming majority; porphyries from the Dalarne are also very common, whereas Baltic boulders are only present in small numbers. The various indicator boulders occur in the same proportions to the south in Jylland as far as the boundary-line Bovbjerg—Dollerup, whereas the Baltic boulders are in the majority in southeast Jylland.

The stone-counts which have been made on the geological map-sheet Bække in the areas where the uppermost moraine must be regarded as being Moraine C, have given, as the mean number of 23 calculations, 0.82, with a mean error of 0.056. Four stone-counts made in "lower" moraines further to the east, on the map-sheet Fredericia, where the surface moraine must be regarded as being Moraine D (see p. 115), gave a mean number of 0.73 with a mean error of 0.075. As the mean number of all 27 coefficients 0.80 was arrived at, with mean error 0.049.

The 57 stone-counts made in Moraine C in south-east Jylland within the area bounded by the coast, the Danish frontier, the line C on the map, Pl. II, and a line from Farre Station to Trelde Klint, gave as the mean number the coefficient 0.88 with mean error 0.047.

In Røgle Klint on Fyn, Moraine C consists mainly of moraine clay which, in weathered, dry state looks like ordinary blue moraine clay; in moist condition the colour is of a peculiar dark tone, presumably due to a blending of mica clay. Its nature varies, however, in one part of the cliff Moraine C is light-blueish grey, very rich moraine clay, which in some places is practically free of stones, in others very stony. The stone-counts show that in this moraine, as in Moraine B, there is a difference between lower and upper, the mean number of 43 calculations in the upper part, $C_2$, being comparatively high: 0.81 with a mean error of 0.40, whereas the mean number of 18 calculations in the lower part, $C_1$, is only 0.49 and the mean error 0.012.

The dislocated Ristinge Klint on Langeland displays a series that has been of the greatest importance to the comprehension of the construction of dislocated cliffs, and not less to the study of the Eem deposits and the moraines of the Last Glacial Period. It is built up of the following series:

| | |
|---|---|
| 7. Moraine D. (the East Jylland Advance).<br>6. Glaciofluvial strata.<br>5. Moraine C.<br>4. Glaciofluvial strata. | 3rd Glacial Period. |
| 3. Eem Clay.<br>2. Freshwater sand, gravelly at the bottom. | 2nd Interglacial Period. |
| 1. Glaciofluvial strata (»the shiny clay») | 2nd Glacial Period. |

Moraine C occurs in Ristinge Klint in the form of a bed of reddish moraine clay, about one metre thick, in which Baltic boulders have been taken in situ. As the mean number of 15 stone-count coefficients 0.68 was arrived at, with 0.064 as the mean error.

By means of studies of the terrain-forms and of the changes in the drainage courses, and by means of the indicator boulders and the stone-counts, it has been possible over long or short stretches to show the stationary-lines, the traces of the position of the ice-margin in the terrain when, during the melting of the inland ice, it remained for a long time almost in the same place, or again advanced some distance.

The stationary-lines make it possible to follow, at any rate roughly, how the melting of the inland ice proceeded.

The Main Stationary-line (I. Stage, see fig. 9 on pag. 112; cf. the map, Pl. II), for the most part the boundary of the spread of the inland ice in the Last Glacial Period, forms the most important geological and geographical shed in Jylland. It is there that the East Jylland tunnel-valleys end, in it were found the ice-caves through which the melt-water streams of the tunnel-valleys poured out over the ice-free land in front, and it is at this line that the great West Jylland heath-plains begin, having been deposited by the meltwater streams.

When the melting of the inland ice commenced, the northern ice-edge retreated first, so that the meltwater which flowed over Karup heath-plain, SW of Viborg, and which formerly had been carried away by the river Storaa direct to the North Sea, now secured an outlet over Hjelmhede to Venø Bugt in Limfjord; Skive Aa made its appearance and, with it, the valley-systems which have cut into Karup heath-plain, connecting with this river and its tributaries (II Stage, see fig. 10). It is probable that there was simultaneously an advance of the eastern ice-edge. That part of the boundary line which lies between Sebstrup and Dollerup (W and SW of Viborg) is presumably rather younger than that part of it which lies between Dollerup and the North Sea. After a time the eastern ice-edge also retreated and the meltwater found an outlet through Falborg Valley (SE of Viborg), first past Skive to Venø Bugt (III. Stage, see fig. 11), later to Hjarbæk Fjord (IV. Stage, see fig. 11). At this time the stretch of marginal moraines from Hundborg in Thy, over the north of the isles Mors and Fur to Sønderbæk (13 km WNW of Randers), was formed. The meltwater could now get away through the valley of Skalsaa; this commenced the V. Stage (see fig. 12), during which the meltwater which collected in the valley of Gudenaa could follow the lower part of it almost to Randers. From there it had to run westwards and northwards and out through the valley of Skalsaa. Still later on the meltwater obtained an outlet to the Cattegat through Randers Fjord; but as the inland ice still extended from Sweden to Vendsyssel, it had to make its way westwards through Limfjord. About this time the marginal moraines in Vendsyssel,[31] shown by Axel Jessen, were formed. Finally the northern part of the Cattegat also became ice-free, the inland ice retreated a long way, although how far is not known.

At a farm on Smidstrup Mark, 400 m north of Klausholm, in Gadbjerg Parish, NW of Vejle, the well was sunk through

# Map of Karup heat

(scale abou

The densely dotted stretches are the ice-free land surrounding the heath-plai
sea is hatched horizontally. The successive positions (stages) of the ice-edge a
sent time. (Aft

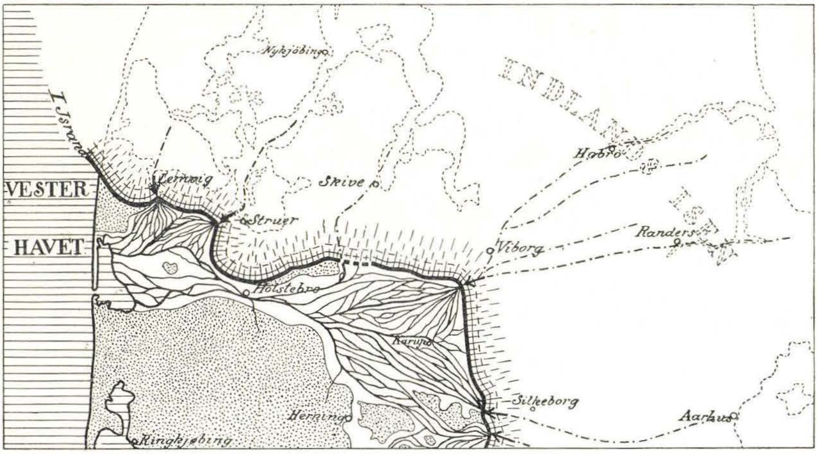


Fig. 9. I stage. The thick black line indicates the limits of the maximal extent of the land ice in the Third Glacial Period, the Main Stationary Line. The great West Jutland heath-plains were formed. The meltwater had its outlet through the valley of the river Storaa, past Holstebro to the North Sea (Vesterhavet).

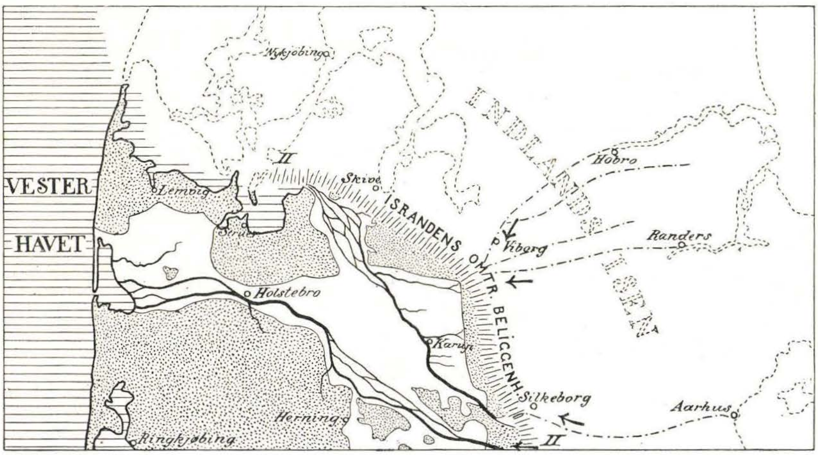


Fig. 10. II stage. The ice-edge has retired a little. The meltwater has its outlet over the heath-plain Hjelmhede, SW of Skive, to Venø Bugt in Limfjord.

## ain and its environs

1 500 000)

d river valleys. The heath-plains and river valleys have no signature. The
ırked I—V. The dotted lines indicate the situation of the coasts at the pre-
V. Ussing).

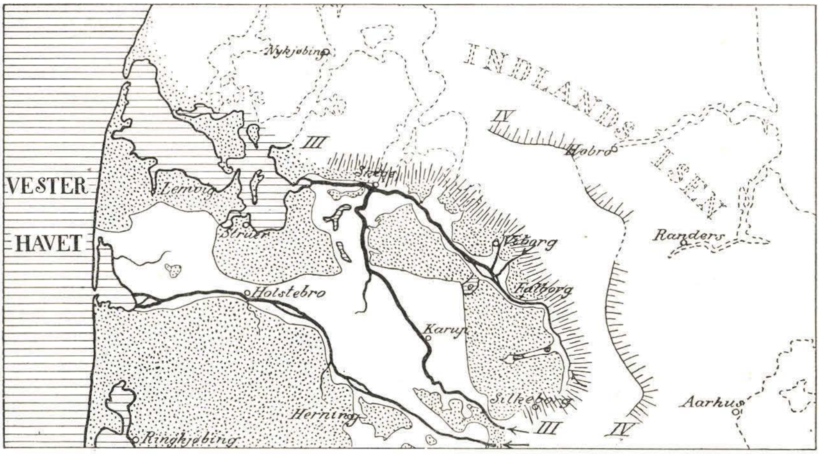


Fig. 11. III and IV Stage. The ice-edge has retreated still more. The melt-water makes its way out through Falborg valley, first (III stage) past Skive to Venø Bugt, later (IV stage) to Hjarbæk Fjord, NW of Viborg.

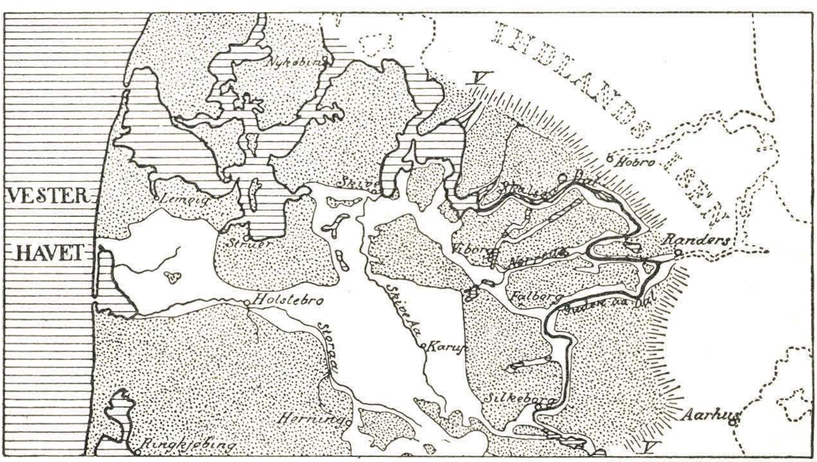


Fig. 12. V stage. The ice-edge has retreated still further. The meltwater has now secured an outlet through the valley of the Gudenaa, almost to Randers, and on through the valley of the Skalsaa to Hjarbæk Fjord.

a peat bed which was overlain by moraine-clay. MILTHERS[29,11] investigated this by means of an excavation and found in it:

1,4 m mould and transitional stratum.
1.3 » moraine clay.
0.8 » mud and peat with twigs.
Moraine clay.

In the mud not only Arctic plants such as *Betula nana*, *Salix herbacea* and *Dryas octopetala* have been found, but also more thermophile plants, which especially occurred in the middlemost part of the stratum, such as *Betula pubescens*, *Pinus silvestris* (pollen), *Rubus saxatilis*, *Juniperus communis*, *Empetrum nigrum*, *Geum rivale*, *Potentilla palustris* and others, as well as excrements of elk and, perhaps, beaver, evidence of subarctic climate conditions very similar to those which much later were found under the Allerød Oscillation (p. 133).

It thus appears from this very interesting find that the climate became so mild that birch and fir were able to take possession of the country, and the elk and, perhaps, the beaver made their appearance, before the inland ice during the East Jylland advance again spread over this region and deposited the moraine above the mud stratum.

## The East Jylland Advance.

After a long period had elapsed—doubtless some centuries—the climate again became colder and the inland ice once more spread over southeast Jylland. It reached as far as the East Jylland Stationary-line shown by POUL HARDER[32] (indicated on the map, Pl. II, as Line D) and the meltwater from the inland ice ran away through the valley of Gudenaa, which now developed throughout the whole of its length.

Both in Ristinge Klint and in Røgle Klint it is to be observed that in the Third Glacial Period two rather different moraines were deposited, Moraine C and Moraine D, separated by glaciofluvial sand of no slight thickness. Moraine C was deposited in the period when the inland ice, in the Last Glacial Period, was most widely extended, during which it got as far as to Line C; Moraine D was deposited during the East Jylland advance when the inland ice, after having melted a good way back, again advanced and got as far as Line D in Jylland.

In Ristinge Klint, Moraine D is a blue-grey, fairly thick deposit of moraine clay, in which both Baltic and Norwegian boulders have been taken in situ. Its stone-count coefficient is 1.20, with mean error 0.119 (the mean of 15 stone counts).

In the most western part of Røgle Klint, the so-called "sand section", Moraine D is to be found at the surface as the remains of weathered moraine clay, with a thickness of up to 2 m. In the eastern parts it occurs as rather rich and stiff moraine clay with considerable smears or pressed out portions of Plastic Clay. Its stone-count coefficient is 1.22 with a mean error of 0.050 (the mean of 7 calculations). Thus the conformity between the stone-count coefficients in Moraine D in Ristinge Klint and in Røgle Klint is very great; the difference between them is less than the mean error.

The stone-counts made on Fyn show that Moraine D occupies the whole of North and Mid-Fyn inside the watershed between the streams which run to the Cattegat and Odense Fjord and the streams which run to the Belts. Moraine D's stone-count coefficient on Fyn, as the result of 116 counts, is 1.29 with a mean error of 0.032.

The 14 stone-counts on the northland of the isle of Samsø show that this, too, is occupied by Moraine D, the coefficient being 1.40 with mean error 0.105.

Those made in southeast Jylland in the districts (mapsheets Fredericia and Bække) where the uppermost moraine must be regarded as being Moraine D, i. e. between the lines D and E on the map Pl. II, have given a coefficient of 1.08 and a mean error of 0.067 (the mean of 51 calculations).

Moraine D is one of the Danish moraines which are richest in flints; this is shown directly by the stone-counts. That it is also rich in material which has come from the north, Norwegian boulders, and from the northeast, boulders from the Dalarne, is shown by the studies and collections of indicator boulders which have been made during the geological mapping, and especially by MILTHERS' researches.[29] It has turned out that on the area of Fyn which is occupied by Moraine D, the proportion between the numbers of Norwegian and the Baltic boulders is this, that there are 10—20 per cent. of Norwegian and 80—90 per cent. of Baltic, the Dala-porphyries exceeding the Baltic boulders in number.

The East Jylland Advance forms a separate, significant section of the Last Glacial Period. At the ice edge in Jylland, Løsning heath-plain SW of Horsens and several ice-dammed lakes were formed, and rather later the splendid marginal moraine hills (of which a part bears the name of Mols Bjerge) around the central depressions Æbeltoft Vig and Kalø Vig, as well as the marginal moraine at Odder NE of Horsens. On Fyn several eskers were formed and, during the melting, a large, ice-dammed lake at Stenstrup[33,34]. The inland ice melted so far back that the whole of Fyn and at any rate large parts of Sjælland became ice-free.

## The Belt Advance.

Again the inland ice made a new advance, the Belt Advance, so that it reached the Line E indicated on the map Pl. II forcing its way like a great glacier up through the Little Belt towards the north to Tavlov in the Kolding area; in South Jylland it reached the watershed between the streams which flow to the North Sea and those which flow into the Little Belt and the Baltic. That this watershed came to lie just where it does was due to this very ice advance. In West Fyn it got as far as the "Fynske Alper", the big ridge which forms the watershed between the streams running into the Little Belt and those running into the Cattegat; in East Fyn it covered the coast-land and Hindsholm. To the north it spread beyond the south of Samsø and covered the most of Sjælland. Stone-counts in Northwest Sjælland show that the inland ice at any rate reached northwards on a level with Røsnæs and Holbæk Fjord.

During this advance ranges of moraine gravel hills were formed at the ice-edge on northeast Fyn especially between Revsvindinge and Davinde; furthermore the remarkable heath-plains between Langeskov station and Odense Fjord, their feeding-eskers between Birkinde and Rynkeby east of Odense, and the marginal moraine hill range round Kertinge

Nor, which fills its central depression; this hill range is broken by Munkebo feeding esker west of Kerteminde and its small heath-plain. Finally, the "transverse-hills" (see p. 151) were formed on Hindsholm and on the south of Samsø. RØRDAM[35] draws the ice-edge from the northwest coast of Stavns Fjord on Samsø over the islands Bosserne to Sejrø and Nexelø and, at a little later stage, from the north point of Hindsholm over Lille Grund, Bolsaxen and Falske Bolsax to Røsnæs on Sjælland.

The inland ice caused the overthrusts and disturbances in the Eem-strata and the overlying moraine clay beds and glaciofluvial beds in Ristinge Klint on Langeland and in the cliffs on Ærø, whilst the Little Belt glacier carried along with it numerous floes of Eem Clay and the overlying moraines and deposited them in its moraine. All occurrences of Eem-floes hitherto found, with the exception of the occurrences in Stavrby Skov, south of Strib, and Urnehoved near Aabenraa, lie within the area of the Little Belt glacier.

According to MILTHER's investigations,[36] the ice-sheet on Sjælland was divided by the river Halleby Aa, which absorbed the water from the upper course of Susaa and, through Bregninge Aa, had an outlet to Saltbæk Vig in Sejrø Bugt, so that, if not before, there now at any rate was formed a Great Belt glacier, the drainage basin of the Halleby Aa at that time becoming ice-free southwards to Fensmark—Haslev in SE-Sjælland. In Odsherred and in the Jyderup area were formed the magnificent marginal moraine bows described by MILTHERS[36] and, somewhat later, the marginal moraine ridges in North Sjælland. Finally, Køge Esker and Mogenstrup Esker at Næstved were formed.

The moraine of the Belt Advance, Moraine E, on East Fyn, Hindsholm and the south of Samsø contains so to say no Norwegian boulders. During the mapping work only very few have been found in these parts of the country as great rarities. It is otherwise on the coast-lands by the Little Belt; there the Norwegian boulders are by no means scarce. At any rate, with a little search they are to be found all over, wherever there is an abundance of stones. They originate from the transported parts of Moraine D.

Accordingly, the stone-counts on the south of Samsø, Hindsholm and East Fyn are very uniform and low, whereas those within the area of the Little Belt glacier vary greatly. The following results have been obtained:

| | | | | | | |
|---|---|---|---|---|---|---|
| Southern Samsø | (15 stone counts) | 0.34 | with | mean | error | 0.040 |
| Northwest Sjælland | (40 » » ) | 0.27 | » | » | » | 0.022 |
| Hindsholm | ( 7 » » ) | 0.54 | » | » | » | 0.057 |
| East Fyn | (38 » » ) | 0.88 | » | » | » | 0.058 |
| The coast lands round the Little Belt, including Taasinge | (229 stone counts) | 0.82 | » | » | » | 0.026 |

## The Langeland Advance.

After the inland ice had melted completely away from the Fyn island group, it again made an advance, and the ice-edge reached the line F shown on the map Pl. II. This advance must be regarded as corresponding to the Gothiglacial Stage in Sweden. During this the inland ice, according to De Geer, still extended into the Cattegat along by the west coast of Sweden. In Denmark the inland ice got as far as Langeland proper, but not beyond Ristinge peninsula. The ice-edge stood along by the southern and middle part of the west coast of Langeland and went on over the series of shoals which extend along the west coast of northern Langeland, over Vresen and Sprogø to Halskov at Korsør on Sjælland. From there it passed in a curve (with the concave side facing northwest) through South and East Sjælland and, at Helsingør (Elsinore), reached over the Sound to Skåne.[12]

During this advance were formed the Langeland transverse hills which give the scenery on this island its particular character. On Sjælland came the marginal moraine range which reaches from Korsør Nor to the southeast, northeast of Skelskør. The striae at Faxe, Stevns Klint, and in the neighbourhood of Køge and København were graven on the hard Danian limestone rocks which occur at these places. Most of these striae run in directions from SE or SSE, although here and there are older ones running from NE, and, at København, the youngest system runs from S.

Among the indicator boulders on Langeland the Norwegian are extremely scarce, so scarce that during the mapping work, despite careful search, only two or three specimens could be found. KARL A. GRÖNWALL,[37] through his examinations of the fossiliferous boulders which were collected on Langeland, southern Fyn and Ærø during the mapping-work, has come to the following conclusion: "The close consideration of the finding places of the boulders within this really rather restricted area shows a decided difference with regard to their distribution and the distance over which they have been carried. For on Langeland, boulders which have only been carried a short distance, and which have their native place in southeast Skåne, on Bornholm and the adjoining part of the Baltic, are decidedly in the majority compared with boulders which have been brought from further afield, for instance from Gothland and East Balticum, whereas on South Fyn and the southwesterly islands the boulders from East Balticum predominate, and boulders from southeast Skåne and Bornholm are very rare..." ..."The Langeland moraine material has been deposited by a later advance of the inland ice and has only been transported a comparatively short distance. This advance has scarcely been of long duration and the ice has probably not been particularly thick."

The stone-counts made on Langeland have given low coefficients, the mean of 26 calculations being 0.29 with mean error 0.027.

At last the inland ice melted entirely away from the islands, but for a long time yet it surrounded Bornholm and on the rocks of that island graved numerous striae which, north of a line from Nexø to Knudskirke, run mostly from northeast, whereas south of this line it is the direction from ESE that is most prominent. These latter striae are the youngest; they were not made until the inland ice there had become so thin that Bornholm's comparatively high granite terrain jutted up from the ice like a nunatak.

By the end of the Last Glacial Period Denmark was in all essentials completed in form. Hill country and flats, plains and valleys had, in their main outlines, the forms which we see today. Only the distribution of sea and land was different.

Summary of Stone Counts.

| | | | |
|---|---|---|---|
| Moraine A. | Esbjerg | 0.55 | with mean error 0.035 |
| | Røgle Klint | 0.36 | » » » 0.044 |
| Moraine B. | Area between Esbjerg and Brøns | 1.44 | » » » 0.103 |
| | Maps Varde and Bække | 0.84 | » » » 0.057 |
| | Remainder of West Jylland, S. of the line Varde-Grindsted | 0.87 | » » » 0.042 |
| | Røgle Klint $B_2$ | 0.82 | » » » 0.026 |
| | » » $B_1$ | 0.82 | » » » 0.049 |
| Moraine C. | Surface moraines on map Bække | 0.82 | » » » 0.056 |
| | Lower moraines on map Fredericia | 0.73 | » » » 0.075 |
| | total | 0.80 | » » » 0.049 |
| | Southeast Jylland (see pag. 109) | 0.88 | » » » 0.047 |
| | Røgle Klint $C_2$ | 0.81 | » » » 0.040 |
| | » » $C_1$ | 0.49 | » » » 0.012 |
| | Ristinge Klint | 0.68 | » » » 0.064 |
| Moraine D. | Southeast Jylland: (Maps Bække and Fredericia) | 1.08 | » » » 0.067 |
| | North Samsø | 1.40 | » » » 0.105 |
| | North and Mid Fyn | 1.29 | » » » 0.032 |
| | Røgle Klint | 1.22 | » » » 0.050 |
| | Ristinge Klint | 1.20 | » » » 0.119 |
| Moraine E. | South Samsø | 0.34 | » » » 0.040 |
| | Northwest Sjælland | 0.27 | » » » 0.022 |
| | Hindsholm | 0.54 | » » » 0.057 |
| | East Fyn | 0.88 | » » » 0.058 |
| | Coast-lands around Little Belt | 0.82 | » » » 0.026 |
| Moraine F. | Langeland | 0.29 | » » » 0.027 |

*Victor Madsen.*

## Lateglacial and Postglacial Periods.

The periods which have elapsed since the last inland ice began its retreat—not from the extreme boundary to which it had reached during its advance, but from the Main Stationary-line referred to on p. 110—are described as the Lateglacial and Postglacial (Alluvial) Periods. The Main Stationary-line is marked on the map Pl. II by the boundary between the singly and the doubly hatched areas.

The Lateglacial and Postglacial Periods are characterised by exactly similar oscillations in the temperature conditions to those which characterise the Ice Age itself, although in these later oscillations there is not the great difference between maximum and minimum as between the temperature minima of the Glacial Periods and the maxima of the Interglacial Periods. In the period which lies between the retreat of the ice-edge from the Main Stationary-line referred to above and the new advance of the inland ice to the East Jylland Stationary-line (Line D on the map Pl. II), there has already been a temperature oscillation which is revealed by the aforementioned (p. 114) section in the freshwater strata on Smidstrup Mark, west of Gadbjerg. In the period which followed between the retreat of the inland ice from the ice-edge position, shown on the map Pl. II as Line F, and its position at the Mid-Swedish Main Stationary-line, came the temperature oscillation which is known as the Allerød Oscillation (see below, p. 133, named after Allerød Brickworks in North Sjælland, in whose pits it was discovered for the first time).[38] Even after the coming of the great forests, in the Postglacial or Alluvial Period, clear, although less prominent, temperature oscillations can be proved.

Just as Denmark during the Glacial Periods and the Interglacial Periods was subjected to a number of level changes, the shore line during the Lateglacial and Postglacial Periods was exposed to a varying series of positive and negative changes, the traces of which are to be seen so much the more clearly as no later glaciation has destroyed them. See the chapter on changes of level, p. 157—172.

As the natural conditions which must be called Lateglacial were closely connected with the inland ice, which for the most part was then retreating, and therefore made their appearance at different times at the various places as the ice gradually evacuated the country, no exact boundary can be laid—even in such a small area as Denmark—between the Lateglacial and the Postglacial Periods. As a whole it may be said that the latter period is reckoned from the time when the forest had occupied the country.

No more exact, absolute age determination of the various phases within these periods has not yet been practicable in Denmark in a satisfactory manner. In Sweden, G. De Geer and his school have maintained that they could fix the lateglacial and postglacial natural events by counting the "varvs"*) in the clay deposited by the meltwater rivers and their successors, the postglacial rivers.[39] This method has also been tried in Denmark, but hitherto without success.[40] It is true that varvs have also been found here, but the varv-series counted in Denmark have been too short and too irregular to be capable of giving a safe basis for a comparison with the strata in other—near or more distant—localities.[41,42] One of the reasons why the method has so far been unsuccessful is that many of the Danish varvs have been deposited in connection with "dead" ice and not the "living", retreating ice-border.[34] Another reason is certainly—as maintained from a Danish source[43]—that most of the varvs which De Geer has measured in Danish localities are not annual varvs, but subdivisions of such varvs.

In connection with the geochronological time-scale drawn up by means of varv-counting, the Late and Postglacial Periods have in Sweden been divided into different sections: the Daniglacial, the Gothiglacial, the Finiglacial and the Postglacial Periods. The Daniglacial Period means the time which lay between the stoppage of the ice-edge at the Jylland Main Stationary-line and its stoppage at the ice-edge line which encircles the Scanian ice-lake and reaches out to the Swedish coast a little south of Hälsingborg, and which is continued in Line F on the map Pl. II; the Gothiglacial Period is the time between the retreat of the ice-edge from the last-named line and till its stoppage at the Mid-Sweden moraines; the Finiglacial Period is the time during which the ice-edge

*) By a "varv" (annual bed) is understood a stratum which, at the bottom, consists of coarse sand, which passes upwards insensibly into finer sand (with intercalate clay layers) and concludes with fine clay. It is thought that a varv is deposited in the course of a year, as the flow of the currents decreases from the spring and until winter.

retired to the point in Eastern Jämtland in Sweden where the last remnants of the land ice were divided into two parts. Then followed the Postglacial Period, which is reckoned from the bipartition of the ice till the present day.[44]

As yet this division is only little used in Denmark, whereas the division of the Postglacial Period on the basis of changing climatic conditions, made by Swedish geologists, has won general approval in our country (see below, p. 135). In addition, divisions have been used that are based upon the marine deposits and also upon the changing forest vegetations. A. C. JOHANSEN has attempted a division into three periods, based upon the appearance of the freshwater molluscs, the appearance of *Bithynia tentaculata* forming the first boundary line, and the appearance of *Planorbis corneus* the second. In the first period were deposited the freshwater sediments which form the Planorbis stroemi and Valvata cristata zone; it corresponds to the commencing forest period. Then follows the Planorbis stroemi and Bithynia tentaculata zone which, for the most part, comprises the fir period, and finally the Planorbis corneus zone, which most nearly corresponds to the period of the oak mixed forest and later.[16]

In the Lateglacial and Postglacial Periods there was a new immigration, of gradually more and more species of thermophile plants and animals. The reason why the number of species, especially for the higher animals, is so overwhelming in comparison with that of the interglacial periods is exclusively this, that we have a much wider knowledge of the lateglacial and postglacial deposits, which is again due to the easily accessible, numerous and large—natural or artificial—sections of these formations. Many of the species known from the interglacial deposits, for instance mammoth, Irish elk, fallow deer, the spruce, *Dulicium* and *Brasenia*, have not appeared in Denmark since the Last Glacial Period (the spruce, *Picea excelsa*, and the fallow deer were, however, later brought in by man). The higher animals, mammals and birds, attain their greatest abundance of species at the end of the time of the fir forests and in the time of the oak mixed forests, the Boreal, Atlantic and Subboreal Periods (see below), whereafter they begin to decline slightly during the course of the Subatlantic Period. It was only during the cultivation of the land within most recent times and man's radical transformation of the landscape that our fauna rapidly declined.

Although it might have been expected that even during interglacial times Denmark must have been very suitable for the habitation of man, no definite evidence of his presence has been found in this country prior to the Lateglacial and Postglacial Periods.*) The earliest actual settlements (those of the Maglemose or Mullerup culture) date from the close of the Ancylus Period (the Boreal Period),[45, 46, 47] but the earliest known implements from this country, a flint arrowhead[48] and some axe handles of reindeer antler, date from the beginning of the Forest Period or possibly from the preceding Tundra Period. The reindeer became extinct in Denmark shortly after the forest had come in.[49]

*V. Nordmann.*

**Lateglacial and Postglacial Marine Deposits.**

A continuous succession of Lateglacial and Postglacial marine deposits, with a corresponding development of the character of the fauna from High-arctic to distinctly Lusitanian, such as has been shown in Norway[50, 51, 52] and West Sweden, is not known in Denmark. The three submergences with subsequent emergences which have occurred to Denmark after the Last Glacial Period (see the chapter on level changes), have effected such changes in the coast-line that, even if the more recent depositions of marine sediments might have taken place above the older ones, they are always separated from these by distinct lacunas.

As an example of the occurrence of such marine strata deposited over each other, from widely different sections within the Lateglacial and Postglacial Periods, may be mentioned an apparently insignificant section in the river bank opposite the brickworks at Tversted Aa, north of Hjør-

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*) But see ANATHON BJØRN, 1928: Nogen norske Stenaldersproblemer. Norsk Geolog. tidsskrift, Vol. 10. There the author figures and describes a palaeolithic stone implement from Harebjerg, south of Brørup Station in Jylland.

ring in Vendsyssel Here, at the lowest part of the river bed, are to be seen Lateglacial Yoldia Clay, overlain by a Zirphaea deposit up to 3 m thick, the lowest part of which is gravel with a large quantity of rolled mollusc shells and shell fragments; over the gravel is seen beautifully stratified sand with subordinate gravel layers and with scattered shells. The Zirphaea Sand is overlain by a bed of peat, from 5 to 10 cm thick, from the Continental (Ancylus) Period; this peat bed is again overlain by a thin layer of marine mud with remains of *Zostera* and *Pinus* and, above this, argillaceous, marine sand with *Ostrea edulis, Cardium edule, Scrobicularia piperata, Litorina litorea* and many others. Thus these three marine deposits each represent a distinctly marked marine period: the Yoldia Period, the Zirphaea Period and the Litorina Period (see below), between which the sea had retired from this place.

The most important lateglacial deposit in Denmark is the younger or Lateglacial Yoldia Clay,[31] which occurs over large stretches of Vendsyssel as well as west and east of Aalborg to the northern part of Lille Vildmose SE of Aalborg, near the coast of Cattegat; with regard to the levels at which this occurs, reference must be made—as for all the other marine deposits—to the chapter on level changes. It was formed during a submergence of the land immediately after the last melting of the inland ice and it overlies lateglacial sea-sand (Lower Saxicava Sand), which in places may contain numerous shells of *Saxicava arctica*. The Yoldia Clay, the thickness of which sometimes reaches 20 m, is here and there rather arenaceous towards the bottom, and upwards contains a number of thin sand strata; the stratification is usually horizontal and undisturbed and the clay contains only very little stone, brought here by drift ice. As a rule it is overlain by Upper Lateglacial sea-sand or Postglacial deposits and in many places lies fairly close to the surface. It contains a markedly arctic fauna, comprising 24 mollusc species of which may be mentioned *Portlandia (Yoldia) arctica, P. lenticula, Axinopsis orbiculata, Kennerleya glacialis, Leda pernula, Lyonsia arenosa, Modiolaria laevigata, Cylichna scalpta, Fusus despectus var. fornicatus, Saxicava arctica,* *Tellina calcarea* and many others. Apart from *Portlandia arctica* the fauna is characterised by the high-arctic *Tellina Torellii* and *T. Lovenii*, which have not been found in the Portlandia Zone of the interglacial Skærumhede Series. Of other animal remains from the Lateglacial Yoldia Clay may be mentioned bones of the Greenland whale (*Balaena mysticetus*) and the grampus (*Orca sp.*). Some walrus teeth (*Trichechus rosmarus*) found on the beach at Rubjerg Knude, south of Lønstrup, probably come from there too.

As has been stated, the Yoldia Clay is overlain by Lateglacial sea-sand (Upper Saxicava Sand), which has been formed during the subsequent emergence of the land. This is of rather greater extent than the Yoldia Clay, for, being a shallow water deposit, it could be deposited at much shallower depths than the clay; but much of the sea-sand which, resting upon the glacigenous deposits, occupies a greater area than the Yoldia Clay, is contemporary with the clay deposited in the deeper water. The sea-sand forms the surface of the high plateaux over which the hill ranges, which have never been covered by the sea, lift themselves in the shape of islands or continent. On the whole, molluscs are extremely rare in the sand, probably because this particularly meagre deposit is so easily penetrable for water and air that the shells have decomposed. Two occurrences at Raaholt and Borgbakke near Frederikshavn, about 20—25 m above the sea, are, however, exceptions from this. In the sand and gravel there has been found a boreoarctic littoral fauna, comprising 10 mollusc species, characterised by *Mytilus edulis*, *Tellina baltica*, *Buccinum undatum*, *Lacuna divaricata* and *Litorina rudis*. These species show that the temperature—at any rate of the upper layers of water—must have risen a good deal even at the close of the "Yoldia Period".

How long was the duration of the emergence, during which the Upper Saxicava Sand was deposited, is not known; but when it was again succeeded by a submergence there had, as the now arrived fauna shows, been a further rise in the temperature of the sea water: it was no longer a particularly boreoarctic, but more nearly a northern boreal fauna which then thrived on the coasts of Denmark. From the deposits formed during the new submergence—the Zirphaea Beds,[31] which are only shallow water deposits of sand and gravel—we know about 20 species of molluscs, of which, however, many have only been found in a few localities. Genuine high-arctic species are lacking; the common ones (according to the number of localities where they have been found) are: *Tellina calcarea, Saxicava arctica, Mytilus edulis, Zirphaea crispata, Tellina baltica* (a large, thick-shelled variety), *Cyprina islandica, Mya truncata* and *Buccinum undatum*; the remainder were only found in one or very few localities; among these are: *Trophon clathratus, Natica groenlandica, N. clausa, Spirialis balea, Pecten islandicus* as well as two fragments of *Cardium ciliatum*, which, however, possibly have been washed out of the Portlandia arctica Zone of the Skærumhede Series. *Cyprina islandica* and *Zirphaea crispata* are characteristic of the temperature conditions; today the former has its northerly boundary in the Gulf of St. Lawrence, on the north and east coast of Iceland, on the coasts of East Finmarken and in the "warm area"[53] of the White Sea; *Zirphaea crispata* has its northern boundary in the Gulf of St. Lawrence, on the south and west coast and perhaps also the north coast of Iceland and off West Finmarken in Norway.[53]

This submergence, which has only been slight and probably of short duration, was succeeded by a considerable and long period of emergence: the Ancylus or Continental Period, during which the forest spread over Denmark in earnest and passed through its development in the Subarctic and Boreal Periods. In the subsequent period, the Atlantic, a third (and last) submergence of the land took place. This submergence is called the Litorina or Tapes Submergence and, during this and the subsequent emergence, a fauna immigrated which was quite different to that of the Zirphaea Beds, with quantities of Lusitanian species, of which, however, several had already appeared on the coast of Norway and West Sweden during the previous Continental Period. Of the species*) most

*) The species marked with an asterisk have now again disappeared from Danish waters inside Skagen or only appear now and then. *Pecten varius,* however, still occurs in the west of Limfjord, which

characteristic of the fauna there are: *Cardium edule, C. echinatum, Ostrea edulis, *Pecten varius, *Tapes aureus, *T. decussatus, T. pullastra, Scrobicularia piperata, Corbula gibba, Nassa reticulata, Trochus cinerarius, Bittium reticulatum, Litorina litorea* and a large number of southern small forms, including some *Rissoa* species. But besides these, there is a number of boreal species which today do not appear in the Mediterranean, so that the fauna must be said to bear a southern boreal stamp. Apart from the widely diffused, genuine (older) Tapes Beds, there are at Frederikshavn and about the eastern mouth of the Limfjord some younger deposits which only attain to a low height above the sea (3 m at Frederikshavn, where the older Tapes Beds reach up to 13 m); these have been separated under the name of the Dosinia Beds[54] and are characterised by: **Dosinia exoleta, D. lincta, *Lutraria elliptica, *Tapes edulis* (= *virgineus*), *Pecten maximus, P. opercularis, Mytilus adriaticus, Lucina borealis, Lucinopsis undata, *Psammobia vespertina, *Pholas dactylus, *Cypraea (Trivia) europaea, Nassa incrassata, Turritella terebra, Scalaria Turtonis* and many small forms; none of these species have been found in the older Tapes Beds. The fauna, which has been enriched both with Lusitanian and boreal species, has on the whole retained its southern boreal character. The Dosinia Beds must be regarded as being contemporary with the shell beds in Norway which belong to the Ostrea Stage established by ØYEN, during which the climate changed from subboreal, relatively dry, to subatlantic and moist.

The deposits of the Tapes Sea vary greatly from place to place. In narrow gulfs and fjords and in straits with little current there is a soft, often black, fetid mud bottom with a thin-shelled fauna poor in species; in straits with a strong current, on open broads and by the outer coasts there are sand and gravel deposits with a rich fauna, the shells of which often occur in beds of considerable extent and thickness; extensive oyster banks have been found in several places. The

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is the one of the Danish waters that bears most resemblance to the Tapes Sea.

circumstance that there was a relatively rich fauna in narrow fjords or far into the Danish waters (the oyster, for instance, to the waters south of Fyn, and, indeed, into the bays at Kiel and Neustadt in the Baltic,[55] whereas at the present time it is only found sparsely in the northern Cattegat and in Limfjord), bears evidence of a greater salinity and higher temperature than at present; as a consequence, the molluscs in the Tapes Period also appeared in rather shallower water than they do now.[54] As an example of how conditions have changed it may be mentioned that only about ten species are known from the Roskilde Fjord in Sjælland of today, whereas alone in the Tapes Deposits at Bilidt, near Frederikssund, on the coast of the named Fjord, twice as many species have been found. Many of the forms common to the past and present occur in a fossil state with bigger and thicker shells.[56] At times the fauna alone can give information as to the sea connections of that time: apparently there has been an open connection between the North Sea and the Cattegat through a broad sound over the area that is now occupied by Store Vildmose in Vendsyssel; the fauna in the marine deposits there, however, apart from their greater wealth of species, quite corresponds to that which is now found on the broads of Limfjord and, for instance with respect to the size and thickness of the shells, differs greatly from the recent fauna in the North Sea and also from the fossil fauna in the Tapes Beds west of Fjerritslev. The area in question must therefore have been cut off from direct connection with the Skagerrak and has only been a broad in the "Limfjord" of the Tapes Period, which only extended from Løgstør to a little east of Aalborg[57] (see fig. 13).

Between the high land at Fjerritslev and the high land at Thisted there was, however, in the Litorina Period, a cluster of islands with broad sounds and extensive connection between the North Sea and the waters which occupied the site of the present broads of the west part of Limfjord. Along the coasts of this archipelago are tremendous raised beaches with coarse gravel in which are intermixed thick, strong but very much rolled shells of *Buccinum undatum*, *Litorina litorea*, *Ostrea edulis*, *Cardium edule*, *Tapes aureus* and *decussatus*, *Mactra subtruncata* and others. *Purpura lapillus*, which is very rare in the eastern areas, occurs frequently in these western raised beaches and the fauna in this region contains several species which have not been found in the Tapes Beds

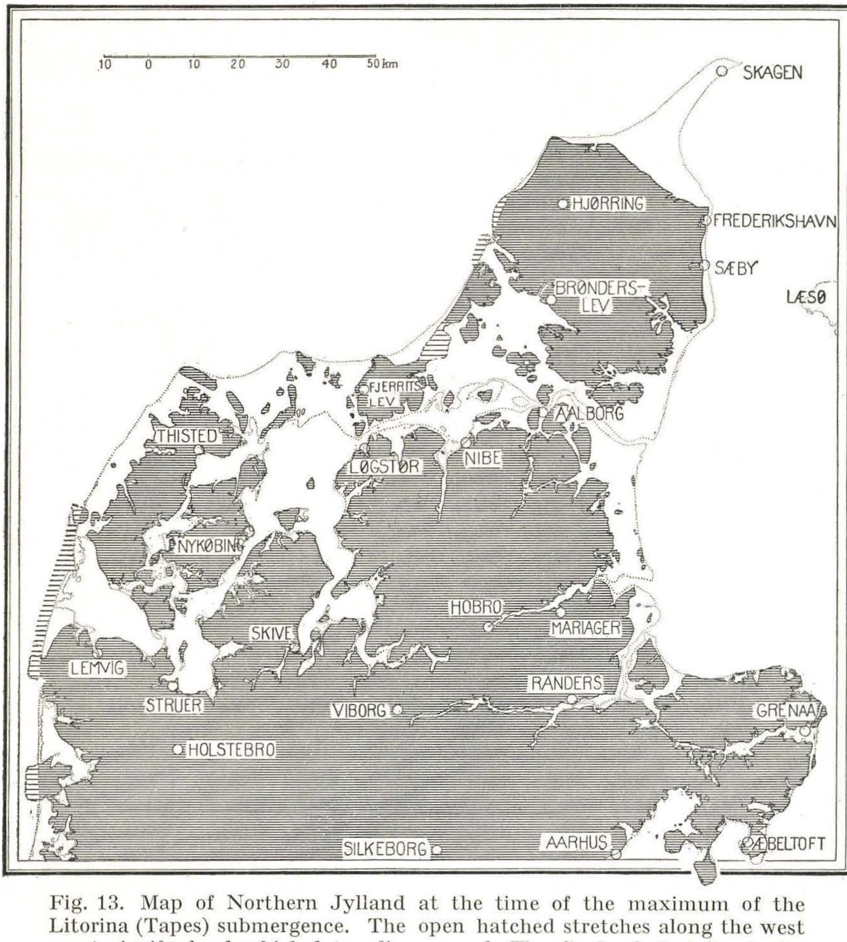


Fig. 13. Map of Northern Jylland at the time of the maximum of the Litorina (Tapes) submergence. The open hatched stretches along the west coast signify land which later disappeared. The finely dotted line is the present coast-line.

in eastern Jylland or on the Islands, for example *Donax vittatus*, *Helcion pellucidum* and *Patella vulgata*. Further to the SW, in the marine Alluvium between Nissum Bredning and Ferring Sø W of Lemvig, we again find an only slightly varied and thin-shelled fjord fauna, which shows that this apparently open area has, during the Litorina Period, been a more enclosed water. Nor are there any large raised beaches or other signs of an open North Sea coast.[58]

On Fyn the marine Alluvium is particularly diffused between Bogense and Næraa Strand, at Odense Fjord and south and north of Kerteminde.[2,59] Stately beaches occur on the peninsula east of Nyborg Fjord. In particular, the area round the mouth of Odense Fjord was an archipelago and the peninsula Hindsholm was an island, separated from Fyn by a narrow and winding sound between Odense Fjord and Kerteminde Bugt. The fauna, which comprises 33 species, is altogether less considerable than at Vendsyssel, whence we know 112 species.

On Sjælland the marine Alluvium is principally spread along the north coast and round Isefjord and its branches, not only the broader, more westerly parts, Holbæk Fjord and Lammefjord,[36] but also round Roskilde Fjord which, for a great part, is very narrow. On the stretch from Saltbæk Vig to Hornbæk the coast was cut up into a number of irregularly shaped peninsulas with large and small islands before them; Arresø formed the head of a wide fiord or gulf running in from the Cattegat, the northern part of Hornsherred was separated from the southern part by a sound between Isefjord and Roskilde Fjord, and so on.[12]

The fauna comprises 35 species which are widely diffused in all the ramifications of the sea; thus the oyster, for instance, went right into the head of Roskilde Fjord at Kattinge. Numerous kitchen middens along the shores show that the Campignien population made great use of this rich animal life.[61] The poor fauna in the marine Alluvium at the Øresund and Køge Bugt forms an exception: it numbers only 13 species and several of the forms characteristic of the Litorina Period, for instance *Ostrea edulis* and the *Tapes* species, are missing. *Scrobicularia piperata*, which, however, has not been found in all localities, must be named the characteristic animal of this part of the marine Alluvium.[12 62]

The emergence which, in north-east Denmark, followed upon the maximum of the Litorina Submergence, was concluded on the whole with the Dosinia Beds; further to the south the submergence continued with the result that the Tapes Beds south of Fyn and Sjælland and along the east coast of Slesvig and Holstein are now found in deeper water than that in which they were originally deposited. In the younger marine deposits, which are now for the most part accessible in the artificially embanked gulfs and friths, the fauna is poorer because several of the species named above are now extinct in Denmark. *Mya arenaria*, which immigrated after the Iron Age, is characteristic of this poorer fauna.

Among the more recent marine deposits, which are still in course of formation, must be named the Marsh Clay which is being deposited on the west coast of Slesvig. When the tide wave from the North Sea forces its way twice in the twenty four hours into the Wade-sea between the North Sea islands and the mainland, it washes out a quantity of fine ooze from the bottom mixed with the fine material brought down by the rivers; during high water this is deposited on the shoals ("Wades") and the flat coasts, where it is bound by the gasteropods (*Hydrobia*) and amphipods (*Corophium*), and also partly with the help of the vegetation, so that it is not carried away again by the ebb. The sedimentation of the Marsh Clay began after the Bronze Age, and a later emergence had the effect that the older areas of it now lie so high above the tide wave that its formation is now ended over considerable stretches.[63]

*V. Nordmann.*

## Lateglacial and Postglacial Freshwater Deposits.

The Lateglacial Period, or Tundra Period, comprises the time between the disappearance of the last ice-sheet and the final appearance of the forests. The freshwater deposits of this period, first recognised in 1870 by NATHORST,[64] consist of sand and calcareous clay, Dryas Clay, with arctic and subarctic plants such as *Dryas octopetala, Betula nana, Salix polaris, S. reticulata*, etc.; remains of reindeer are often found, remains of wolves and elk have been discovered occasionally. The Dryas Clay is deposited in small hollows on the surface of the moraine clay and attains a thickness of 5, and even up to 10 m; it is frequently overlain by peat or mud. On Bornholm, Sjælland, Møen, Fyn and in East Jylland evidence has been found of a considerable climatic oscillation, the Allerød Oscillation,[38.65.66.67.68.34] in lateglacial times, for where the series is most completely developed we find at the bottom Dryas Clay, above that mud with macrophyllous birch, an abundance of fir pollen, and the fresh-water molluscs *Anodonta cygnaea*, *Planorbis fontanus*, *Ancylus lacustris*, *Limnaea stagnalis*; furthermore, beaver and, on one occasion, common bear,[69] which bears witness of a higher summer temperature; at the top is Dryas Clay again. The smooth transition to the Alluvium, as regards fauna and flora, is proved in certain districts by the presence of the usual lateglacial forms together with the first traces of the forest and its fauna. Thus from a deposit at Nørre Lyngby,[48] south of Lønstrup, in Vendsyssel, belonging to this transitional period, there are finds of reindeer, Alpine hare, *Lepus variabilis* PALL., and rock ptarmigan, *Lagopus mutus* MONT., together with beaver and certain insects associated with the forest. From this locality there is also a find of a ground squirrel, *Spermophilus rufescens* KEYS. & BLAS., as well as the earliest traces of man in Denmark which it has been possible to date more or less accurately, viz. an arrow head of silex and an axe shaft of reindeer antler. There are also other Danish finds of reindeer antler worked by man,[19] corresponding to the fact that the reindeer has repeatedly been found in peat strata of the oldest part of the Postglacial Period.[49]

The most important groups of our Alluvial freshwater deposits are peat and mud, which are found in the bogs, often overlying the clay strata of the Lateglacial Period, and also calcareous tufas as well as sand and clay which in particular occur adjoining the water courses. Bog iron-ore, which is formed near the surface in some bogs, also belongs to this group. The bogs, whose alluvial strata sometimes attain a thickness of about 11 m, are divided according to the manner in which they were formed into Accretion Bogs,[70] which are formed by the overgrowing of lakes and river courses (lake bogs and riverside bogs), Swamped bogs,[70] in which the formation of peat has started without a previous limnic stage (most of the high bogs in Jylland are among these), and

Spring bogs,[70] which occur where springs run out in the sides of the valleys. In areas rich in lime, especially East Danish areas, spring bogs frequently occur as deposits of calcareous tufas. These are oftenest granular and incoherent, but sometimes occur in the form of a compact limestone suitable for building purposes (see p. 183). Of the various muds that are deposited on the bottom of open water special mention must be made of the light, lime mud, which may be rich in mollusc shells, the darker muds rich in humus and diatom-mud. The kinds of peat[71] can be classified into two main groups, all according to the demands of their parent-associations (i. e. the vegetable communities, of whose more or less decomposed remains the peat beds have been engendered) regarding the presence of nutritives, especially the eutrophic low-moor peat series and the oligotrophic Sphagnum peat series. The low-moor peat series, which in particular occur in riverside bogs and spring bogs, are classified according to the demands of their parent-associations for moisture, i. e. their height above the surface of the ground water, into limnic formations (for instance Phragmites peat), telmatic formations (for instance Magnocaricetum peat) and terrestric formations, the last section of which is swamp forest peat. The peats of the Sphagnum peat series can also to a certain extent be arranged according to the same principle, limnic and telmatic phases being represented by quaking bog formations which in places are overlain by Calluna peat, birch or fir peat. To the last section of this series belongs, as far as the degree of humification is concerned, the very varying Sphagnum peat (composed especially of *Sphagnum magellanicum* and *S. fuscum*) in the high moor which, as regards their needs of moisture, are only dependent upon the rainfall (ombrogene peat).

Often the peat strata are found to be deposited in progressive succession in dependence upon the steadily rising bog surface; but in the series of strata of almost all large bogs there are cases of inverse sequences: the high-level associations have been ousted by more hydrophile associations, i. e. the moisture in the bog has been considerably increased. This brings about the so-called dried horizons in the bog profiles, to which in a similar manner correspond mould strata in the calcareous tufas. These dried horizons are known from widely different regions in North, Central and East Europe and, as it can be shown to a great extent that they are contemporaneous in the various bogs, the stratigraphy of the bogs and calcareous tufas, combined with their fossil content, give valuable evidence of the different climatic periods of the Alluvial Period.

Besides remains of water and bog plants the mud and peat strata, as well as the calcareous tufas, also contain remains of the forest communities which at various periods prevailed in the forests surrounding the bogs.[68] This was already observed by Japetus Steenstrup in 1837.

In the first period of the Alluvial time, the Boreal Period, which is almost contemporaneous with the Ancylus Period, the fir was the prevailing forest tree, although birch and aspen, especially at the beginning after the disappearance of the Tundra flora, were particularly frequent in certain areas. Towards the close of the period our oldest (epipalæolithic) Stone Age Culture—the Mullerup Culture—unfolded itself, and is especially known from large settlement finds in Sjælland bogs.[45.74.75] In these culture strata are found the earliest traces of oak, elm and linden, as well as remains of thermophile species such as *Najas marina*, mud tortoise (*Emys orbicularis*) and *Planorbis corneus*; on the other hand, the oak does not seem to have reached Vendsyssel until the following period. The lower dried strata which has been observed in several places in calcareous tufas[76.77] and bogs dates from the Boreal Period. The climate was continental in character and gradually became mild, the summer temperature at the end being at least as high as at the present time. The beginning of the postglacial warm period came in the later part of the Boreal Period.

In the Atlantic Period, which is contemporaneous with the first part of the Litorina Period, the fir was almost entirely displaced by the oak mixed forest which was so rich in species; the climate became oceanic, numerous lakes became

| Geological development of Cattegat and Baltic | | | Climatic periods | Vegetation periods | | Immigration (and extinction) of some important plants | Immigration (and extinction) of some important animals | Archaeological periods |
|---|---|---|---|---|---|---|---|---|
| ostglacial Period (Alluvial Period) | | Mya Sea<br>Development of Cattegat and Baltic to present conditions<br>Dosinia Sea | Present, drier<br>Subatlantic Period, cold and moist | | Beech Period | *Viscum album* extincts<br>*Pinus silvestris* almost disappeared<br>*Trapa natans* disappeared | | Historic<br>Iron Age |
| | Litorina Sea | | Subboreal Period, warm and dry | lluvial warm period | Oak mixed forest Period | *Carpinus betulus*<br>*Fagus silvatica* | *Helicodonta obvoluta*, *Succinea elegans f. typica*, *Cyclostoma elegans* | Bronze Age<br>Neolithic Stone Age |
| | | Older Tapes Sea | Atlantic Period, warm and moist | | | *Viscum album*, *Acer platanoides*, *Fraxinus excelsior*, *Humulus lupulus*, *Ceratophyllum submersum*, *Trapa natans* | Urus and Elk disappear | Campignien: Kitchen middens (Ertebølle Culture)<br>Brabrand Culture |
| | | Øresund is formed | | | | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Ancylus Sea, continental Period | Boreal Period, dry and gradually rather warm | Th… / Fir Period | *Alnus glutinosa, Quercus robur, Tilia cordata, Ulmus glabra, Ceratophyllum demersum, Najas marina.* *Corylus avellana* *Cladium mariscus, Carex pseudocyperus* | *Planorbis corneus.* Mud-tortoise, Bison, urus, stag, roe deer, boar, bear, wild-cat, black woodpecker etc. | Epipalæolithic Stone Age | Mullerup Culture |
| | Zirphaea Sea | | Birch-fir Period | *Betula pendula, Prunus padus, Pinus silvestris, Betula pubescens, Populus tremula* | *Bithynia tentaculata, Pyramidula ruderata. Planorbis stroemi, Valvata cristata,* reindeer, elk, beaver, Alpine hare, rock ptarmigan | | Axes of reindeer-antler »N.Lyngby Culture« |
| Lateglacial Period | Mid. Swedish Sound | Subarctic (Climate) | Younger Dryas Period | *Arctostaphylus alpina, Betula nana, Dryas octopetala, Salix polaris, Salix reticulata, Saxifraga oppositifolia* | Reindeer, wolf *Limnaea peregra, Fossarina, Sphaerium corneum* | | |
| | Yoldia Sea / Baltic Ice Lake | Arctic (Climate) | | | | | |
| | | Subarctic (Climate) | Allerød Period | *Betula nana, Bet. pubescens, Juniperus communis, Pinus silvestris, Populus tremula, Rubus saxatilis* | Elk, beaver, brown bear, Reindeer. *Anodonta cygnaea, Ancylus lacustris, Planorbis fontanus, Valvata piscinalis f. antiqua, Valv. cristata, Physa fontinalis, Planorbis stroemi* | | |
| | | Arctic (Climate) | Older Dryas Period | *Betula nana, Dryas octopetala, Salix polaris, Salix reticulata, Saxifraga oppositifolia* | Reindeer | | |

Last Glacial Period.

overgrown and the main part of the Sphagnum peat of the swamped bogs was formed. The piling up of the kitchen middens proceeded in this period.

In the later part of the oak mixed forest period, the Subboreal Period, the climate changed and became more dry, and the upper dried strata of the bogs, appearing in the form of fossil forest soil with stump beds or as heath turf, was formed. As in the Atlantic Period, the summer temperature was rather higher than now. *Trapa natans* grew in various parts of the southeast of Denmark as also in Mid-Sweden and South Finland, where it was widely diffused in atlantic and subboreal times. During the latter period it is probable that a southern community of molluscs immigrated in Denmark, with *Helicodonta obvoluta*, *Succinea elegans f. typica* and *Cyclostoma elegans*.[78] The beech now started to spread in the forests of East Denmark. Finds from younger (Neolithic) Stone Age and from the Bronze Age have been taken from the strata of the Subboreal Period in Northern and Central Europe.[72,73].

During the Subatlantic Period there was a swamping of the bogs to a great extent, this being observable in the high moors by the deposits of the fresh "Upper Sphagnum Peat" over the subboreal dried strata and the atlantic, often very humified "Lower Sphagnum Peat". The climate had become more moist, the summer cooler and most of the thermophile species mentioned had either disappeared or become very rare. The beech gained the ascendancy over the oak mixed forest in most eastern Danish areas. Finds from the Iron Age have been taken from the subatlantic strata of the bogs.

Vertebrate remains[19,79,80,81,82] in bogs and other postglacial formations include numerous species; of those which later disappeared from Denmark are the elk, urus, bison, beaver, bear, lynx, wolf, wild-cat, black woodpecker, capercally, great auk, pelican and mud tortoise.

*Knud Jessen.*

### Aeolian Deposits.

In open places where sand forms the surface, that is to say on sandy beaches, the wind blows the sand and fine gravel together into large or small drifts: the dunes. Apparently they form a most irregular landscape of more or less steep crests; in some places, principally along the southern part of the west coast of Jylland and on the North Sea Islands, the dunes are arranged in several rows or walls parallel with the coast, and between these are extensive, wide or narrow dales, often with quite a smooth bottom.

The dune landscape occupies an area of about 700 sq.km, of which the greater part lies along the west coast of Jylland, from Skagen to Blaavandshuk, in a belt which in places is about ten kilometres wide; they are also to be found on the islands in the North Sea and, to a smaller extent, on the isles Læsø and Anholt in the Cattegat, along the coast of North Sjælland, and on the south and west coast of Bornholm. Here and there between the shore dunes and to the east of them lie blown sand in the form of a smooth covering over peat and other formations.

The younger dunes are quite naked (the "white" dune) and, owing to the fact that the wind blows the sand over to the lee side, they are moving in the direction of the prevailing wind.

Barcans, naked dunes in the form of parabolas, their openings turning away from the wind, do occur, but seldom last long. The largest barcan in Denmark is Studeli Mile at Raabjerg, SW of Skagen. Its top is 41 m above sea level, 20—22 m above the surrounding plain; it is about 1 km long from north to south and 600 m west to east; it moves about 8 m a year.

The dune is gradually covered with a vegetation of beach-grass, moss and lichen, etc. whereby the "grey" dune appears which forms the main part of the dune landscape. The grey dune also occurs in the form of a parabola, but its opening faces the direction of the wind. It is formed by the vegetation of an ordinary grey dune becoming destroyed and the sand exposed, whereupon "wind-breaches" are made, hollows from which the wind gradually sweeps the sand over to the lee side so that the dune again begins to move. The wings of the parabola gradually become longer and longer whilst the middle portion shrinks and, when at last it has been entirely blown away, there appear two parallel dune arms extending in the direction of the wind with a valley between them (fig. 14).

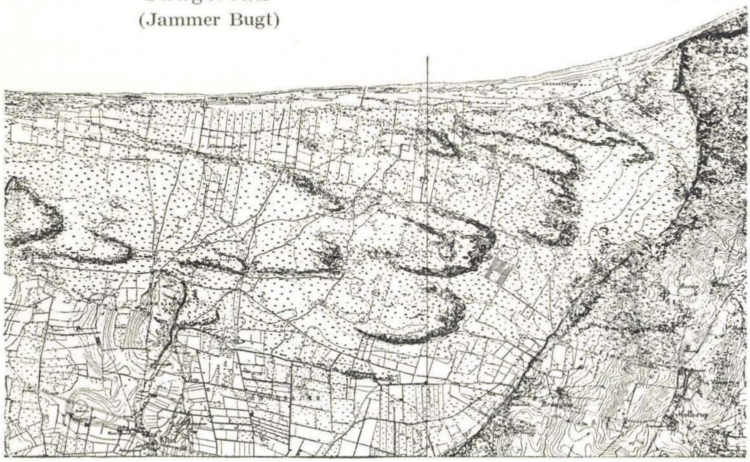


Fig. 14. Parabola-formed dunes west of Svinkløv. Photo from General Staff survey sheet, reduced to scale 1 : 110,000. (According to K. J. V. Steenstrup).

The conditions which cause dunes must certainly have been present during the whole of the Lateglacial and Postglacial Periods as well as earlier, but old shore dunes cannot be proved with certainty. Neither along the coasts of the Litorina Sea nor along the still older coastlines of the Yoldia Sea is it possible to prove the existence of large stretches of blown sand; on the other hand, within the boundaries of the present dune area one sometimes sees blown sand overlying peat-bogs which contain implements of the Stone and Bronze Ages, as also, where the sand has been blown away, one can recognise the original land surface with its layer of mould, its plough furrows, cart tracks, etc. At a few places several mould strata overlying each other, separated by blown sand, have been found. The sand-drift seems to have first begun seriously in historic times after the destruction of the forests, and is particularly known from the sixteenth century, from which time we begin to hear of great destruction caused by the sand-drift.[24.31]

The so-called inland sands, often miles away from the shore, are dune areas of much smaller extent. They have nothing to do with the shore, their material having been obtained from the arenaceous soil on which they stand. Thus the inland sands are to be found especially on heath-plains, in the sandy lateglacial river valleys or on hills formed of glaciofluvial sand. In contrast to the shore dunes, their origin can sometimes be traced far back. Thus the extensive banks of fine, stoneless sand to be seen in the West Slesvig marsh area (Ydre and Indre Bjergum at Ribe and the banks on which the villages of Abterp, Ubjerg and others stand) must be of lateglacial or early postglacial age, as they jut out through the marsh from the underlying heath-plain and can scarcely be presumed to have been formed after a rather dense, cohering cover of vegetation had taken root on the surface of the heath-plain.

Other inland sands too, for instance those NV of Egtved and Rækkebjerge east of Grindsted, have been proved to date from the Lateglacial and the beginning of the Postglacial Periods.[29] At several places tumuli of the Stone and Bronze Ages have been found, built upon blown sand or built of turf from the blown sand heaths.[29]

The inland sand area which covers the hill-island Rubjerg Knude, between Lønstrup and Løkken, is of peculiar origin. The blown sand has not come from the shore below at all, but from the upper part of the cliff made by the sea, strong gales hollowing out deep clefts in the glaciofluvial sand between the inclined argillaceous floes and carrying the sand up over and inside the edge of the cliff.[31]

A characteristic feature of certain areas in Mid-Jylland is the occurrence of blown sand as a covering over the glacial deposits without it having been formed into dunes. It must be assumed that the blown sand has been held upon the moist surfaces of these areas in lateglacial times.[29]

Where the sand is blown away from gravelly and stony sand deposits, peculiar Stone Plains are formed with a surface that is closely paved with the stones left behind. These are often sand-ground in characteristic forms with one or more sharp edges.[83]

The lower jaw of a ground squirrel, *Spermophilus rufescens*, which was found in 1877 by JAP. STEENSTRUP in the freshwater strata at Nørre Lyngby (see p. 133) has repeatedly occasioned the propounding of the supposition in literature that, during the transition between the Lateglacial and the Postglacial Periods in Denmark, there was a Steppe climate and scenery similar to that which prevailed in Central Europe during the glacial Steppe Periods. This supposition has, however, never been confirmed either by finds of Loess or Steppe plants or other remains of Steppe animals than the lower jaw in question. The presence of this *Spermophilus* in Denmark may be explained in another manner.[18,48]

The only geological deposit which, in Denmark, might lead one's thoughts to natural conditions similar to the Steppe is the dust deposits which have been found here and there on hill slopes, for instance Øxnebjerg near Langeskov, on Fyn[19,60] or at the top of cliffs (Ristinge Klint on Langeland);[22] but in the first place they are too thin (up to 1.6 m), secondly they are too insignificant in volume, and finally they date from such a late section of the Postglacial Period that there can be no question of construing from them any Steppe climate or Steppe scenery in Denmark. In these dust deposits there have been found here and there quantities of split, gnawed or partly digested bones of small mammals, birds, reptiles and toads, for instance fitchet (*Mustela putorius*) which has long been extinct, or exterminated, on Fyn, badger (*Meles taxus*), mole (*Talpa europaea*), shrew-mouse (*Sorex vulgaris*) and others; wood-cock (*Scolopax rusticola*), mallard (*Anas boscas*), robin (*Erithacus rubecula*), snake (*Tropidonotus natrix*), frogs (*Rana*) and toads (*Bufo*). These bones originate from the fox and badger holes of these hills, whence they have been thrown out and embedded in the masses of dust caused by earth-drift, and also from the gulp of birds of prey.[84]

*V. Nordmann.*

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## Abbreviations:

Dansk geol. Foren. = Meddelelser fra Dansk geologisk Forening. København.
D. G. U. = Danmarks Geologiske Undersøgelse.
N. G. U. = Norges Geologiske Undersøkelse.
S. G. U. = Sveriges Geologiska Undersökning.
G. F. F. = Geologiska Föreningens i Stockholm Förhandlingar.
Vid. Medd. Naturh. Foren. = Videnskabelige Meddelelser fra Dansk Naturhistorisk Forening i København.
Vid. Selsk. Overs. = Oversigt over det kongelige danske Videnskabernes Selskabs Forhandlinger.
Vid. Selsk. Skr. = Det kongelige danske Videnskabernes Selskabs Skrifter.
Aarb. f. nord. Oldk. = Aarbøger for nordisk Oldkyndighed og Historie.

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# Forms of the Surface.

The surface of Denmark has principally received its forms from the activities displayed by the inland ice and its meltwater during the Last and the Last but one Glacial Periods. To a smaller extent they are the result of fluviatile and marine accumulation and erosion as well as earth-flow, earth-creeping and the effects of the wind. Emergences and submergences have also contributed towards giving Denmark its present shape.

In a low country like Denmark, which to a great extent is built up not of rocks but of earth-layers, it was particularly in the marginal zone of the inland ice and within a belt on the outside of it that the forming of the surface went on, a certain series of landscape forms appearing as a result of the activities of the inland ice and its meltwater, especially when the ice-edge remained stationary at the same place for any length of time.

For some distance inside the edge the inland ice for the most part worked in this manner: it swept and smoothed its underlayer, moving steadily forward over its ground-moraine, the latter at the same time being carried along by the ice and gradually deposited under it. Under the ice, some way from the edge, there thus was formed a moraine-flat, an even surface which rises and falls gently in broad, flat undulations. Examples of typical moraine-flats are the "heath" between København, Roskilde and Køge, the "plain" in North Fyn, and the district round Fredericia. A moraine-flat may have been formed as a central depression, which later on may have contained a bay, as for instance Køge Bugt, Lammefjord and Sidingefjord in Odsherred, Kertinge

Nor on Fyn, the broads in the western part of Limfjord, Kalø Vig and Æbeltoft Vig on the east-coast of Jylland, Gudsø Vig at Kolding Fiord. A moraine-flat may lie so high that it forms a plateau, the edge of which is often deeply indented by late-glacial and postglacial erosion. The country to the north of Aarhus and the land between Horsens and Kolding Fiord may be quoted as an example of a plateau. The erosion may have had the effect that a small portion of the plateau has been cut out so that it forms a "false" hill, as for instance Himmelbjerget near Silkeborg, Skræderbakken in Grejsdalen and several "hills" at Vejle Fiord.

That part of the underlayer which the inland ice carried along with it was pushed out towards the edge. As these masses of earth, which were constantly increasing, approached the edge, the ability of the ice to transport them became less and less as its thickness decreased out towards the edge. The greater part of these masses of earth remained lying in under the ice and, when it melted, made their appearance in the form of a hill-country which, in its typical form, is characterised by hills of all sizes, quite close together and frequently steep, often running into one another. Between the hills there are depressions with bogs and lakes, sometimes dry hollows. The details of the forms are for the most part due to the original, irregular accumulation of the earth masses. The hollows have often occurred through the melting of lumps of ice which had become embedded in the earth masses. The original forms have been further shaped by late- and postglacial erosion, or somewhat blurred by earth-flow and earth-creeping. We have hill-country typically developed in several districts famed for their natural beauty, such as the Himmelbjerg district at Silkeborg, the environs of the lake Hald Sø at Viborg, Mols, Tolne Bakker in Vendsyssel, Svaninge Bjerge at Faaborg and the ridges round the central depressions in Odsherred.

A part of the earth masses transported by the inland ice was, however, carried right out to the edge and deposited along it as a marginal moraine which, when the ice melted, remained as a long ridge in the same direction as the edge of the ice, built up of moraine material, principally moraine gravel, and meltwater material, pebbles, gravel, and sand. The position of the marginal moraines is in the outermost parts of the belts of hill-country. Sometimes they can be followed as continuous mounds over long stretches; but much more frequently they occur as short ridges, only a few hundred metres long, linked up in long rows. Examples of typical marginal moraines are that at Horneby, south of Hornbæk in North Sjælland, Torpshøje marginal moraine at Løsning SW of Horsens, the marginal moraines in front of the hill-country on Mols, Tulsbjerge between Hobro and Salling.

Not infrequently do we find systems of marginal moraines lying parallel and so close one behind the other that we have a marginal moraine landscape. There are several of these in North Sjælland, for instance in Gribskov, in Teglstrup Hegn west of Helsingør (Elsinore), in Rude Skov and at Søllerød.

A particular form of marginal moraine is the transverse-hill, a rounded, elongated hill running in the same direction as the ice edge, consisting of glaciofluvial gravel and sand or of material of a nature between this and moraine sand. The position of the strata is disturbed, the strike is along the direction of the hill and most often the strata dip outwards towards the sides of the hills. Here they run down under the moraine clay cover of the flatter, surrounding country, the moraine clay often continuing some way up the sides of the hill; sometimes the whole of the transverse-hill may be covered with moraine clay. It would seem that the transverse-hill has been forced up in front of the ice edge by the pressure of the ice. Transverse-hills appear particularly on Langeland, on Hindsholm and on the southern part of Samsø, where there are so many that the observer finds himself in a transverse-hill landscape.

When it happened during the melting that the movement of the marginal zone of the inland ice ceased, so that for a time the ice-sheet was stationary before it quite disappeared, the final melting produced the hummocky moraine landscape which consists of a large number of small hills and bog holes, lying quite irregularly as regards each other. The depressions have appeared where the ice has lasted longest, and the hills where the moraine material has accumulated between the masses of ice. A typical example of a terrain of this kind is on the stretch south of Hareskov and Jonstrup Vang, northwest of København.

An interesting hummocky moraine landscape overlying an older terrain with large, regular and evenly formed ridges the shape of which it only partly conceals, is to be seen at Kalø Vig (see fig. 15).

Here and there we find isolated solitary mounds or cones, consisting of glaciofluvial gravel and sand, usually with irregular bedding. We believe that the material which forms them has been washed together in the hollows in the surface of the ice; this sand infilling has then, when the ice melted, remained in the form of a hill. A similar manner of formation must be imagined for hills consisting exclusively of stratified clay, "plateau clay."

The meltwaters of the inland ice flowed together in subglacial streams in ice-tunnels; as they were under pressure in these tunnels they were able to run "up-hill" to the ice-edge, where through ice-caves they rushed out in the open air over the country in front. In deepening their beds in the substratum of the ice they produced tunnel-valleys. The erosion of the subglacial river bed was naturally irregular, according to whether the tunnel was high or low and according to whether ice had fallen from the roof of the tunnel into the river bed. As a consequence, the bottom of the tunnel-valley became uneven, with long, irregular depressions in which long-lakes were formed, when the inland ice melted. In the tunnel-valleys, especially near to the mouth, masses of gravel were deposited here and there and, when the ice melted away, these remained as ridges, eskers, their longitudinal direction at right-angles to the ice-edge and as a rule rather winding in form.

The longest of the tunnel-valleys can be traced right from the Cattegat to the eastern boundary of the great heath plains; in many places the sea has made its way into the eastern part of the tunnel-valleys and has there formed fiords.

When the meltwater rivers flowed out over the open country in front they deposited the gravel and sand which they carried along and thus filled up the lower parts of the country. Thus the outwash plains, called in Denmark "heath-plains," gradually formed, those in Middle and Western Jut-

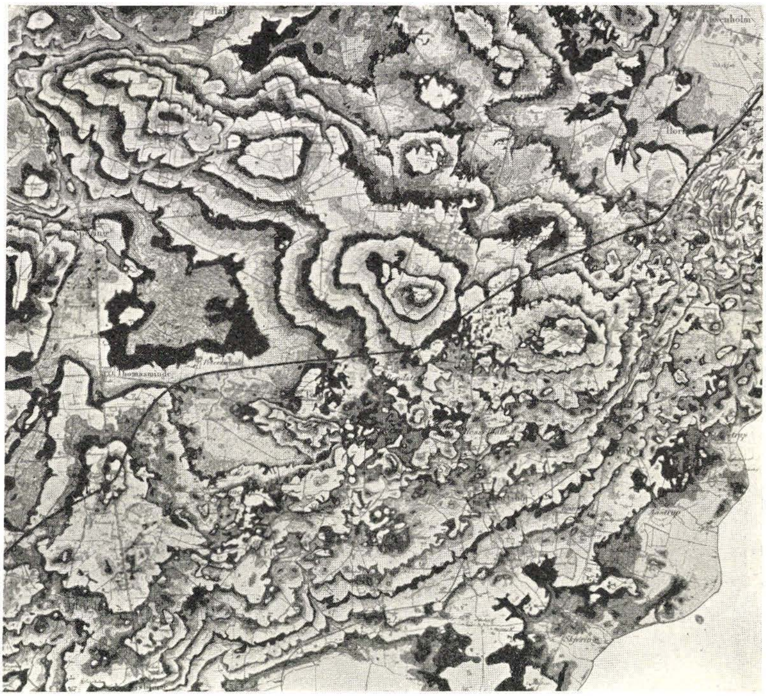

Fig. 15. Terrain Map (scale 1 : 140 000) of the area between the valley of the river Lilleaa and the bay Kalø Vig, NE of Aarhus in Jylland. The boundary lines between the darkest and the lightest belts mark the 40 ft contours; the 10 ft contours are indicated by the intermediate, lighter tones. The black line which runs across the map is a part of the East Jylland stationary line (see p. 114); here it forms the boundary of the Kalø Vig ice-tongue. SE of the black line is a hummocky moraine landscape which overlies an older terrain with large, regular and smoothly formed hill-ranges, the forms of which it only in some measure conceals. NW of the black line this older terrain makes its appearance with its big, regular and evenly formed hill-ranges. (After POUL HARDER: En østjydsk Israndslinje. With an English Summary of the contents: An ice-edge line in East Jutland and its influence on the water-courses. D. G. U. II. Række, Nr. 19).

land being by far the largest. They consist of glaciofluvial sand and gravel; they form flat half-cones (alluvial fans) the tops of which lie where the tunnel-valleys end. Here is the coarsest, stony material; farther away is the finer gravel and sand. At the end of the tunnel valley the fall of the heath-plain is as a rule 1 : 400 or 1 : 500, in the middle of the plain 1 : 700 and, out by the North Sea, 1 : 1000.

Where the old land from the previous Glacial Period was too high to be covered with heath sand, hill-islands were formed, large or small areas which, in the form of islands, jut up out of the heath-plains. In the surface of the hill-islands are Denmark's oldest surface deposits, moraines, which as a rule are sandy, and glaciofluvial deposits of the Last but one Glacial Period, in which weathering has penetrated deep down. From the end of this Glacial Period through the Last Interglacial Period, the Last Glacial Period, the Lateglacial and the Postglacial Periods, the hill-islands have lain there, exposed to the activities of the disintegrating forces. The original forms of terrain have been effaced during this long passage of time. There are no longer any lakes, the depressions without an outlet have for the most part been filled up or converted into valleys, steep slopes have been evened out, hill tops and ridges have become lower and flatter, the tunnel-valleys have lost their particular stamp, the main waterways are consequent, the tributary water-courses insequent. Wide valleys have been formed with an even fall; water courses and valleys "match each other". The whole surface has acquired a quiet, expansive old character. The cycle of erosion has long ago reached its maturity stage.

The three types of landscape: moraine-flat, hill-country and heath-plain, are thus related in origin. The longer the ice-edge remained at the same place, the more marked did they become; the quicker the melting of the ice proceeded, the less did they develop; there then sometimes appeared intermediate forms, about which it is difficult to say whether they ought rather to be called moraine-flat, hummocky moraine landscape, or hill-country.

The inland ice always had a tendency to raise the terrain at its edge by the deposition of hill-country, marginal moraines and heath-plains, the highest parts of which were at the ice-edge. We therefore frequently find that watersheds coincide with the stationary lines. When the ice melted back quickly from a position which it had held for a long time, the meltwater could not secure an outlet forward over the stationary line but had to make a new way behind it. Thus the meltwater streams gradually eroded normal extra-marginal river valleys, the floors of which have an even fall, the streams now and then making use of parts of the old tunnel-valleys still existing. A close study of the various valley systems shows through what courses the meltwater of the inland ice streamed away at the various periods. When the meltwater thus secured a shorter route to the sea, its eroding powers increased and terraces appeared in the valleys. Fine examples of extra-marginal valleys are given by the valleys of the rivers Gudenaa and Skalsaa, which in many places are more than 50 m deep and 2 km wide. Large valleys like these show clearly that the masses of water to be got away were very great. The valleys are "too large" for the rivers of today; valley and river do not "match".

With the exception of the hill-islands, the terrain forms described here are not older than from the end of the Last Glacial Period. Since their formation they have not undergone any great change. The fall of the valleys is often not levelled up yet; there are often lakes in them. In a morphological sense they are young; the cycle of erosion is still in the youthful stage. Where we find this form-complex we may be sure that we are in the area of the last glaciation.

Of the surface forms which have appeared in the Lateglacial and Postglacial Periods, the marine plains occupy the largest areas. It is possible to differentiate between the higher lateglacial plains in Vendsyssel, and the lower alluvial coast plains in the northern parts of Jylland, Fyn and Sjælland, both of which consist of raised sea floor, and the marsh plains formed after the Bronze Age in southern West Jylland. To the marine plains are attached the accumulation forms: accumulation terraces, beaches, spits and points and the lakes cut off from the sea by the rising of the land, for instance Arresø, and the beach or lagoon lakes cut off by beaches, for instance Kjeldsnor at the south end of Langeland and the not yet wholly closed

Ringkøbing Fiord and Nissum Fiord, and also the erosion forms: cliffs and erosion terraces.

The river plains, which in some cases are of no small size, for instance round Gudenaa at Randers and the delta of Skjern Aa, and also the bogs, of which the largest are Store and Lille Vildmose, are both freshwater deposits.

The action of the wind has produced the dune landscape which has already been described on pages 139—141.

*Victor Madsen.*

# Changes of Level.

Marine sediments play a predominating part in the geological structure of Denmark and the constant change from sandstone, clay shales, limestone, sand and clay bears witness of changing geographic conditions and of the numerous transgressions and regressions of the sea.

The Cambrian series of Bornholm: sandstone, arenaceous shales, bituminous clay shales, is evidence of a steady submergence and of the transgression of the European Cambrian sea in over these areas. Far into the Silurian there was sea here, whereas the absence of deposits from Devonian and Carboniferous would indicate a regression and that this part of the earth's surface has for a long time been land. Whether this also applies to the Permian is uncertain, for as yet we have no exact knowledge of how far the Permian strata of Mecklenburg and Holstein can be traced northwards. Not until the close of the Triassic can we definitely show a new transgression from the south in over parts of Scandinavia. The nature of the Rhæt-Lias strata on Bornholm, where freshwater beds alternate with lagoon and marine deposits, indicate, however, a border zone with regular alternations between land and sea.

From the middle of the Jura to some way into the Cretaceous Period no marine deposits in situ are known within the borders of Denmark, and nothing is known of the level of the country. Numerous boulders of limestone and sandstone from this period, for instance the large numbers of Kimmeridge-Portland boulders in North Jylland, would indicate, however, that such rocks are to be found deep down or close to the coast and that, at any rate in certain sections of the Upper Jurassic and Lower Cretaceous Periods, the sea has extended in over Denmark.

During the course of the Mesozoic Period there have been very considerable vertical displacements along the fault zone which runs NW—SE, from the Cattegat over Skåne and Bornholm and forms the boundary between Fennoscandia, which throughout long periods was always high, and the submergence area to the south of it, Denmark and the North German lowland. The thickness of the Mesozoic deposits south of this boundary amounts to several kilometres and even the sediments which were deposited over Denmark during the last subdivision of the Cretaceous Period, have a thickness of about 1 km.

The occurrence of deposits from Cenomanian, Upper Turonian and Lower or Middle Senonian on Bornholm show that then the sea reached as far as that at times. In continuation there were deposited the thick beds of lime marl and chalk which must be assumed as forming a continuous substratum under the whole of the country (with the exception of Bornholm). Whereas from Middle Senonian and into Upper Senonian—from the Quadratus Zone to the Mucronata Zone—we must presume a sinking of the sea floor to fairly great depths, in the end of Senonian there occurs an upheaval with the result that parts of the bottom of the Chalk Sea are brought up to and partly over the surface. There is, however, much to indicate that at the boundary between Senonian and Danian we must count with two regressions, separated by a slight transgression.[1] At the beginning of Danian the land sank again so that the sea covered, if not the whole of Denmark, at any rate the greater part of it; the rather variegated chalk and lime beds deposited in this period indicate changes in the depth of the sea. Throughout Upper Danian and until the close of the Danian Period there was a steady rise, at the culmination of which large and small areas lay above the water. During a subsequent submergence the Paleocene strata were deposited, first littoral strata, later—at greater depths—clays, usually with decreasing lime content.

At the transition from Paleocene to Eocene there were probably considerable displacements along the boundary between the Scandinavian high land and the plain land, built up of sediments, outside it, and in the first part of the Eocene period Denmark was covered by the sea. The absence of Upper Eocene(?) and Lower Oligocene indicate that the country has then been above sea-level, but again in Middle and Upper Oligocene Denmark was covered by the sea and, under changing geographical conditions, sometimes very rich, sometimes sandy, clay was deposited. In the beginning of the Miocene the land rose so much that considerable freshwater strata (lignite) could be formed, but only to be partly covered by the sea again in Middle and Upper Miocene, when arenaceous clay and thick sand strata were deposited. No marine deposits are known in Denmark from the Pliocene. But that the sea has not been far away can be seen from the occurrence of marine Pliocene on the island Sylt.[2]

Very little is known of the levels of Denmark during the Ice Age, even though the researches of the past forty years have brought to light much that is new. For the present we must assume that Denmark has lain at a high level, both in the Pliocene and in the oldest part of the Ice Age. The first signs that the country—or parts of it—have been under water are from the beginning of the First Interglacial Period, when marine clay was deposited at Esbjerg.[3] The deposition of the clay directly over an older moraine, and the character of the fauna (see p. 90) give evidence of a steady emergence and, simultaneously, a rising sea temperature. The extent of the clay and the nature of the fauna indicate that the area at Esbjerg in the beginning of this Interglacial Period must have lain at least 20 m lower than it does now.

During the melting of the first inland ice and the retreat of the ice-edge across Jylland, at any rate the south of Mid-Jylland must have lain above the sea level, as is evidenced by the widespread Diluvial Clay deposited in fresh water, free of stones and, in a few places, plant-bearing.[3] By the Little Belt the now considerably dislocated Tellina Clay (see p. 92) in Røgle Klint indicates that the sea has reached as far as this, probably shortly after this area became ice-free.

If one may venture to group the deposit of marine clay at Hostrup,[4] west of Skive (p. 93) under the First Interglacial Period, this will mean a fairly considerable change of level for this area, it being taken for granted that the strata lie on primary basis. The marine clay extends to about 25 m above sea level and has been deposited at a depth of between 15 and 150 m, so that the land must have lain at least 40 m lower than now. As the overlying sand, with a Boreal ground-water fauna, extends to 27 m above sea level, there must, as at Esbjerg, have been an upheaval of the land simultaneous with the supposed rise in the temperature of the sea.

At the boring at Skærumhede,[5] fragments of arctic molluscs were found in the oldest moraine (of Baltic origin) and at a depth of 160 m. These show the presence of sea east or southeast of Vendsyssel, either at the beginning or the end of the First Interglacial Period and may, owing to the unusual depth, indicate that the sea floor at that time lay at a higher level than now. And furthermore, if some of the scattered occurrences of pleistocene, marine, shell-bearing clay[6] (for instance Kibæk and Ansager in Jylland) were deposited in the same Interglacial Period, the distribution of land and sea in certain later sections of that Period must have been very different to what it is now; as to the levels, however, they give no direct information.

The Danish marine deposits known from the Second, the Last Interglacial Period, found in situ, all date from the warm part of this period and from the subsequent period with a falling sea temperature. Until we have evidence to the contrary we must therefore assume that in the first part of this Interglacial Period Denmark lay at a higher level than it does now.

In the south of Denmark is it principally the Eem deposits[7] from which we can gather anything regarding the distribution of sea and land. From the diffusion of the Eem deposits, their nature and fauna, it appears that the Eem sea formed a long, comparatively narrow fiord which, from the southern part of the North Sea, stretched eastwards over South Jylland, the South Fyn islands and on into the southern part of the Baltic. Furthermore, the stratigraphical position of the deposits show that, at any rate in Southern Denmark, a submergence took place at that time and later on an emergence, the result being that the series from below upwards was: peat, brackish water bed, pronouncedly marine clay and, at the top, sea sand, and that both the positive and the negative alteration of the shore line took place during the temperate part of the Interglacial Period. Within Denmark's boundaries the Eem deposits are only found undisturbed in situ along the North Sea coast, south of Blaavandshuk; on this stretch they attain an average height of 10—12 m below the sea level and, as the fauna is partly a littoral fauna and partly must be looked upon as a low-water fauna, Southwest Denmark during the maximum of the transgression cannot have lain at a much lower level than now. Both before and after this maximum that part of the country has, during the whole of the Interglacial Period, lain at a higher level than now.

As regards the most northerly part of Denmark, the thick marine series at Skærumhede[5] gives fairly complete information regarding the levels during the Last Interglacial Period. The lowest strata of the Skærumhede series must, judging from the fauna, have been deposited at a depth of 40—60 m under the sea and the other part—the greatest—at a depth of 60—80 m. As the stratum is now at a depth of 157 m to 83 m below the sea level, this part of Denmark must have been at least 100 m higher when the deposition began than it is at present. Today the 100 m depth contour runs a little way north of the northern point of Jylland, along the south edge of the Norwegian Deep and from there roughly towards the west in the direction of Scotland. Although during the Last Glacial Period a great deal of moraine material was deposited in the Skagerrak and large masses of clay and sand were washed out into the North Sea, thus raising its floor and making it even, it is certain that large portions of the sea floor west of Jylland have been dry, and the possibility is not excluded that, during the Second Interglacial Period, there has been a land connection between Jylland and England.

Simultaneously with the deposition of the 74 m thick, boreal Turritella Zone, there was a steady sinking of the land so that at last it reached a level that was only 10—20 m higher than it is now. During the subsequent deposition of clay with a boreoarctic fauna, the submergence was replaced by an emergence, bringing the land up to a level which probably lay 40—60 m higher than that of the present day, only to sink again, during the deposition of clay with an arctic *Portlandia arctica* fauna, to a level which, judging by conditions at Skærumhede, was 15 to 25 m higher than the present one. But if we consider other occurrences of the clay strata of the Portlandia arctica Zone, about which it is possible, in view of the extent of the clay and its thickness, to say with the greatest certainty that they are *in situ*, we arrive at a still lower level. In the cliff at Hirshals, north of Hjørring, the clay reaches a height of 2—4 m above sea level, and at Frederikshavn, where out on the plain-land it forms a flat abrasion plane with an extent of at least 7 km from Frederikshavn northwards to Strandby and can also be traced southwards along the foot of the hills to Sæby, the surface of the *in situ* clay lies 2—5 m above sea level and, at certain places, undoubtedly 15 m above sea level; as the clay was deposited at a depth below sea level of at least 10—20 m, this area at the end of the Interglacial Period must have lain at least 20—30 m lower than it does now.

While the inland ice in the subsequent, Last Glacial Period pushed its way over Vendsyssel, a regression of the sea was simultaneously proceeding, the deposition of clay gradually taking place above the sea, in fresh water, and likewise the thick sand masses overlying the clay and deposited immediately in front of the ice are exclusively glaciofluvial deposits.

The occurrence of mollusc shells of both boreal and arctic species in the moraines in Northeast Sjælland,[8] as well as the *Tellina calcarea* clay at Høve, in Odsherred[9] — probably contemporary and not on its original place of deposition — show that the sea in which the marine Skærumhede series was deposited also extended some way into the Cattegat.

Thus the geographical conditions of Denmark have been subjected to great changes during the Second Interglacial Period. During its first part the whole country has probably lain at a higher level than it does now. It was only in the temperate period, and possibly only during a brief part of it, that a submergence towards the south occasioned the formation of an arm of the sea which stretched from the west along the south coast of the North Sea, over South Jylland and into the Baltic. The information provided by the marine series at Skærumhede, viz that Northern Denmark—likewise in a part of the temperate section of the Interglacial Period—lay very high, more than 100 m higher than now, may possibly explain why the fauna in the Eem sea-arm in the south must have immigrated from the warm sea by the coast of France and has either not at all, or only to a slight degree, been added to from more northerly areas, whereas inversely the fauna in the Skærumhede strata in Vendsyssel must exclusively have immigrated from the north and northwest, from the sea between Norway and Scotland, the more southern part of the North Sea probably being land at that time. While the Interglacial Period was drawing to a close and the inland ice was again approaching Denmark, there took place in North Jylland a submergence—interrupted by a brief emergence—down to about the level of the present day, whereas Southern Denmark still lay higher than it does now.

Very little is known of the levels during the Last Glacial Period; but there is no doubt that the ice-free, western part of Denmark has all the time been higher than now, as there is no trace of any marine deposit from this period.

The melting period—the Lateglacial Period—provides better material for judging the levels. Whereas the north-eastern part of the country was lower than in our day and sank still more simultaneously with its becoming ice-free, the southern and southwestern part of Denmark was undoubtedly rather high, as is for instance shown by the deep channels excavated or modelled in The Sound and Little Belt in front of the ice-edge. With regard to The Sound, our knowledge of the level changes of the subsequent period is still rather uncertain. The occurrence of lateglacial coast lines along the east side of the Sound and of marine, arctic clay as far south as Lomma, NE of Malmö, where it is found up to several metres above the sea, presupposes a positive shoreline change which has possibly affected the Danish side of the Sound too, although no trace of it can be found. It is peculiar that whilst the uppermost limit of the lateglacial ice sea is indicated as lying at a height of 20 m to the south of Hälsingborg, at 38 m to the north of that town, and 51 m at the promontory Kullen, above the present sea level, not a trace of marine coast lines or deposits from that period has been found on the Danish side. If they have existed, they have lain at such a low level that they have later on been covered or destroyed in the Tapes Period, that is to say that at Helsingør (Elsinore)—Hornbæk they have lain less than 10 m above the present sea level and at Rungsted less than 6 m.[10] For the present we must therefore hold to the well-known view that, in the Lateglacial Period too, there have been displacements in a vertical direction along the old fault line, which from the west side of Kullen runs in through The Sound.

While the inland ice continued to melt away from the southern part of the Baltic, a considerable emergence took place in this region. The water in the Baltic, which to the north was dammed by ice, secured an outlet to the Cattegat through channels in the bottom of what are now the Danish sounds, but, as a consequence of the upheaval of the land, was stemmed higher and higher up—according to Swedish investigations as much as 55 to 56 m—over the water level in the Cattegat. As the subterranean ridge which, as a continuation of Gedser reef stretches southeast to Pomerania and which formed a lip over which the water had to flow out, is now 18 m under the sea level, the most southeasterly part of Denmark must thus have lain 73—74 m higher than at the present time, possibly rather more.

Whilst the country to the south at Falster and North Germany must presumably have lain at such a high level, Middle Sweden lay very low. The line of demarcation between the shore lines of the Baltic ice lake and the present level of the Baltic must presumably be drawn from southwest Skåne to the southeast, a little south of Bornholm. On that island the shore lines of the Baltic ice sea (often erroneously given as lateglacial marine shore lines) along the south coast lie about 10 m, to the north at Hammeren 20—21 m, above the present surface of the Baltic.[11]

The supposed very considerable uprising in most southerly Denmark must have involved such a pronounced change in the shore line—least in The Sound, most towards the southwest—that the sea floor round about the Danish islands and in the southwest part of the Cattegat must have been laid dry, even though the extent of the upheaval decreased rapidly in a north-easterly direction. The few hitherto known occurrences of lateglacial freshwater deposits in the waters round Denmark are, however, naturally found so close to the coast and at such slight depths (in The Sound—5.4 m[10] and at Esbjerg—4.9 m), that they do not yield any great contribution to our knowledge of the levels and extent of the country at that time.

In Northern Denmark conditions were essentially different. At some places in Vendsyssel it has appeared that the upper part of the moraine left by the inland ice must have been deposited in the sea. Gradually as the ice disappeared from this part of the country, the submergence continued and the sediment deposited in the sea passed from sand (Lower Saxicava Sand) to clay (Lateglacial Yoldia Clay). Shore lines (erosion terraces and beach gravel) from this period are known from Vendsyssel southwards to Mariager Fjord and to the southwest to the town of Nibe on the Limfjord. The height above the present sea-level decreases rapidly from north to south and southwest.[12] Five or six kilometres south of Frederikshavn there are shore lines 56 m above sea-level, at Sæby about 50 m and at the village Voersaa abouth 40 m. Thence to the southwest there are shore lines at Dronninglund NE of Aalborg, up to 35 m, at Hammer Bakker 25 to 30 m and at Aalborg 20 to 21 m above sea-level. Southwards along the east coast of Himmerland, between the Limfjord and Mariager Fjord, the height decreases, the lateglacial raised beaches at Mariager Fjord being only 6.0 to 6.6 m above the sea. Still further south they coincide or are covered by postglacial raised beaches. The same is the case on the east coast of the peninsula of Djursland and in Northeast Sjælland between Helsingør (Elsinore) and Gilleleje, where it might have been expected that the lateglacial sea had left durable traces.

In the west of Vendsyssel, where stone is very scarce and it is an easy task for the wind to rearrange the loose soil, lateglacial shore lines are rare. Beach gravel is to be found, for instance north of Hjørring, 40 m above sea-level and east of Brønderslev, south of Hjørring, 40.5 m above sea-level; but only in a few cases (for instance at Brønderslev) is there certainty that this is the highest marine boundary. To the southwest the heights above sea-level decrease rapidly; thus at the isle of Gjøl in the Limfjord they are 13 m and NE of Nibe 11 to 9.5 m. West and southwest of this district the lateglacial coast lines are covered by postglacial raised beaches. The zero line must therefore run from NW to SE, from the east of Thy over Djursland and from there in the direction of the north coast of Sjælland.

The sediments which were deposited during the submergence and the subsequent emergence were sand, Yoldia Clay and, at the top, again sand (Upper Saxicava Sand). These deposits infilled the depressions between the hilly portions which jutted out like islands over the ice-sea, and now form very flat plains whose height above sea level decreases evenly towards the southwest. To the north and northeast their height is 30 to 34 m above sea-level, at Sæby up to 22 m and to the south near Hals, at the eastern mouth of the Limfjord, about 10 m. In a south-westerly direction we find the height at Hjørring to be 20 to 25 m, at Løkken and Store Vildmose about 15 m and in southwestern Vendsyssel 0 to 2 m. In the meadow land about Nørresundby and Aalborg, where the Yoldia Clay is greatly used for technical purposes, it lies only few metres above the sea. The most southerly locality hitherto known is at Dokkedal (Muldbjerge) on the east side of Lille Vildmose.

In the most northerly part of Denmark the great lateglacial submergence was succeeded by an emergence during which shore lines were formed at various levels, and at the same time the temperature of the sea rose, the result being that the higharctic fauna was supplanted and a boreoarctic fauna spread. We have evidence of this in two shell banks (now almost dug away) lying at a height of 20 to 25 m, just west of Frederikshavn (see p. 126).

The upheaval of the land was continued (at any rate in North Vendsyssel) until it was brought almost up to its present level, after which it was again subjected to a submergence, but of shorter duration and smaller extent, of up to 15 m below the present level. Littoral deposits, the Zirphaea Beds (see p. 127) from this period, the transition from Lateglacial to Postglacial Period, have been found at a number of places in the most northern part of Vendsyssel.

At the close of the Lateglacial Period the inland ice had melted so far back that the Baltic ice lake obtained a connection with the Cattegat over the Middle Swedish low-land, and the level of the lake sank to the same height as that of the ocean. When this connection with the sea was again closed, the Baltic once more became a freshwater lake, the Ancylus Lake, with an outlet through Närke in Sweden to the Vänern Fjord. As the regions round the Southern Baltic still lay very high, wide areas were laid dry through this lowering of the level; both a theoretical calculation of the height of the coast line and a find of peat and tree stems on the floor of the Baltic have given as a result that the coast line of the Ancylus Lake in the south—for instance around Bornholm—has lain near to the 50 m depth contour, and possibly even deeper. Among the deepest occurrences of submarine fresh-water deposits are finds of *in situ* trunks of fir, some of them to the south of the south coast of Skåne at a depth of 35 to 37 m,[13] others southwest of Bornholm where, on a stretch of about 20 km from Dueodde to the southwest, out towards Adeler Grund, both stumps and stems of fir have been met with at a depth of 35 m.[14]

As a consequence of the continued upheaval of the land in Northern Scandinavia, the Ancylus Lake transgressed southwards until the water level there had become so high that the water could flow over the aforementioned lip between Gedser and Pomerania. Then the water level of the Ancylus Lake may, according to Swedish investigations, be estimated to have been at least 20, and possibly 32 m above sea level and, as the submarine ridge as already mentioned lies at a depth of 18 m, the most southeasterly part of Denmark has at this time been 38 m, and possibly 50 m, higher than it is now.

Numerous finds of freshwater deposits from Danish sea, principally peat and mud, are evidence of the greater extent of the land at that time. Thus there are bogs and other freshwater deposits in Køge Bugt at — 11 m, in Kongedybet near København at — 13.8 m, in Kronløbet near the sea fort "Trekroner" — 9 m, in the Free Port of København at — 8 m, north of the isle of Saltholm — 5 m and at Rungsted — 4 m.[15] Peat deposits, found by means of borings under younger, marine deposits, have on Hindsholm (NE Fyn) been met with at a depth of — 6 m and, on the west side of Fyn by the Little Belt, 6.5 m under the level of the sea. On the west side of the Jylland peninsula peat deposits have been found in Graadyb, off Esbjerg, at a depth of 6.9 m and further south, off the west coast of Slesvig, at — 20 m. If we add to this that trawling in the North Sea has brought to light peat at various places, for instance a large area west of Nissum Fjord at between 20 and 40 m depth, between Horns Rev and Dogger Bank at about 40 m depth and finally, that a good deal of peat (moorlog) has been known for a long time and is still fished up on the Dogger Bank, oftenest from a depth of 35 to 40 m, and that this peat, judging from its plant content, was formed from the time of the dwarf birch *(Betula nana)* into the time of the fir forest, that is to say the beginning of the Continental Period, the same thing seems to apply to the southern and eastern North Sea as to the southern Baltic, viz. that these areas then were up to 40 m higher than they are now; the greater part of the North Sea south of a line from Hanstholm southwest to the mouth of the Humber, must then have been land.

There are very few observations from the Cattegat area to throw any light upon the levels. Submarine peat *in situ* has only been found at slight depths; on the other hand, at a depth of 26 m east of the isle of Læsø and in the southeast part of the Cattegat there have been found mollusc shells of species (including *Litorina litorea*) which must be described as littoral forms or shallow water animals.[16] These finds should undoubtedly be placed to the Continental Period and show that the floor of the Cattegat, even as far north as at Læsø, must have lain higher (perhaps about ten metres or more) than at the present time. In the most northerly part of Jylland occurrences of peat, overlain by younger marine deposits, show that in the Continental Period the district round Aalborg has lain at least 6 m higher than now; it is probable that differences in the level decrease the further north one goes. As to the northern part of Vendsyssel we know that it has lain at any rate at the same level as it does today.

The close of the Continental Period and the beginning of the next period (the Litorina Period, the Stone-Age Sea Period) is, as regards the whole of Denmark, characterised by a very considerable submergence, whereby large stretches in the present Baltic and the southern part of the North Sea were covered by the sea. Gradually as the land sank, such an open connection was formed through the channels between the Cattegat and the Baltic that the salt sea-water was able to make its way into the latter sea.

In Northern and Eastern Denmark the maximum of the submergence coincided with the "kitchen midden" period (Ertebølle culture) of the Campignien and, as the transgression was here succeeded by a regression, it has been possible to determine the level of the country at that time. Furthest north, in the region round Frederikshavn—Hirshals, the country had, during the maximum of the Litorina Period, sunk to the greatest depth, about 13 m lower than at present.[17] The further one moves from here towards the southwest, out through Thy or southwards along the coast of the Cattegat, the less does the difference from the present level become, until one reaches the zero line already drawn by FORCHHAMMER for the upheaval, from Nissum Fjord southeast through the country, cutting the east coast of Fyn a little south of Nyborg. Southwest of this line the general submergence has been still greater, greatest in the southwest; but as the land there already lay at a very high level, it had not yet, at the time of the maximum of the Litorina Period, during the Ertebølle culture, got down to the level of the present day. Southwest of FORCHHAMMER's line the coast line ran outside the present one, but beyond that we know very little about the levels.

The few finds of implements of the Ertebølle culture, which originate from the waters along the coast of South Denmark, lay in such shallow water that they signify only little in this respect. By the coast of Lolland and Falster they are found 1 to $2\frac{1}{2}$ m below the sea-level, at South Fyn — 2 m and in Kolding Fjord at — 3 to — 4 m (the indications swing from — 3 to — 6 m). Implements like these have previously been found at Flensborg at a depth of — 4 m, at Husum — 4 m, and at Kiel there was a culture stratum from the Ertebølle Period at a depth of — $8\frac{1}{2}$ m to — 9 m.[18] These figures indicate the minimum measurement of how much Southwestern Denmark at that time lay higher than it does today.

In the following period, through the Later Neolithic Stone Age and the Bronze Age, and possibly still later, the submergence in Southwestern Denmark continued until the present distribution between land and sea was reached. Along a part of the west coast of Jylland, from Rømø to north of Blaavandshuk, this submergence seems, however, to have ceased even in the Bronze Age and to have been succeeded there by an emergence which, judging from the height of the marsh land in Ribe district, may be estimated at 1.2 to 1.4 m.[18] On the stretch from Blaavandshuk to Filsø, older, high, raised beaches also indicate an emergence, though less than that at Ribe,[19] whereas still further north no signs are known of a negative shoreline movement. The same applies to the southern part of the west coast of South Jylland, where it has not been possible to prove such an emergence. Still further south, in the coast lands around the Gulf of Heligoland, there are even signs of a submergence which has lasted into the Recent Period.

In Northeast Denmark, conditions developed in another manner. Even in the Campignien the transgression was superseded by a regression, most pronounced in the northeast, ebbing out towards the southwest towards the FORCHHAMMER line from Nissum Fjord to the southeast through Denmark.[17] In the region Frederikshavn—Hirshals, where there are raised beaches up to a height of 15 m above sea-level, and fiord mud with shells up to 12.5 m above sea-level, the upheaval of the land since the maximum of the Litorina

Period has been about 13 m. From there to the southwest, out over the western end of Limfjord, the height of the old shore lines decreases; but, as a consequence of their varied situations, some of them in open, some in protected places,

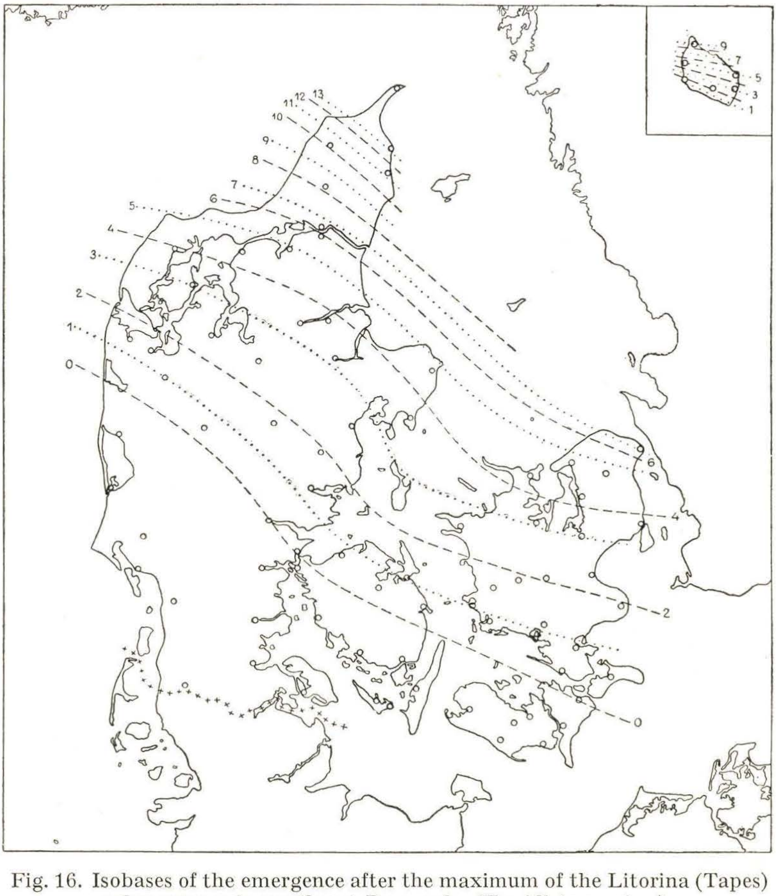

Fig. 16. Isobases of the emergence after the maximum of the Litorina (Tapes) submergence in northeast Denmark. (Equidistance 1 m).

their heights, even at points lying closely behind each other, are very varying. Here, as in many other places in the country, the upheaval can therefore only be given approximately, as the height to which the sea can throw up a beach at the particular spot cannot always be given exactly.

The sketch-map, fig. 16, gives, by means of 1 m contours, a survey over the extent of the upheaval of the land in North-east Denmark, from the maximum of the Litorina (Tapes) Period to the present day. At Løkken it may be estimated at 8½ m, Bulbjerg about 5 m, the isle of Mors about 3 m, at Agger—Oddesund, in the western part of the Limfjord, about 1½ m and at Nissum Fjord 0 m. South along the coast of the Cattegat there is a similar decline in the figures of the extent of the upheaval. Læsø, whose highest point (apart from the dunes) is 11 m above sea-level, has been entirely covered by the sea in the Litorina Period (see fig. 13); the upheaval of the land there must be assumed to have been rather similar to that at Frederikshavn. On Anholt the upheaval has been at least 8 m. At Hals—Aalborg the land has risen about 6 m and at the mouth of Randers Fjord about 4 m; at Fornæs, the promontory of the peninsula Djursland, which lies far to the east, where the raised beaches attain a height of 7.8 m above sea-level, the land rising has been about 5 m. On Samsø it has been 3 to 2½ m, on Fyn at Kerteminde 1 m, and from there decreasing in height both to the west towards the Little Belt and towards the south along the east coast of the island.

On Sjælland[20,21] the coast lines which have been raised highest, 10.0 to 10.2 m above sea-level, are to be found at Hornbæk, NW of Helsingør (Elsinore), corresponding to an upheaval of about 7½ m. From here there is a fairly even decrease in the height of the shore lines, both southwards along the east coast and westwards along the north coast, although the more or less protected situation plays an important part. The upheaval itself along the east coast may be estimated at: at Rungsted about 5 m, at København 3 to 3½ m, at Stevns about 2 m and on the north coast of Falster 0 m. Along the north coast of Sjælland the upheaval at Tisvilde has been about 5 m, on Sjælland Odde 4½ m, on Sejrø 3½ m and at Røsnæs 2½ m. On Bornholm the upheaval has been very marked;[11] the marine raised beaches towards the north reach a height of 11 m above sea-level, towards the south 3 to 4 m, corresponding to an upheaval of the land of 8 and about 1 m respectively.

*Axel Jessen.*

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## Abbreviations:

Dansk geol. Foren. = Meddelelser fra Dansk geologisk Forening. København.

D. G. U. = Danmarks Geologiske Undersøgelse.

Vid. Medd. Naturh. Foren. = Videnskabelige Meddelelser fra Dansk Naturhistorisk Forening. København.

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# The Faroe Islands.

The Faroe Islands lie in the Atlantic Ocean between lat. 61°00′ and 62°24′ N, and between long. 6°15′ and 7°41′ W of Greenwich, about 300 km NW of the Shetland Isles. They form a part of the great North Atlantic Basalt Area. They consist of 17 inhabited islands besides some small islets that are uninhabited; their area is 1399 sq. km. The group forms an uneven basalt plateau of an average height of about 300 m; above this, however, steep mountains tower everywhere, sometimes reaching over 800 m (highest point: Slattaretind on Østerø, 882 m), whilst the plateau itself is in many places broken by valleys which often stretch right across the islands. Out towards the open sea there are almost everywhere high, vertical cliffs (Myling on Strømø, about 620 m, Enniberg on the north point of Viderø about 720 m); on the other hand the channels between the islands and also the valleys are mostly bounded by more even slopes, which are nearly always stepped in terraces corresponding to the various basalt beds. There are tectonic fissures in large numbers, appearing in the form of deep, very regular and straight-lined ravines (Gjógv's) of up to 1 km in length. Their direction varies, although SE—NW and E—W, or ENE—WSW predominate. At the foot of the cliffs the same fissures appear as clefts and sometimes as caves, of which there is a great number, often very deep.[1,2,3]

The geological structure is extremely uniform, there being no other rocks than basalt and sediments formed of the components of the basalt (a single tuff layer, recently found, with liparitic elements, might be taken to have originated from one of the bigger eruptions on Iceland). The principal mass is formed of beds with a total thickness of at least 4000 m. The various beds are 10—30 m thick and can often be followed over long stretches, across the channels and valleys; in many places, however, one can see how they taper off to nothing. Each bed represents a single stream of lava and the upper plane oftenest shows characteristic lava surface. The basalt varies in appearance, the colour changing from black to fairly light and the size of the grain differs too. From olden times a distinction has been made between anamesite strata below the coal-bearing horizon and basalt (dolerite) above the latter, the first named often being rather more coarse-grained whereas the latter is more fine-grained or aphanetic, often with well-developed phenocrysts, mostly of labradorite. Large quantities of olivine are found in some strata. The basalt is of normal composition with about 50% $SiO_2$. Columnar structure is not particularly prominent in the beds. These lie almost horizontally, on Suderø with a dip of a few degrees towards NE, on Myggenæs with up to 15° dip to the east; on the islands in the middle there is usually a very slight dip, whereas the beds on the more northerly islands are quite horizontal or dip very faintly towards NE. There are some displacements, but only of a height of a few metres.

The basalt beds are separated by tuff strata which for the most part are very thin (less than 1 m) and red in colour (burned by the overlying basalt bed); in a few places, however, there are sediment series (sandstone and shales) of thicknesses up to several metres. In particular there is a series, 4—10 m in thickness, mostly shales, on Suderø, which contains a single coal-seam, or, to be more correct, lenticles of this, up to a thickness of 1.5 m. The coal, which is lignite, is mined locally, whereas various attempts at coal mining on a larger scale have soon had to be abandoned. On lower horizons there are some quite insignificant beds. On Myggenæs, Tindholm and the western part of Vaagø there are unimportant sediment series with quite subordinate lignite beds. On Myggenæs, definable impressions of *Sequoia Langsdorfii* have been found in the shale; both here and on Suderø are indeterminable impressions of dicotyledon leaves.[6·7·8·9]

Volcanic vents are to be found in rather large numbers; most of them are seen in the steep cliffs (especially fine in Dalsnypen, on Strømø), and they mostly become visible by the fact that one or more beds are cut through by a breccia-like mass with fragments of every possible kind of basalt. Whether these formations are sections of crater funnels or of fissures, can hardly be determined. Particularly grand phenomena of this kind are to be seen by the coast between Frodebønypen and Kvalbø on Suderø, where there are thick breccia-conglomerates over a wide stretch, interspersed with a number of irregular dykes. In other cases the beds are not interrupted by tuffs but by basalt, which is seen to pass directly into an overlying bed or intrusive mass (as for instance at Frodebø on Suderø, where there are fine, curved basalt columns).

There are very large numbers of dykes and sills; most common are the dykes which as a rule are not especially thick (up to about 10 m). They consist of aphanitic or very fine-grained basalt; sometimes they are porphyritic. They do not seem to have any general direction; sometimes they follow the previously mentioned tectonic fissures and may form the bottom of the clefts, but just as often do they run across these. They are usually very regular, with plane-parallel sides, but they may also be winding or ramified; at times they cross each other. As a rule they are less capable of resistance than the surrounding basalt; the opposite can also be the case, however, (especially a dyke at Gjov on Østerø, which juts up like a row of wood-stacks).

The sills are not nearly so numerous, but often attain much more important dimensions (up to about 50 m); there is a particularly prominent one which cuts through the mountains north of Selletræ on Østerø, and one which cuts the mountains (Skjellingsfjeld, etc.) between Leinum and Nordredal on Strømø. Only in part do they follow the boundary between the two beds, and often run obliquely up into other levels. The thicker intrusive dykes consist of a medium-grained basalt; they all have a regular columnar structure, with columns metres thick. They are particularly resistant against decomposition and consequently form the surface over fairly wide stretches, which are characterised by the regular, polygonal column ends and by being almost entirely without vegetation.

Faroe Island basalt is rich in minerals. Most of the known zeolites have been found in it, often in large and fine crystals. There are also calcite (peculiar twins at Saxen, violet cube-shaped crystals on Hestø), chalcedony, of which mineral especially large specimens have long been known, and opal, which formerly in a semi-precious form was collected in fairly large quantities, especially at Kollefjord on Strømø. Native copper has been found, some of it together with zeolites on Nolsø and some in the form of plates, as thin as paper, in tuffs at Famien, on Suderø.

As to the age of the Faroe Island formations nothing can be said with certainty; it is possible that the eruptive activity took place in the Older Tertiary; at any rate a long period has certainly elapsed, during which erosion has worked not only in the modelling of the islands but undoubtedly also in the eroding of tremendous masses of land which have probably connected them with Great Britain on the one side and Iceland on the other and of which there still remain submarine basalt ridges. During the Ice Age and subsequently there has been a finer modelling of the details.[10]

During the Ice Age the Faroe Islands formed a separate glaciation region; the striae, which are present everywhere, run in radiating directions to all sides. The whole of the plateau has been covered by the ice and the lower mountains have been shaped like "roches moutonnées"; in many places on the slopes there are regular cirques. Boulder clay exists in many places but never has any great extent or thickness.

Alluvial deposits are only of slight importance; marine alluvium is lacking entirely, as the Faroes, in contrast to other North Atlantic lands, have not lain at a lower level than they do now since the Ice Age. There are blown sand, but only in small quantities; in greatest quantities they are found on Sandø. Peat is widely diffused in all lower areas but with only slight thickness (rarely more than 1—1.5 m). The peat is mostly fen peat, with a single, probably sub-boreal bed consisting of *Calluna* and *Juniperus*. At the coast it is sometimes found under such conditions that one may conclude that since its deposition there has been a submergence of at least 3.5 m.[11,12]

*O. B. Bøggild.*

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# Stones and Earths of Technical Utility.

Nature has only equipped Denmark with few useful stones and earths and the home raw-products which are used in our mineral industry are on the whole of little marketable value; nevertheless they play an important part in our country's economy and, in several domains, for instance the cement industry, Danish products and Danish enterprise have succeeded in gaining recognition all over the world.

## Fertilisers.

In few places in the world does agriculture utilise a greater part of the surface of the country than in Denmark, the cultivated soil representing about 77 per cent., whereas forests only cover 9 per cent. of the total area. The remainder, which is occupied by heaths, bogs and lakes, etc. is being diminished every year through cultivation and draining. The high standard of Danish farming is especially due to its organisation into co-operative enterprises; for even if there is fertile soil over wide areas, it cannot compare with the nutritive soil which has come into existence under other climatic conditions; in Middle and West Jylland, especially, much soil is cultivated that, in most parts of the world, would be allowed to lie untilled. Both with regard to soils and climatic conditions Middle and West Jylland are less fortunately placed than the remainder of the country, there mostly being meagre heath sand, Diluvial sand, stony sand and blown sand. The climate is more harsh and the rainfall a little higher than in other parts. Middle and West Jylland belongs to Northwest Europe's very humid heath region, where the Mor-profile (Mor, Blegsand and hard-pan, see p. 84) occurring as a result of podzolation is most widespread. East Jylland and the Islands belong to the Northwest European humid, Brown soil region. Its soil is more clayey and less podzolised than the soil of the heath area. The most widely diffused earths in the surface are moraine clay and more or less argillaceous, glaciofluvial sand. Through the incomplete podzolation there has arisen a brown-black soil with a comparatively small humus content. Only at places where it has been difficult for the water to run away has there developed a black, peaty soil rich in humus. Draining is resorted to in order to get rid of the injurious water and the acid reaction (want of lime) which is due to humus substances or the washing out of calcium carbonate, is made good by the addition of fertiliser lime or marl.

Nearly all kinds of chalk and limestone are utilised as fertiliser lime.[1] Soft chalks such as White Chalk and Blege Chalk, poor in silica, usually crumble in a short time from the effects of frost and can therefore be spread over the fields in small lumps, whereas harder limestone must be pulverised before use.[2]

Fertiliser lime of Cretaceous limestones does not nearly cover the consumption of the country; Tertiary and Quartary calcareous deposits are also used to a great extent. Of the Tertiary earths, Paleocene marl, with up to 70 per cent. calcium carbonate, is of most importance. It is found in Eastern Jylland from Randers to Vejle and on Sjælland; south of Aarhus and on Sjælland it only forms floes in the moraine.

Diluvial clay and moraine clay are the Quartary deposits mostly used as marl; the former especially is often very calcareous and is of particular importance in West Jylland, where there are deposits with about 60 per cent. calcium carbonate, whereas other lime and marl deposits here are of less consequence. Thus the moraine clay in Middle and West Jylland rarely contains more than about 15 per cent., whereas in East Jylland and the Islands it often contains 20—30 per cent. calcium carbonate. Chalk moraines consist mainly of White Chalk and the calcareous content is very high. Calcareous glaciofluvial sand and Interglacial lacustrine marl are also used for marling, but are of less importance; on the other hand both Interglacial and Lateglacial Yoldia Clay are used in Vendsyssel in fairly large quantities. In East Jylland and the Islands the deposits there of Lateglacial and Alluvial calcareous tufa bog and lakemarl are widely used. The value of the marl and fertiliser lime used annually cannot be stated, as it is often used on the owner's own land.

At the end of the Great War the phosphorite nodules in the Cenomanian greensand deposits on Bornholm were utilised in the production of phosphate fertiliser, but the extraction ceased after a short time.

## Building Materials.

### Natural Building Stones.

When the Ice Age had passed, large parts of the country were more or less densely strewn with stones, some of which originated from the Scandinavian Archæan region, others from younger deposits which the ice had met on its way. These field-stones were at an early date used for practical purposes, as is evidenced by our many dolmens and passage-graves of the neolithic Stone Age and the rune-stones. Of the numerous stone churches from the Middle Ages, which replaced the first church buildings of wood, a surprising number are built of field-stones.[3,4] With the introduction of brick-kilning in the last half of the twelfth century the use of natural stones as a building material declined, and they were piled up into heaps or used for stone fences. Nowadays this store of stones is utilised for metalling roads and ballasting railways. Now and then, however, buildings are still built entirely or partly of hewn field-stones. In the walls of the rebuilt castle Christiansborg Slot in København field-stones are used which are gifts from about 750 of the country's parishes.

For harbour works, etc. sea-stones, which are taken up from the sea floor, are principally used, whereas the supplies of granite and similar stones needed by the big towns are almost exclusively procured from stone quarries. On Bornholm, granite has been quarried for about a hundred years and the output is growing, almost one and a half times as much having been quarried in 1926 as in 1913. Besides as building-stone, Rønne granite is used for grave headstones, as on being polished it assumes a handsome, dark colour. This enables it to command a higher price than the other Bornholm granites. Paradisbakke granite is a favourite facade stone on account of its fine, white flamed appearance. The other granites, such as Hammer granite, Vang granite and Svaneke granite, are also used as building-stone,[5] paving stones etc.

The Faroe Island basalt, which dates from the Tertiary, has been used in some buildings on the Faroes and attempts are being made to introduce it as a building and monument material in the other parts of the country.

In 1754 the Danish State opened a quarry north of Nexø in the Cambrian Nexø sandstone, its name being Frederiks Stenbrud (quarry); later on, however, it passed into private ownership. When the flood came in 1872 the sea ran into the quarry and it was not emptied again until 1922. Stone is now being quarried again in these old workings.

The Bryozoan Limestone of the Danian in some places forms a rather soft, porous limestone which is called »Limsten«, or technically, Chalk Stone. As early as in the Middle Ages it was used as a building stone at Stevns, in Köbenhavn (ABSALON's castle) and at Klim in Hanherrederne (northern Jylland). The "chalk stone" from Stevns, where there are quarries in the cliff, is soft and rather porous in fresh condition; it improves, however, in the course of time and it is frost-proof. At Faxe there are both Coral Limestone, and Bryozoan Limestone similar in nature to that in Stevns Cliff. Both of these limestones may occur with the intervals wholly or partly infilled with hardened lime powder and is then called Faxe marble.

Calcareous tufa usually occurs in the form of an incoherent, granular powder, but it sometimes also contains coherent portions of the character of limestone. In the Middle

Ages, under the name of "Fraadsten," this calcareous tufa was used as a building-stone. Orthoceratite limestone (Bornholm marble), greensand-stone, greensand-limestone and bog iron-ore have also been used as building-stone.

## Bricks.

Although brick-kilning was introduced into this country about the year 1160, the development from a home industry to a factory industry has mostly taken place during the past hundred years. This has brought about the establishment of a number of large brickworks and many small concerns have ceased to exist. This concentration of production now seems to have been effected to a suitable extent, the great falling off in the number of brickworks having now come to an end. In 1926 there were 262 brickworks in operation. A separate position is occupied by those brickworks which make fire-bricks and other fireproof articles of this sort out of the Bornholm Rhæt-Lias clay and, in certain cases, kaolin. For ordinary bricks a great variety of clays are used, of which principally the same demands are made as of potter's clay, especially where thinner, better products are turned out. For facing-stones and tiles most use is made of red brick, which is made of the upper, weathered and non-calcareous red clay, whereas yellow facing stone is made of clay which becomes yellow through baking, calcium carbonate and iron-oxyde being present in such proportions that yellow silicates of iron and calcium are produced. Sometimes the partly weathered clay which underlies the red clay gives yellowish-red or discoloured bricks which are not used as facing stone. Diluvial clay, lateglacial freshwater clay and Yoldia Clay are those mostly used as brickworks' clay. The great deposit of Lateglacial freshwater clay at Stenstrup, on Fyn, is of especial importance. The brickworks sometimes use moraine clay, especially in the vicinity of large towns; the cost of production is, however, increased by the preliminary treatment which the clay must undergo before it can be pugged and moulded. If the clay does not contain large limestones, it is sufficient to crush the stones in a mill; otherwise it must be washed, as lumps of calcium carbonate are, during the burning, converted into calciumoxyde, which becomes slaked with water and bursts the bricks. Quantities of finely distributed calcium carbonate up to 30 per cent. do not harm the bricks. Interglacial Cyprina Clay (Eem Clay) and Alluvial Cardium Clay are of less importance as brick-works' clay. Several Jylland brickworks employ Oligocene and Miocene clays; but as these sometimes contain quantities of injurious substances such as pyrites and gypsum, these ought to watched for when laying down new plant as well as when making tests. If necessary, these injurious substances must be removed by washing.

Of late years a good number of lime-sand bricks have been used for building purposes. The bricks, which are made of burnt lime and sand under steam pressure, were being turned out by eight establishments in 1926. Cement bricks and other cement goods are in large quantities made of cement and sand.

The lower strata of the Mo Clay,[6] which are fairly free of volcanic tuffs, on being burned give a reddish-yellow, light, porous and fairly strong brick, which during the past few years has found increasing employment for building purposes, where special demands are made with regard to the lightness and insulating properties of the material.

## Mortar Substances.

Most hard and coherent limestones with more than 90 per cent. calcium carbonate are very suitable for lime burning, whereas soft limestone and chalk are less suitable. There are historical records of the burning of limestone from the isle of Saltholm back to the 13th century. In the 16th and 17th centuries there was a very large—according to the standards at that time—lime burning industry at Mariager Fjord, in the area containing the Danian at the middlemost part of the fiord. Both quarrying and burning probably ceased shortly after the year 1700, partly because of the felling of the forests in that region, partly because the most suitable limestone near to the fiord had all been used up. Limestone for burning has also been quarried from olden times at Davbjerg and Mønsted West of Viborg, at Gudumlund SE of Aalborg and Faxe in South-Sjælland. The latter quarry is now the largest in the country and it supplies great parts of Denmark with limestone and burnt lime. Coral Limestone is particularly suitable for burning, as it is hard, and yet very porous; the carbon dixoyde released in the burning can thus better escape than from dense limestone. The quarry, which is an open one, has a length of more than one kilometre and a depth of about 30 m. In the Bryozoan Limestone and Coccolith Limestone of the Danian, there are often hardened parts which have been called Saltholm Limestone. This hard limestone is very suitable for lime burning. In several places boulders of Saltholm Limestone are to be found in such large quantities in glacial deposits that they are used for lime burning, for instance at Farum, northwest of København, at Klintebjerg in Odsherred and especially the environs of Grenaa at Glatved Strand. The hardened portions in the Blege Chalk, "Blegerne," are also used for lime burning and are quarried at Mønsted and other places. The Blege chalk that is unsuitable for burning is sold as fertiliser lime. Quarrying is partly in open works, partly in drifts ("Kover" in the Jylland dialect); drift-mining for limestone is also carried on in other parts of Jylland. Softer limestone and White Chalk are in exceptional cases used for burning*).

Argillaceous limestone (clay content 10—20 per cent.) is difficult to slake after burning; but, after burning, the pulverised argillaceous limestone acquires hydraulic properties (the property of hardening when mixed with water) and is then called hydraulic lime.[7] With a higher clay content (25—35 per cent.) the burnt limestone will not slake and the hydraulic properties increase so much that the binding can take place under water. Products of this kind are called Roman cement,[7,8] but the boundaries between hydraulic lime and

*) Quicklime is principally used for mortar and other building purposes, but it is also used for disinfection and in the chemical industry, as for instance in the cleaning of beet sugar. In this process use is also made of the carbon-dioxyde freed in the burning.

Roman cement can only be fixed by standards which are not yet authorised in Denmark. Of limestones which have been employed in this manner are the Orthoceratite Limestone and Andrarum Limestone from Bornholm, the "cement stone" from the Mo Clay deposits on Mors and Fur, boulders of Paleocene greensand limestone from Klintebjerg in Odsherred and siliceous Blege Chalk or White Chalk from Mariager. The last two are in constant use.

This production, however, is quite insignificant in comparison with the manufacturing of Portland cement which, on the basis of chemical analysis, is so composed that the finished cement can have the best possible properties. The raw materials of the three cement works at Mariager Fiord are White Chalk and dark grey, Tertiary clay (although of late years Cardium Clay has, I believe, been used exclusively), whereas the five works at Aalborg use White Chalk and lateglacial Yoldia Clay, although one of them uses washed out moraine clay. Danish White Chalk is very pure (95—99 per cent. calcium carbonate) and especially excels by its low content of magnium compounds, which rarely exceed 1 per cent. This is of great importance to the quality of the cement. The output not only covers the domestic consumption, but more than half of it was exported in 1926.

By means of adding pulverised Mo Clay stone to cement a Mo Clay cement is obtained which is better suited to submarine work than ordinary Portland cement.

Before the Great War the output and exportation of crude chalk were much greater than now. This decline is particularly due to the fact that the Russian cement works are buying much less crude chalk than they did formerly.[9]

## Kaolin and Pottery Ware.

After Böttger in 1709 had discovered a method of making porcelain, there was great interest in most European countries in this and in the raw materials of which it is made. The search for kaolin deposits in this country led to the discovery in 1755 of kaolin—not in situ—at the river Grødby Aa on Bornholm, about 5 km south of Aakirkeby; about 1775 the main deposit of kaolin was found northeast of Rønne, at the place where Rabekkegaard Works now stand. At high temperatures (above cone 9), Bornholm kaolin becomes grey or yellowish, for which reason it is not now used for the finer porcelains; on the other hand it has found employment as a filling in the paper industry, as it is obtained pure white from the quarry. For this purpose the kaolin must be freed of quartz by means of washing out.[10] The raw kaolin and the more coarse products of washing are employed together with fireclay for various fireproof goods (kaolin bricks, etc.).[11]

As in most other parts of the world, clay has in Denmark from early times been employed in the making of utensils by means of baking, as may be seen in our Stone Age finds. The making of red and yellow pottery was a town privilege in olden times, whereas black pottery (or Jydepotter as they are called on the Danish Islands) was made in the country. Various clays were used for Jyde pottery: Mica-clay, Diluvial-clay, Moraine-clay. The black colour of the objects is not due to the clay but to the primitive method of baking in pits with peat, the effect of which was that through the effect of the smoke the objects became black and watertight without the use of colour or glaze. Despite the primitive conditions under which this domestic industry was carried on, the ware became of such good quality that it could be used as cooking pots.[12] The properties which characterise good pottery clay: baking colour, plasticity, retention of shape during drying and baking, interval of vitrification and refractoriness, are to be found in clays of very varying geological origin. Of fireproof or semi-fireproof clays in this country there are only the Rhæt-Lias clays, on Bornholm.[10] They are used for "Bornholm stone-ware" with vitrified body and for faience, majolica or terracotta with porous body. Some Bornholm clays are highly coloured, but not fireproof; they are used for the colouring of ceramic bodies. Pottery that is not baked at very high temperatures is also made of our other clays, especially Diluvial and moraine clay, which are most widely diffused. Moraine clay must, however, be washed before use. In 1926 there were 4 Bornholm faience works, 9 terracotta and majolica works, 12 works for coarser earthenware and 52 small pottery establishments.

## Fuels.

Peat is the only domestic fuel of any importance at the moment; it is mostly used in the rural districts, for as a rule it does not pay to transport it long distances. Heath-peat, which is cut from the Mor cover of the heath, was formerly used for fuel in the heath areas but is now of no importance. High-moor peat is formed on a moist bottom, where the water did not contain dissolved salts of lime. The uppermost loose layers are not used as fuel, whereas the deeper, more converted layers sometimes yield good peat with a high fuel value. Low-moor peat, formed on a moist bottom with lime-charged water, is to be found in all transitional forms from almost purely organic substance with a high fuel value to peaty mud of no value as fuel. "Martörv" in the northern part of Vendsyssel is, like the other peats, of Alluvial origin; on account of the pressure of the overlying mass of blown sand it is very transformed and in places resembles Brown coal. Resinous peat (Lyseklyne) burns with a bright flame and in former days was used for lighting. In some places peat litter is made of peat and, at Holmegaard Glas Works, peat gas for heating the glass furnaces.

During the Great War the Miocene Brown Coal in Middle and West Jylland became of some importance, large pits being opened at Fasterholt, SSE of, and Troldhede, SW of Herning; pitting has now almost ceased, however. The Jylland Brown Coal beds, which sometimes have a thickness of about 2 m, are to be found over a fairly wide area and may be extracted in several places in pits; but as the coal is often friable and has a high percentage of ash and sulphur, it is only rarely profitable to dig it out. Tertiary lignite on the Faroe Islands is used locally, but does not occur in large quantities.

| Commodity | No. of Establishments 1926 | Output 1926 | | Output 1913 | Foreign Trade 1926 | |
|---|---|---|---|---|---|---|
| | | Quantity | Value | Quantity or value | Exports | Imports |
| | | | Kr. | | | |
| Granite | 16 | | | | | |
| Building work | | 2478 t. | 311254 | 6199 t. | 2 t. | 1718 t. |
| Grave monuments | | 996 - | 325518 | 756 - | 5 - | 336 - |
| Paving stones | | 37808 - | 1177162 | 19037 - | 1 - | 103714 - |
| Unworked granite | | 368 - | 14820 | 1190 - | 141 - | 5115 - |
| Metal and débris | | 69963 - | 458085 | 33180 - | 60 - | 65025 - |
| Sandstone | 1 | | | | 3 - | 1082 - |
| Building work | | 222 - | 71100 | | | |
| Grave monuments | | 34 - | 16600 | | | |
| Paving stones | | 160 - | 4600 | | | |
| Other work | | 514 - | 20900 | | | |
| Chalk and Limestone | 51 | | | | | |
| Building stone | | 1215 - | 20000 | 2100 - | | 260 - |
| Limestone for burning & other technical purposes | | 85877 m³ | 894164 | c. 139600 m³ | 93270 - | 42160 - |
| Limestone burnt at Quarry | | 49405 - | | | | |
| Burnt lime (Melkalk) | | 58931 t. | 3746366 | c. 63000 t. | 117 - | 3882 - |
| Crude chalk | | 18685 - | 65407 | c. 100000 - | 17214 - | 18 - |
| Washed chalk | | 12632 - | 293526 | c. 10600 - | 6105 - | 137 - |
| Fertiliser Lime | | c. 77104 - | 650959 | c. 40000 - | 903 - | 6277 - |

| | | | | | | |
|---|---|---|---|---|---|---|
| Flint pebbles.................... | 4 | 13008 - | 377000 | | 12922 - | |
| Flint.......................... | | 15919 - | 73374 | | 9438 - | 5709 - |
| Lime-sand Stone................ | 8 | 20.2 mill. stones | ca. 700000 | | | 146 - |
| Cement......................... | 7+(1) | | | | | |
| Portland Cement.............. | | 569021 t. | 21350000 | 495400 - | 331186 - | 5204 - |
| Kaolin......................... | 2 | | | | | |
| Raw.......................... | | 4625 - *) | | 17723 - | 5 - | 1015 - |
| Washed....................... | | 1694 - *) | | 41822 - | 914 - | 4083 - |
| Fireclay....................... | | | | | 1213 - | 2239 - |
| Finer ceramic goods............ | | | | | | |
| Porcelain.................... | 5 | | 7754000**) | 3105000 Kr. | | |
| Faience...................... | | | 816000**) | 1250000 - | | |
| Finer Bornholm ware etc...... | 13 | | 701000 | | | |
| Earthenware.................. | 12 | | ca. 1300000 | 1000000 - | | |
| Brick works.................... | 262 | | ca.24000000 | 13330000 - | | |
| Mo Clay........................ | 2 | 7.9 mill. bricks.. + other goods | ca. 550000 | 15000 - | | |
| Sand........................... | | | | | 1920 - | 4207 - |
| Bog iron-ore, fresh............ | | | | | 585 - | 71 - |
| — , used.............. | | | | | 1199 - | |

*) Part of the 4625 tons were used to produce the 1694 tons of washed Kaolin.

**) For the most part of foreign raw products.

Bornholm coal from the Jurassic Period has been mined since the commencement of the 17th century, but with many interruptions, as it is only occasionally, and at short periods, that it pays. The coal is of poor quality and difficult to obtain, as the coal seams, which may have a thickness of up to 1 m, dip with their overlying sand strata in such a manner that the shafts are difficult to keep shored up and free of water. South of Hasle an attempt was made during the Great War to exploit the coal, but mining ceased shortly after the end of hostilities.

## Other Uses of Stone and Earth.

Besides the large stones in the moraine deposits, the smaller stones in the sand and gravel deposits of the Quartary Period are broken for use as metal on roads and for ballasting railways. The smaller, usually rounded stones are known as shingle and are used for instance in concrete mixing. Stones larger than 60 mm in diameter and sand and gravel less than 30 mm are removed by screening. By "ral" is understood pebbles from raised beaches (size 15—80 mm); they are especially used for submarine work. Besides being used as building and road material, sand and gravel are also used for filters for waterworks, etc. The Bornholmian Aarsdale gravel is produced by the weathering of Svaneke granite and excels by being almost free of dust. Where sand occurs with a suitable clay content (about 15 per cent.) and otherwise satisfies the demands of the foundries as to plasticity, penetrability for air and fire-resistance, it is used as moulding sand.[13] Diluvial sand, moraine sand and mica sand are used most, although on Bornholm sand from the Jurassic Period is employed.

White Chalk is easily disintegrable to a fine powder which, after washing in water, is put to various technical uses under the name of washed chalk, for instance for paint colours, school chalk, for polishing or as filling in the rubber industry.

Chalk and limestone may contain up to about 50 per cent. of impurities, of which most is silica. As a rule, silica is concentrated in particular flint layers or rows of flint nodules which are to be found in the rocks of both Danian and Senonian, with the exception of the coral limestone. There are also large quantities of flints in the form of boulders in our Quartary deposits. The wealth of our country in flint has made its mark in the highly developed Stone Age culture of this and our neighbour countries. Even in the Stone Age considerable quantities of flint were exported.[14] Flint was used for striking fire and on guns up to the middle of last century; it is now used as a road material, in the ceramic industry and, occasionally, as a building material. Of particular interest is the use of flint pebbles in tube mills, Denmark being the principal purveyor of this commodity on the world's market.[15]

Interglacial diatom earth[16], formed in fresh water, is only used to any extent at Hollerup, west of Randers, where there is a bed 4 or 5 m thick, and south of Gudenaa at Vellev. Diatom earth occurs in a pure white state or darkly coloured by organic matter; it is used, raw or burned, in many different ways, but especially for the insulation of pipes and boilers of both heating and refrigerating plant. It is used as an admixture in clearing and filtering liquids, for heads and igniting surfaces in the match industry, in the preparation of polishes and for the making of silicate preparations. Danish diatom preparations are superior to many from abroad by their purity; this is of importance especially in insulation work, where authorised standards must be adhered to everywhere.

Bog iron-ore was during the Middle Ages and some way into the more recent time used for the smelting of iron by reduction with charcoal. Remnants of the primitive furnaces and slag-heaps are still to be seen in various parts of the country.[17] In the middle of last century attempts were made to use bog iron-ore in a blast-furnace plant at Rendsburg, but the scheme had to be abandoned owing to financial difficulties. Later plans for the building of iron works have never fructified. Bog iron-ore is, however, used to an ever increasing extent in the purifying of gas, which is led over flat trays with bog iron-ore in order to free it from sulphur and cyanic compounds. As the cyanic compounds can be extracted from bog iron-ore that has been used in purifying gas, it has a certain commercial value and is exported. The output of this purifier supplies not only the Danish gasworks; in 1926 585 tons were exported. In some places in Jylland bog iron-ore is used as a road material.

On an emerged sea-floor or areas which have been laid dry by reclamation, there are often big shell banks or beds, most of them of postglacial origin. Shells deposited in sand are comparatively easy to clean and are then used as poultry or pig feed. Shell deposits are exploited in many parts of the country, for instance in the reclaimed Lammefiord in Odsherred, NW Sjælland, at Odense Fiord and at Limfiorden. In a similar manner the crumbled Bryozoan limestone from postglacial raised beaches at Gøttrup in Øster Hanherred, northern Jylland, is exploited.

As historically interesting uses which are no longer practised may be mentioned the making of alum from Cambrian alum shale, the using of Eocene Plastic Clay for fulling cloth (fuller's earth) and the using of feldspar from the Bornholm pegmatite dykes in the ceramic industry. In the prehistoric times amber played a great part in bartering with foreigners; by the west coast of Jylland about 150 kg of amber are collected annually.

According to statistical reports for the past few years there has been a marked decline in the Danish mineral industry; but as this also applies to other branches of industry, there is reason for supposing that production normally will be somewhat greater than in 1926.

*Johannes Andersen.*

## The Physical Properties of Some Danish Clays.

Thanks to the wide spread of the Quartary and Tertiary in Denmark, the country is comparatively rich in clays differing greatly in composition.

The examination of these clays has previously been for the principal purpose of placing them in the geological column, and therefore most attention has been paid to how they were deposited and their contents of fossils. But in Denmark during recent years—as in most other countries—the practical significance has been recognised of classifying the clays according to their physical properties: size of grain, plasticity, hygroscopicity, etc. and therefore a commencement has now been made with an examination of these properties in the clays.[18]

This examination has not yet proceeded so far, however, that one may venture to draw up a detailed table of Danish clays on this basis, and the following classification merely indicates the main headings of such a classification:

| | |
|---|---|
| I. Very rich clays....: | Eocene Plastic Clay (Røsnæs, Trelde, Røgle). |
| II. Rich clays........: | Grey Paleocene Clay (Mors)?<br>Rich Oligocene and Miocene Mica Clay (for instance Uldal, Ulstrup, Mariager Fiord). |
| III. Less-rich clays....: | Most of the Paleocene clays (for instance Rugaard, Kerteminde). The most argillaceous Quartary clays. |
| IV. Meagre clays......: | Arenaceous Oligocene and Miocene Mica Clay. The meagre Quartary clays. |

Only the two extreme items of the table have been finally examined: Eocene Plastic Clay and meagre, glacial clay (moraine clay), there having been an opportunity, through test borings for bridge constructions at the Little Belt and Alssund respectively, to examine several hundred undecomposed samples (with natural water content) of the two clays which each form the substratum in the two Sounds.

These very clays, however, have a special claim upon our interest, Plastic Clay as being the most peculiar, moraine clay as being the most widespread Danish clay, and the results of the examination of the samples from these two localities will therefore be dealt with in the following.

## I. Size of Clay Grains.

(Determined by washing and sieving).

| Diameter: | 2—0.2 | 0.2—0.02 | 0.02—0.002 | < 0 002 mm |
|---|---|---|---|---|
| | % | % | % | % |
| Eocene Plastic Clay... | 0 | 0.1 | 8.7 | 91.2 |
| Rich moraine clay.... | 9.6 | 38.1 | 28.0 | 23.6 |
| Meagre moraine clay.. | 23.7 | 39.8 | 18.8 | 18.0 |

By another method the diameter 0.002 mm was found to be the limit of the particle sizes which—after shaking in a 30 cm high water column—are able to remain suspended more than 24 hours. The greater part of the particles of Plastic Clay can remain suspended for several months without precipitating and their diameter is thus much less than 0.002 mm. In none of the other Danish clays hitherto examined has such a fine grain been found.

## II. Consistence-limits of Clays.

By the consistence limits of clay is understood the percentage*) of water at which the clay goes from one form to another, for instance from firm to plastic and from plastic to liquid form.

For the clays examined the two limits, shown in approxmate figures, were:

| | I. Limit between firm and plastic consistence | II. Limit between plastic and liquid consistence |
|---|---|---|
| Plastic Clay.................. | 27% water | 60% water |
| Rich moraine clay............ | 15% — | 25% — |
| Meagre moraine clay.......... | 12% — | 20% — |

The percentage of water which indicates the limit between the clay's firm and its plastic state is called the lower limit of plasticity, whereas the percentage of water at which the clay goes from plastic to liquid state is called the upper limit of plasticity. The interval, expressed in percentages of water, between these two limits is called the index of plasticity of

*) The water percentages are calculated on the total substance (clay + water).

the clay and this forms a good basis for the comparison between the fineness of different clays. As the table shows, the index of plasticity is:

33 for Plastic Clay
8—10 for moraine clay.

In none of the other Danish clays so far examined has the index of plasticity been higher than 20.

## III. The Natural Water-Percentage of Clays.

The natural water-percentage of a clay is the mean water percentage at which a clay bed shows a tendency to adapt itself on its natural place of occurrence. Of course, the natural water percentage is only of value in judging the samples when the deviations from the mean figure are not too great as regards each sample.

The mean water percentage of 116 samples of Eocene Plastic Clay from the deposit in the Little Belt was 31.7.

The water percentage of only 9 samples deviated more than 5 from the mean figure.

The mean water percentage of 89 samples of the moraine clay in Alssund was 11.9 The water percentage of only 8 samples deviated more than 3 from the mean figure.

Plastic Clay, which forms the actual sea-floor in the Little Belt, has thus, in that part of the deposit of which we have samples (the top 20 m), everywhere adapted itself to a water-content which lies a little above the lower limit of plasticity of the clay, whereas the moraine clay in Alssund has, on the whole, adapted itself to a water-content which is very closely below the lower limit of plasticity for this clay.

## IV. Hygroscopicity of Clays.

The same ratio between the fineness of the clays, reflected in the physical properties referred to above, also appears in their index of hygroscopicity. The index of hygroscopicity indicates the water-content to which a clay attains when, on being placed in a room with a constant steam pressure, it is allowed to freely satiate itself with moisture. The index of hygroscopicity depends upon the total surface area of the particles; it therefore gives a measurement of the degree of fineness of the clay. The index of hygroscopicity for the clays referred to was:

| | |
|---|---|
| Eocene Plastic Clay, Little Belt........... | 21.4—23.8 |
| Moraine clay, Alssund..................... | 4.0— 4.5 |

As the index of hygroscopicity of the other Danish clays so far examined has always been lower than 16, it will be seen that the index of hygroscopicity of Plastic Clay is unusually high.

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Between the two clay types: Eocene Plastic Clay and the meagre moraine clay, lie, with regard to physical properties, all the other Danish clays.

The boundary between Group I and II in the table on p. 195 is extremely well-defined. And, judging from experience so far, there will not be much difficulty in deciding whether a clay is to be placed in Group II or in Group III: on the other hand there are all stages of transition between the last two groups of the table, especially as regards the Quartary.

*Ellen Louise Mertz.*

## Literature.

### Abbreviations:

Dansk geol. Foren. = Meddelelser fra Dansk geologisk Forening. København.

D. G. U. = Danmarks Geologiske Undersøgelse.

Aarb. f. nord. Oldk. = Aarbøger for nordisk Oldkyndighed og Historie.

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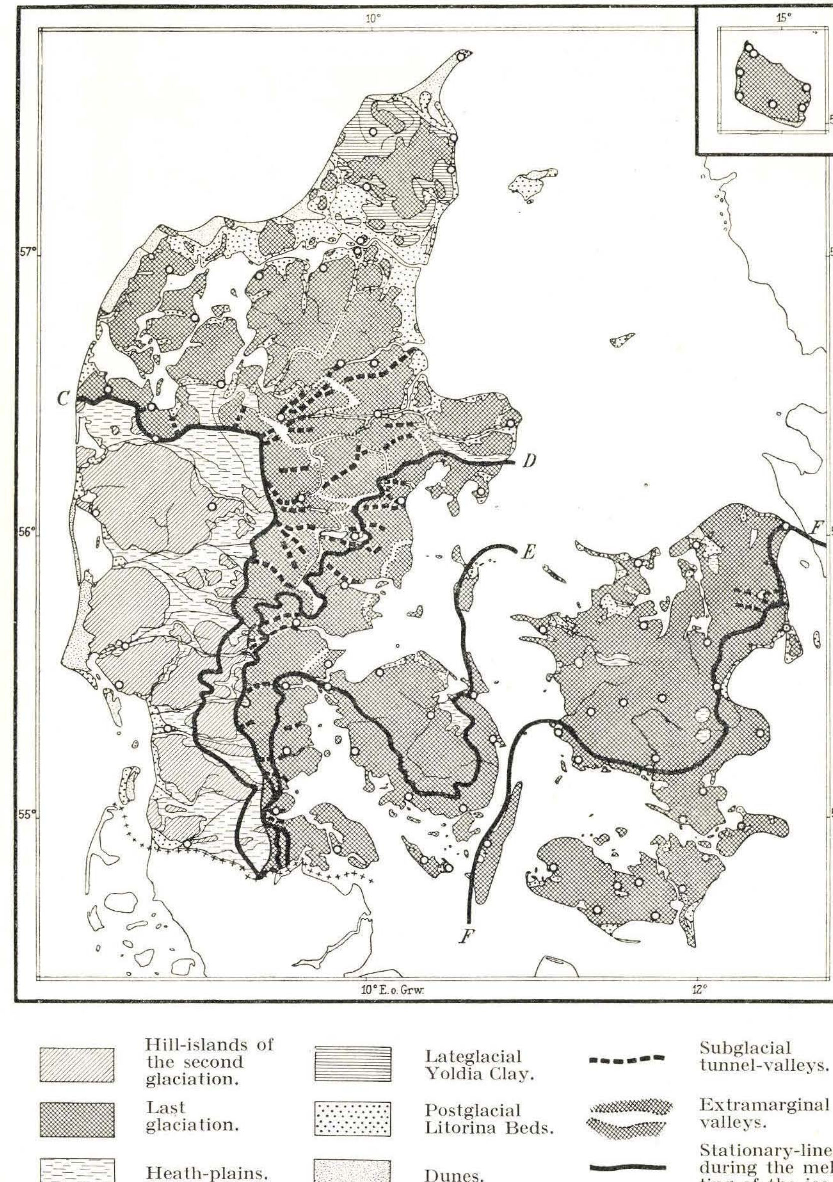
# Index.

## I. Subject Index.

## II. Index to some more important localities.




Map of Denmark's Quartary.