STUDIES IN DANISH GEOLOGY.

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I. INTRODUCTION.

THE kingdom of Denmark lies between the North Sea and the Baltic, and extends northwards from Slesvig to the Kattegat. It consists of the peninsula of Jutland on the west and of several large and some hundreds of small islands forming an archipelago between Jutland and Sweden. The principal islands from west to east are Fyen, which is separated from Jutland by the Little Belt, and Sealand, between which island and Fyen lie the broader waters of the Great Belt. Eastwards of Sealand, and separating it from Sweden, the narrow strait of sea, the Sound, connects the Kattegat with the Baltic. Jutland lies between the same parallels of latitude as Scotland south of Inverness. On the west the shores are low, sandy, and for the most part unindented. The drift of shingle and of blown sand has cut off several wide lagoons from the sea, but such areas are subject to continual exchange between land and sea and many disastrous submergences have occurred in western Jutland from this cause. The sand dunes are often of great height, especially in the northern point of Vendsyssel, known as the Skaw.

The East coast of Jutland presents a very different aspect and is diversified with several beautiful fiords or inlets of the sea.

The northern part of Jutland is completely cut off from the peninsula by the tortuous waters of the exquisite Limfiord, and small boats are able to pass through this inlet from the North Sea to the Kattegat. Southwards of this fiord lie in turn Mariager Fiord, Randers Fiord, "Aarhus Bay," Horsens Fiord and Veile Fiord, while Sealand is penetrated by the beautiful Ise Fiord and Roskilde Fiord. A long range of groups of moraines trending generally north-north-eastwards forms the landward termination of the Jutland Fiords. Their formation was due to the ice-sheet which diverted the previous drainage and laid down the great series of moraines which are characteristic of this picturesque district. Most of the coast consists of low cliffs or klints composed of Glacial deposits, but locally of the underlying "Solid" rocks, as, for example, in the island of Mors, where remarkable interbedded diatomaceous earth and volcanic ashes are exposed in a great cliff section to be mentioned later on. Similarly the cliffs by Mariager and Aalborg are composed of the Chalk and Tertiary Beds. Wide areas of Central and Western Jutland consist of flat and featureless heathland, alternating with dismal peat bogs, but

FIG. 6.—GEOLOGICAL SKETCH MAP OF DENMARK.
SHOWING THE SOLID FORMATIONS.
(*After Dr. V. Madsen.*)

eastwards the beautiful lakes around Silkeborg form typical Danish landscapes.

The island of Fyen is the richest part of Denmark on account of the moraine clay which yields abundant crops and good pasturage. Similar land also forms that part of Sealand lying between Roskilde and Copenhagen.

Of trees, the beautiful beech forests are the most characteristic, but many young plantations of conifers are now growing on what was formerly barren heathland.

The peninsula and islands are alike covered with Drift deposits, and apart from the coast and the artificial sections one scarcely ever sees the Solid formations. Where these are exposed, however, they richly repay careful examination and yield to few elsewhere in their scientific interest.

Denmark is without metalliferous deposits and in consequence derives her wealth almost entirely from agriculture. This poverty in minerals is not, however, so serious a loss as it might seem, because the country is saved from many of the objectionable practices and people who are frequently connected with mining and finance, and it is not likely to suffer the sudden and violent changes to which countries more richly endowed with mineral wealth are exposed. An important industry, however, is fostered by her richness in limestone, and the great quarries at Faxe, Aalborg and Mariager are a source of considerable wealth.*

The whole kingdom is underlain by the Upper Chalk; the lowest zone exposed being that of *Belemnitella mucronata*. Chalk of this zone forms the majestic cliffs on the island of Möen. The extensive line of cliffs facing the Baltic at Stevns Klint, on the eastern side of Sealand, display clear sections of this zone and also of the overlying Bryozoa Chalk. Rarely do the Tertiary Beds come to the surface, but along the northern coast of Fyen they form low cliffs, as also in the Limfiord.

The series of terminal moraines, of eskers, and long lakes are all due to glacial activity, and everywhere in Denmark ancient glacial landscapes are only thinly disguised by vegetation and cultivation. The features are so fresh and undisturbed that they can easily be recognized, even while one is passing them in an express train.

But to many the most interesting deposits are those which contain the handiwork of early man, the great peat-mosses and the shell-heaps, while the connection between Neolithic man and changes of sea-level are better preserved in Scandinavia than in any other country.

In preparing this address I have resorted to my notes made during a recent visit to Denmark and Sweden, but have also drawn extensively upon the excellent accounts published in the Danish Geological Survey Memoirs.† Abstracts of many of these have been taken in order to follow closely the words of the

* In this paper I do not propose to deal with the geology of Bornholm, because it has already been described by several authors.

† *Danmarks Geologiske Undersøgelse,* which in this paper is referred to as *D.G.U.*

authors concerned, and the publication of them has been made in the hope that they may prove of use to English readers who do not wish to go to the trouble of translating the original memoirs.

I wish to take the opportunity presented by this address to offer my sincere thanks to the Danish geologists and archæologists for the great assistance they have afforded me both while visiting with them the sections in the field and by correspondence. Especially would I thank Dr. Victor Madsen, Director of the Danish Geological Survey, who not only acted as my guide to many localities in Denmark, but also placed at my disposal the publications of the Survey. To Dr. Knud Jessen and to Professor O. Bøggild I am indebted for guidance both in the field and in the Museums.

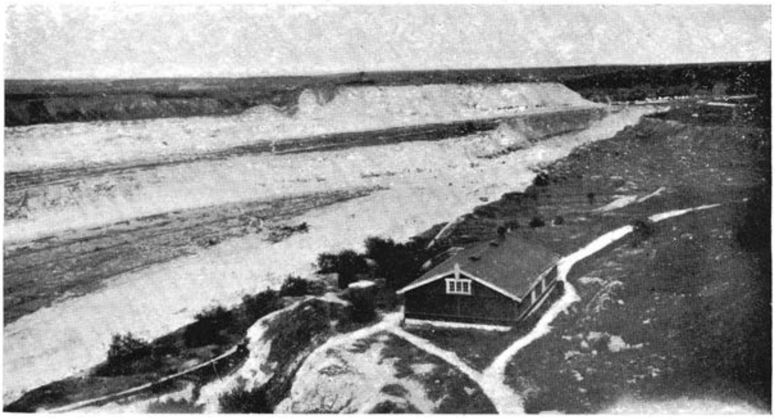
Professor W. C. Brøgger and the Baron de Geer have also much assisted me, and I wish to place on record my appreciation of their kindness. To my wife, however, my chief thanks are due, for without her translations of the numerous monographs I could not have dealt with the subjects adequately, and I am also deeply indebted to her for the beautiful drawings which have been reproduced as illustrations in this paper.

II. THE CHALK.

The Chalk, of which the distribution is shown upon the map, fig. 6, p. 118, has been provisionally divided into the " White " or " Writing Chalk " (Skrive Kridt) and the " Newer Chalk " (Nyere Kridt). The former includes all the Chalk exposed in Denmark, or met with in boreholes, up to and including the Zone of *Belemnitella mucronata* : while the Newer Chalk embraces the Danian limestones, which in turn comprise the Bryozoa Chalk, the Coral Chalk of Faxe, the Crania Chalk and the Saltholms Chalk. An impersistent bed of brown chalky clay containing fish-remains lies above the Writing Chalk locally, and is called the Fiske Ler or Fish Clay, and overlying it in turn or in places resting directly on the White Chalk, is a pseudo-breccia, containing casts of *Cerithia*, called the Cerithium Chalk (plate 7).

The Writing Chalk forms the great cliffs at Möens Klint, underlies most of the islands of Laaland and Falster and extends northwards into Sealand, where it is exposed in Stevns Klint and has been proved in borings beneath Copenhagen and its neighbourhood. The northern part of Jutland is also underlain by the White Chalk, which is exposed in the great quarries at Aalborg and in Mariager Fiord, where it is exploited for the manufacture of Portland Cement. The White Chalk is thus folded into a wide syncline with a north-west and south-east axis.

The overlying Danian or Newer Chalk extends from the



FAXE QUARRY, SEALAND.
The Danian Bryoza and Coral Chalk.

STEVNS KLINT, SEALAND.
Senonian overlain by Danian Chalk, with the Fish Clay at the Junction.

[To face p. 120.

south part of Sealand northwards over that island, and extends into eastern Fyen and the northern part of Jutland between Aarhus and Aalborg.

No lower zone than that of *mucronata* is exposed in Denmark, but a deep boring near Copenhagen proved the following succession and thickness in metres of the Chalk :—

Quaternary deposits	11
Saltholmskalk with flints (Danian)	33
White Chalk with flints (Upper Senonian) ..	246
White Chalk without flints	206
White Chalk rock	38
Marl with thin grey shale seams alternating with seams of white limestone	327
	861

Perhaps the locality where the succession of the Chalk in Denmark can best be studied is the fine range of cliffs facing the Baltic at Stevns Klint (plate 7B), on the eastern shore of the island of Sealand. Commencing near Gjorslev it extends southwards past Mandehoved and Højrup to Rødvig and averages an altitude of 30 ft.

At the base of the cliff the White Chalk (Skrive Kridt) forms a concave wall about 16 ft. in height showing almost horizontal bedding : it extends along nearly the whole length of the cliff except towards the south for a short distance, where it dips below the sea-level. A phenomenon peculiar to it is the occurrence of black flints of two kinds, the more common forming blocks disposed irregularly in beds and joined to one another by ramifying twisted processes. Such seams attain an average thickness of 0.2 to 0.4 metres, and lie nearly horizontally along the entire length of the cliff section. There are two principal seams which form conspicuous lines near Højrup, and are seen in plate 7B ; the upper bed lies at about 3 metres below the top of the White Chalk. Flint also occurs in irregularly disposed isolated nodules. There are layers of tabular flint consisting of lamellar masses often arranged horizontally, or more rarely inclined, which appear to have been deposited in faults and fissures. This platy flint is for the most part developed in the southern part of the cliff above the important upper bed of branching black flints. These two sorts of flint are clearly seen to have had different modes of origin. The black branching flints have arisen as the result of concretionary action commencing with the deposition of the Chalk, enclosing casts of numerous fossils, and deriving silica from sponges and other organisms by concentration in a calcareous mud already rich in silica, whereas the tabular flint could only commence to form after the Chalk was sufficiently hard to be faulted and fissured.

The lower White Chalk consists essentially of a coccolith sediment rich in foraminifera, and contains only traces of bryozoa. It is nearly pure carbonate of lime, the percentage ranging from 95 to 98, one sample from Stevns Klint yielding as high a percentage as 99.6.

At the cliff and also from the photograph (plate 7B) two horizons are easily distinguishable ; a lower white one with horizontal beds of flint and an upper greyish-yellow one with wavy lines of grey flint. This upper part is composed largely of broken-up branches of bryozoa, cemented together with crystalline calcite into a hard rock which is called the "Limsten," and presents a greater resistance than the White Chalk does to the assault of the waves and to the weather. In consequence it forms a projecting cornice, which can be seen in plate 7B, along the whole range of cliff.

The White Chalk at Stevns Klint belongs to the most recent part of the Zone of *Belemnitella mucronata* and is characterised by the presence of *Scaphites constrictus*. It is more recent than the White Chalk at the beautiful Möens Klint.

Above the White Chalk lies the Fish Clay: a clay which derives its name from the large number of fish-remains that it contains. It does not form a continuous bed but presents an aspect of large lenses having their greatest thickness in the middle and thinning out each end. The clay is visibly stratified and is of a greyish colour mixed locally with brown seams. Eyes of chalk are preserved in the wavy brown seams of clay much in the same way as one sees seams with lenses of white Chalk in the upper part of the Middle Chalk in England. It was formerly supposed to be a primary deposit, but it resembles rather a result of solution. Chemical analyses show an average proportion of 57.7 per cent of carbonate of lime. Its lower junction, with the White Chalk, is in the form of a series of loops outlined by bands of black flint. It passes by insensible gradation upwards from the underlying and also into the overlying beds, but where it does not occur the overlying beds pass insensibly into the White Chalk.

This overlying bed is the Cerithium Chalk, or Cerithium limestone. It presents the characteristic features of a breccia, or rather a pseudo-breccia, containing semi-crystalline irregular and angular fragments. In thickness it varies from about a foot to two and a half feet. It is yellow to grey in colour and in certain cases includes numerous irregular to cylindrical cavities, representing silica sponges. The fragments are often shiny and appear to be slicken-sided. Nielsen does not regard it as a stratigraphical unit, but rather as a condition affecting several different layers adjacent one to another.

In the sequence White Chalk, Fish Clay, Cerithium Chalk, the Fish Clay often is missing, or else gradually thins out and passes obliquely upwards into and through the Cerithium Chalk. Where it is missing, the White Chalk passes into the Cerithium Chalk, which to a certain extent it resembles, but contains a much greater quantity of bryozoa and is also richer in crystalline calcite. Its fossil contents, however, are far different from those of the White Chalk, and this difference can be attributed rather to the conditions than the period of deposition. The relations of the Cerithium limestone to the Fish Clay are still uncertain and further research is required before a definite opinion can be expressed. Flint occurs in the form of blocks, but seldom in layers. Pyrites and its decomposition products are not uncommon.

Its stratigraphical position was formerly supposed to be with the Danian, but the presence of such species as *Cerithium faxense, C. pseudotelescopium, Scaphites constrictus, Baculites vertebralis* and *Ananchytes ovata* clearly relate it to the Senonian. The chambered cephalopods are the last representatives of the ammonites.

The Bryozoa Chalk.—The whole of the upper part of Stevns Klint, below the covering of Drift, consists of the Bryozoa Chalk. This deposit is composed essentially of fragments of bryozoa in which the interstices between the ramifying branches are infilled with crystalline calcite of a shining vitreous lustre. It is greyish-yellow in colour, hard and semi-crystalline. Flints are developed as continuous beds, either straight or wavy, and differ much from the beds of flint in the White Chalk. They attain a thickness of some 30 cm. at the maximum, and are interbedded with flintless chalk up to 1⅓ metres thick. Their colour is pale grey. A point of great interest to the archæologist is the inclusion in this grey flint of numerous bryozoa. Examples can be found in which the silica is seen to enclose groups of bryozoa which pass gradually into the limestone matrix: in fact, the bryozoa have become silicified. Many of the beautifully fashioned and polished axes of the "thin-neck" type show such bryozoa, and there can therefore be no doubt that much of the material used by the Neolithic artificer was obtained from the Bryozoa Chalk and possibly from Stevns Klint. At first sight the seams of flint in the cliff-face appear to have been folded, but closer examination shows that they follow the current-bedding of the rock.

At Stevns Klint the limestone attains its greatest thickness near the Lighthouse, where it measures 22 metres. Glaciers locally removed the whole of it, as between Storedal and Manhoved. In a very small number of instances the Bryozoa Chalk shows a brecciated structure similar to that of the Cerithium Chalk, and in this rock, fragments of *Cerithium* have been found. It is therefore possible that such fragments were derived from the Cerithium beds during the time when the Bryozoa Chalk was being laid down. These beds are about $\frac{1}{2}$ metre thick and lie generally in the lower part of the limestone. The hard continuous layers of flint form a very resistant rock which, in consequence, is eroded less quickly by the waves than the White Chalk and so forms the projecting cornice seen in plate 7B. At a good many places the ice-sheets have broken up the rock and included flints into a breccia which by subsequent cementation forms a crystalline mass resembling the Coombe Rock. The passage of the ice-sheets is further revealed by the contours of the Chalk surface. Beneath the drift deposits lies a series of long depressions and ridges with a general direction of north-east and south-west.

Between the cliffs at Stevns and Faxe the Limsten is exposed south-west of Rødvig, near the village of Lund and also around Haarlev.

Near Herføgle there are some chalk quarries where the Limsten is overlain by Crania Chalk, which was deposited during a more recent period of the Danian; but otherwise no other kind of chalk is seen near Stevns Klint.

The Coral Chalk.—To study the Coral Chalk it is necessary to visit the great quarries at Faxe, (plate 7A, and map fig. 6). These extend eastwards of the village for nearly a mile and as they have been worked in steps the several horizons can easily be studied.

The Coral Chalk is of very much more restricted occurrence than the widespread Limsten. The hill of Faxe is a mammilated "boss" that protrudes through the Drift deposits and dominates the surrounding flat country where the "Limsten" forms the subsoil (plate 7A); it is the remains of a great coral-reef of Danian age. The Coral limestone consists of a lattice of branching corals, in which the interstices are more or less filled with calcareous mud and organic débris. In some instances the infilling material is scarce and the Coral Chalk then resembles a trellis of irregular branches, mainly of the genera *Lobopsammia* and *Dendrophyllia*. Sometimes the coral is seen to be decomposed when hollow moulds are left in the crystalline rock. "Faxe Marble" is the term applied to the crystalline masses which show sections of the corals. These different sorts of rock are very variable in extent and distribution, and an apparent stratification is caused by the alternation of the crystalline with the soft rock. Such beds represent the original lines of coral growth. In parts of the quarry they incline steeply and give rise to an appearance of dip. No flints have been found in the Coral Chalk, but percolating water has deposited scales of chalcedony of a clear grey colour on the yellow limestone. The Coral Chalk composes the bulk of the rock at Faxe Hill, but important masses of bryozoa are also found. These are normally in the same condition as at Stevns Klint, but have often been converted into a hard limestone which exactly resembles the Faxe Marble ; elsewhere they consist of fine powder. The colour is a purer white than that of the Coral Chalk.

In the rare instances where flint occurs it forms irregular nodules lying in series as in the White Chalk and the Blegekridt. When flint is found it is always associated with dolomite. Dolomite is characteristic of Faxe Chalk ; it is mainly sandy intercalated with limestone, and of a yellow colour. Such seams are up to 3 ft. thick, but there are concretionary and mammilated lumps and even solid beds of the mineral. Both flint and dolomite appear to be of secondary origin.

At Faxe the nature of the rocks underlying the Coral Chalk is unknown ; a borehole put down at a place about 1,200 metres south-west of the church proved, at a depth of 16 metres below sea-level, Chalk-with-flints, undoubtedly the Limsten, and it is therefore possible that the Limsten occurs, as at Stevns, between the White Chalk and the Coral Chalk. Only traces of the Crania Chalk have been recognised at Faxe, but near Herføgle, Solhøjsgaard and Aashøj, above the Limsten, deposits belonging to a higher stage of the Danian have been found. The Crania Chalk is of a clear colour : it is often granular in texture but normally cemented into a compact state. It is readily distinguishable from the Faxe Chalk by such fossils as *Crania tuberculata* and a *Plicatula*. Glauconite forms an essential constituent of this bed : it is of fine grain and in small quantities. Westwards it is overlain by the Green sandstone, as also at Aashøj and at Lellinge.

The foregoing description is taken from the observations of V. Milthers,* supplemented by my own notes. Milthers classifies the Danish Chalk according to the following table :—

Palæocene	Green sandstone
Danian	Crania limestone Marble and limestone of Faxe (Bryozoa Chalk and Coral Chalk)
Upper Senonian	Cerithium limestone Fish Clay White Chalk

The fauna of the Faxe Chalk has formed the subject of many memoirs, among the latest of which may be mentioned those by K. Brünnich Nielsen† and Poul Harder.‡

The fauna described by Brünnich Nielsen comprises nine new species belonging to eight genera and two families. The specimens were collected in a few places in the Faxe quarry, but mainly from that great protruding mass known as Ravn's Nose, where

* " Kortbladene Faxe og Stevns Klint," *Danmarks Geologiske Undersøgelse,* I Raekke, Nr. 11, 1908.

† " En Hydrocoralfauna fra Faxe," *D.G.U.*, IV Reakke, Bd. 1, 1919.

‡ " Om Graensen mellem Saltholmskalk og Lellinge Gronsand," *D.G.U.*, II Raekke, Nr. 38, 1922.

the calcareous matter embedding the fossils is still soft and can easily be washed away, whereas elsewhere in the quarry it is a hard, more or less porous limestone. While the fossils in the hard rock are represented by casts or covered with a crust of carbonate of lime, in the friable material, although they are damaged by pressure which has affected them more or less severely, they are usually well preserved and easy to diagnose.

The fauna presents a relatively recent character. The hydrocorals are closely related to those found in Tertiary deposits, and the same may be said of some of the crinoids, gastropods, crabs nautili and fish.

In considering how many species are common to the Danian and the Senonian, one finds that out of 111 Senonian and 179 Danian species only 33 are common to both formations, and even among these there are several of which the identity is doubtful. There are then, very few species common to both, so that whilst there seems no reason why the Senonian should not be separated from the Danian, there are several reasons why the Danian ought to be placed in the Tertiary. Unfortunately a large Montian fauna is unknown with which the Danian might be compared ; no comparison has previously been made, and there is reason to suppose that a certain number of Danian species have been placed with other names in other faunas. As instances we may cite the discovery of *Nautilus danicus* in the Palæocene of Russia and France ; the discovery in Russia of a species of *Crania* which is with difficulty distinguishable from *Crania tuberculata* ; the discovery of *Argiope acuta* in the Grønsandskalk of Lellingaa ; the identification of *Argiope scabricula* v. Koenen in a Palæocene deposit at Copenhagen with *Argiope acuta* of the Danian.

As it is impossible at present to draw up a list of species common to the Danian and to the Palæocene, only the genera will be given, but these clearly show that a large number of purely Cretaceous ones died out and an equally large number of more recent genera made their appearance precisely at the time of transition between the Senonian and the Danian.

There are no fewer than ten genera that die out and twenty-three that appear, whilst of the total number which are confined to the Danian, or occur in both it, and also in the Tertiary Beds, only one genus, *Isoarca*, seems to disappear with the Danian.

There seems, therefore, to be good reason to accept Grossouvre's classification and place the end of the Cretaceous system where it is found nearly throughout the world, *i.e.*, at the end of the Senonian epoch.* Grossouvre's hesitation to place the Danian among the Tertiary deposits is primarily due to information furnished by Professor A. Hennig, namely, that some species of *Scaphites* and *Baculites* are found in the Danian ; and also

* "Recherches sur la Craie Superieure," 1e partie, Fasc. ii., chap. 22, p. 817, 1901.

that a lithological continuity obtains between the two formations. These reservations are completely negatived by the researches of M. Ravn,* who places the limit between Senonian and Danian above the Cerithium Chalk and relegates to the Senonian both *Scaphites* and *Baculites*. He also proves that a slight unconformity exists between the two formations.

A comparison of the fossils shows that, of the sponges, one is confined to the Senonian and one to the Danian. All the corals and hydrocorals but one, *Parasmilia excavata* v. Hag., belong to the Danian. No Crinoid or Echinoid is common to the two formations, but among the Asteroidea the following forms have been found in both Senonian and Danian rocks :—*Chomataster acules* Spencer, *Lophidiaster pygmœus* v. Hag., *Metopaster undulatus* Spencer, *Pycinaster crassus* Spencer, *Teichaster favosus* Spencer, *Tholaster argus* Spencer. Among the Brachiopoda only *Crania ignabergensis* Retzius, *C. barbata* v. Hag., *Terebratulina striata* Wahlenberg occur in both, whereas numerous lamellibranchs are common to the two formations. A great number of gastropods appear for the first time in the Danian, while only four are found in both the Danian and Senonian beds.

The following classification is that adopted by Brünnich Nielsen :—†

Upper Danian with *Terebratula lens* Nilss.

c. Craniakalk with *T. lens* and *Crania tuberculata*.

b. Upper Bryozoakalk and Saltholmskalk with *T. lens*.

Lower Danian with *Terebratula fallax* var. *faxensis* Posselt.

a. Lower Bryozoakalk (Stevns, Bolbjerg, etc.).

Brünnich Nielsen considers that the Koralkalk of Faxe is equivalent to the Bryozoakalk *a* and *b*.

The Crania Chalk. M. Rosenkrantz took the opportunity afforded by some engineering works in the South Port at Copenhagen to investigate the Crania Chalk, and the following is a resumé of his remarks.

The most recent deposits of the Danian period in Denmark are known as the Crania Chalk or Limestone. It is a littoral formation which takes its name from a shell that is frequently found in it : *Crania tuberculata* Nilsson. Crania Chalk is known immediately west of Kjøge and also forms the subsoil under Copenhagen. Some recent excavations in the town and at the South Port exposed in an exceptionally clear way some sections of the beds, overlain by glacial deposits and marine alluvium. The surface of the Chalk is striated to a remarkable extent by the passage of the ancient ice-sheets. This section proved that there are two sorts of chalk, sharply divided the one from the

* "Molluskerne i Danmarks Kridtaflejringer," III Raekke.

† "Brachiopoderne i Danmarks Kridtaflejringer," *Vidensk. Selsk. Skr.*, 7 R., Bd. 6, Nr. 4, 1909.

other and termed respectively the Upper and the Lower Crania Limestones, which are separated by an unconformity.

The Lower bed consists of hard, grey limestone of fine grain, and is semi-crystalline (the Saltholm limestone) ; it contains innumerable foraminifera and hence was called formerly, by M. Rørdam, the foraminiferal limestone. At the South Port there are some subordinate beds of soft calcareous sand. Flint occurs both in continuous bands and as isolated nodules. There are numerous cavities infilled with Chalk mud which contains beautifully preserved fossils, mostly of small size. The hard chalk contains 98 and the sand 97.5 per cent of $CaCO_3$.

The Upper Crania Chalk comprises at its base a glauconitic conglomerate composed of numerous more or less rolled fossils and occasionally includes also rolled lumps of the lower bed of Crania limestone. Upwards this conglomerate passes gradually into a grey marly, finely granular limestone rock that has been seen overlain by an impersistent, dark, slightly sandy marl bed. The Upper Crania Chalk fills in cavities and fissures in the Lower Crania beds. Calcium carbonate forms 94 per cent. of the conglomerate, about 91 per cent. of the marly limestone rock and 82 per cent. of the dark marl.

Fauna. Fossils are commonly found in the Upper Limestone, but much less frequently in the Lower division. The faunas of the two beds compare well the one with the other. The differences are not of primordial importance in determining the age of the deposits, but they reveal the fact that the crystalline state of the shells of certain forms is different in the two groups. The fossils preserved in crystalline carbonate of lime (calcite) are in a good state, while the aragonite shell is only rarely well preserved and is usually much decomposed ; fossils are better preserved and more numerous in both the Upper Limestone and the marls, but most of them are rolled.

The fossils from the South Port represent a fauna typical of the Crania Limestone, a fauna which is also known almost completely from the same beds elsewhere.

The following are considered to be characteristic of this Limestone :—*Graphularia grønwalli,** *Ditrupa schlotheimi,** *Crania posselti*, *Crania tuberculata,** *Argiope scabricula,** *Lima bisulcata*, *Lima testis,** *Pecten sericeus,** *Plicatula ravni*, *Modiola hauniensis*, *Scapellum steenstrupi,** *Cestracion danicus*. Some of these forms occur also in the Bryozoa Chalk, while *Crania tubercula* and *Argiope scabricula* are known from more recent deposits. Those forms marked with an asterisk are represented in the Palæocene marls of Denmark, and among these *Lima testis* and *Pecten sericeus* are characteristic of the marls, while the rest are rarely found in them. The fossils common to the Crania Chalk and to the Palæocene marls show how closely the two are related and the differences cannot be explained by a difference of age. The effect of the crystalline condition of the shells appears to have a greater influence, for the aragonite shells are better preserved in the marl than in the limestone.

The fauna had long been known from collections derived from erratics, but in 1898 M. Grønwall found it *in situ* and assigned it to its true place in the Danian. A complete study of the rocks and fossils of the Crania Chalk, however, does not yet exist. In consequence, it has been necessary to pass in review the materials derived from different localities and compare them with that from the South Port. Similar beds are found near Malmö, in Southern Sweden, overlain by a conglomerate, and also at Kjøge, and at Grenaa in Jutland. At Kjøge, Bryozoa Chalk underlies the Crania bed, while at Lellinge it is overlain by a marly limestone of Palæocene age which exteriorly resembles the marly limestone of the South Port. At Fredericksholm Upper Bryozoa Chalk is overlain by the Crania Limestone, and also in the West gasworks at Copenhagen, where the base of the marl is conglomeratic. It is therefore probable that the Crania Limestone passes upwards without a break into the Palæocene marls.

The formation of the Lower Crania Chalk appears to have been during an uprising of the sea-bottom, while the sandy limestones were deposited towards the close of the epoch in fairly deep water and then elevated above sea-level and hardened to a certain degree, being at the same time exposed to atmospheric influences. Next a submergence took place before the fauna had altered its marine character, which permitted the infilling of the cracked and partly eroded surface of the Lower Crania deposits. In deep water was then laid down a conglomerate composed of numerous shells and blocks of eroded Lower Crania Chalk, followed by the marly Upper Crania beds which ushered in the commencement of the marly Palæocene. The Crania conglomerate is therefore the basement bed of the marly Palæocene, and there is a gentle transition from the calcareous Danian deposits into the marly Palæocene beds.

M. Rosenkrantz* concludes his investigation with the remark that it is best to place the limit between the two stages of the Palæocene in the lacuna between the Superior and the Inferior Crania Chalk.

By referring to the lists of fossils it will be seen that in the Danian beds the great Mesozoic group of Ammonites has practically ceased to exist, but instead an important invasion of gasteropods has taken its place. Accompanying this change of faunas is an equally significant change of conditions, for the Danian deposits indicate a shallowing of the sea or an emergence over wide areas. Various authors, partly on account of the extinction of the Ammonites, relegate the Danian beds

* "Craniakalk fra Kjøbenhavns Sydhavn," *D.G.U.*, II Raekke, Nr. 36, 1920.

to the Tertiary. Thus M. Desor* takes the rock at Faxe as being typical of the Danian, and classifies the section already described in downward succession as follows:—Saltholm and Faxe Limestone, Cerithium Chalk, Fish Clay with *Exogyra lateralis*. The normal facies of the stage is the Saltholm Limestone, which is the horizon of *Ananchytes sulcata*, *Exogyra lateralis*, *Terebratula carnea*, and *Glyphæa lundgreni*. This bed of rock locally passes laterally into a homogeneous limestone of fine grain, with flints, which contains hydrozoa, and of which the principal fossils are *Nautilus danicus*, *Temnocidaris danica*, *Holaster faxensis*, *Brissopneuses danicus* and a crab, *Dromiopsis rugosa*. Elsewhere at the same horizon yellow bryozoa-limestone occurs (Faxe Limestone) with *Caryophylli*, *Oculina*, *Isis vertebralis*, etc.

M. Ravn has recently reconsidered this subject and is of opinion that there is more evidence in favour of retaining the Danian in the Cretaceous than for relegating it to the Tertiary System.

III. THE TERTIARY BEDS.

The following table indicates the Tertiary formations that are found in Denmark according to Ussing (map, fig. 6).

Pliocene	Missing.
Upper Miocene	Dark, sandy mica clay of West Jutland.
Middle Miocene	Mica sand and clay of Skyum by Thisted, and of the borings at Varde and Viborg.
Lower Miocene	? Mica sand and clay, with the Brown Coal.
Upper Oligocene ..	Black mica clay of Thisted, Vildsund; dark glauconitic clay of Aarhus.
Middle Oligocene ..	Grey-green septarian clay of Skive; and sandy mica clay of Aarhus.
Lower Oligocene and Upper and Middle Eocene	Missing.
Lower Eocene	Variegated, plastic clay of the Little Belt, &c. Moler (Mo Clay) with volcanic tuffs.
Upper Palæocene ..	Grey non-calcareous clay, of Klitgaard near Mors, and in many borings.
Middle and Lower Palæocene	Kerteminde Marl of Sealand and Fyen. Glauconitic Marl of Lellinge and Copenhagen.

* *Bull. S.G.F, iv., p.* 179.

The Kerteminde Clay. This clay is the most widely distributed Eocene formation in Denmark; its distribution is shown by horizontal lines on fig 6. It is a fine-grained, grey clay containing up to 50 per cent. of lime; glauconite is rare, but tiny cubes of pyrites are usually present in large numbers. Foraminifera and sponges are common, the sponges raising the silica content of the clay in analyses. Siliceous matter forms layers, especially in the lowest part of the clay, and locally renders the beds compact and fairly hard: these "flints," however, are not so pure as those occurring in the Chalk. Molluscs of the same genera as those in the Lellinge greensand are found in the Kerteminde Clay, but are less well preserved. The clay is exposed only at Kerteminde Klint on the eastern shores of Fyen, where it is 34 ft. above sea-level, and is covered with moraine clay. A boring in the town of Kerteminde entered the formation at 92 feet and continued in it to 315 feet under the surface, where the boring was stopped: there it is at least 223 feet thick. Locally, it rests on the Saltholms Chalk, but usually on the Lellinge Greensand. At Odense it is 50 feet thick, but in a few miles entirely dies out south-eastwards. It reappears east of the Great Belt, at Tornborg near Korsør, at a depth of 165 feet and has a thickness of 135 feet. Near Slagelse and Ringsted it has been proved in borings to be adjacent to the Lellinge Greensand.

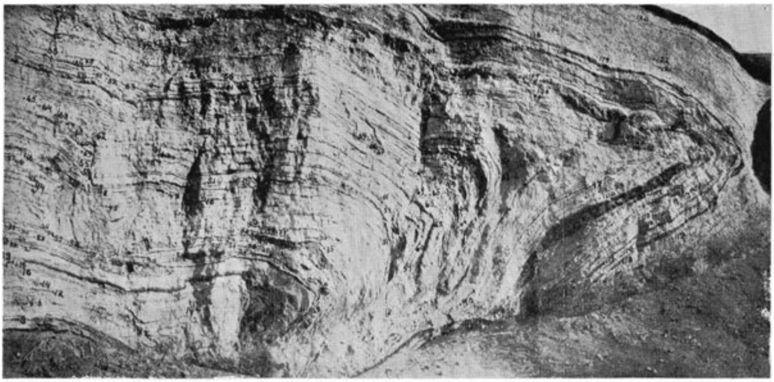
The Plastic Clay is shown on the map by sloping lines and from the map is seen to form the solid deposits of southern Fyen, eastern Sealand and the country bounding the Limfiord on the south, in Jutland.

The cliffs on both sides of the Little Belt expose these clays as at Strib, and Røfnaes, and the clay is seen in section in the cliffs of Mariager Fiord. This plastic clay when wet is squeezed out of the cliffs by the weight of the superincumbent beds and is washed away by the waves, so that the sea for great distances becomes clouded with mud. It moves forward in much the same way as a glacier and carries blocks of more resistant beds on its surface, while inland, wide and deep cracks appear in the fields. These landslips are usually gradual and slow, but areas of many acres have been lost in a single day. The clay is lithologically identical with the Reading Clays, and is mottled in various shades of grey, green, blue and red. Clay-ironstone in irregular lumps with oxidized crust are common, and more rarely barytes occurs. It is exposed in the cliffs east of Strib on Fyen, and at Thisted, Jutland, underlies the Moler, but dips below the surface eastwards in a syncline, the eastern limb of which rises in the Mariager Fiord. It supplies satisfactory material for the manufacture of Portland Cement when used with Chalk, and for this purpose is dug near Mariager.

The Moler or Mo Clay. The most notable deposit of Tertiary age is that described as the Moler. It exhibits its maximum development on the island of Mors in the Limfiord, Jutland, where it displays a series of clear sections especially in Hanklint. It occurs also in the island of Fur, and in small sections at numerous other localities on the mainland and also among the islands, *i.e.*, at Bogense, Fyen.

Moler consists of alternate beds of volcanic débris and of infusorial earth composed of both marine and freshwater diatomaceæ with a small amount of clay. In the moler, cementstones occur with some regularity; they form discs, called "boller," and also tabular layers. They are of relatively minor importance when the total thickness of the deposit is considered, and seldom attain a greater thickness than one and a half feet, but a conspicuous bed is traceable as a continuous layer for a long distance. The "boller" are lens shaped, the largest being 1½ feet thick and 10 feet long. They consist of dark grey limestone containing a small proportion of iron compounds which weather brown, but they are not pure limestone as they contain a large amount of insoluble matter, of which innumerable diatoms form the major part. Originally the diatomaceous earth appears to have been cemented by infiltrated lime, but that the action was gentle is shown by the diatom skeletons being perfectly preserved, whereas they are nearly always fragmentary in the uncemented moler. The soft beds appear to have been completely comminuted either by the weight of the superincumbent strata or by glacial pressure, or possibly by both causes. These "boller" were formerly the source of a local industry, and were dredged up from the sea-bottom and used at Faggeklit, north of Mors, in the manufacture of Portland Cement, in the same way that the London Clay septaria were dredged from the Thames and the Medway and burnt for the same commodity at Northfleet and neighbouring parts of Kent. Some of the concretions were dug out of the Klints, but their occurrence is so sporadic and rare that the number obtained did not pay for the labour involved and the practice was discontinued.

Moler has been used as a fire-resisting substance, as packing for pipes and boilers and for the manufacture of a light refractory brick. When fired it forms a brick of very low specific gravity that barely sinks in water. But the earth contains too much clay to be a good refractory substance and cannot compare with foreign "Kieselguhr" which can be used for the manufacture of dynamite. Cleaner, but less extensive deposits are found near Langaa in Jutland, but these are of Quaternary age. Fossils are common and consist for the greater number of fish remains, both bones and scales, while teeth and also complete skeletons are not rare. The fish resembles a small herring-like creature but no more can be said as to its relationship. Rarely marine gasteropods and lamellibranchs are found. Impressions of



MORS KLINT, JUTLAND.
Consists of interbedded Volcanic Ash and Diatomaceous Earth.

SECTION AT RØGLE KLINT, FYEN.

[To face p. 132.

insects are common and so well preserved that various species of wasps, dragonflies and taege (bug) can be recognised. Of plants in addition to the diatoms, twigs and branches of species so far indeterminable have been collected. One leaf is of an extinct laurel.

The volcanic constituents of these deposits formed the subject of a prolonged and detailed study by Professor Bøggild of Copenhagen, who wrote a finely illustrated monograph upon them, from which the following notes have been translated.*

From the facts we have already considered with regard to the irregular distribution and thickness of volcanic deposits in Denmark it is impossible precisely to indicate the situation of the volcano or the volcanoes which emitted the ashes of the moler. To locate such a centre it would be essential to identify the different beds along a greatly extended line, but this cannot be done as the deposits extend over only a very small area. To cite as an instance one bed only, which in the Limfiord attains a thickness of 4 cm., at Mariager 3—4 cm., at Helgenaes is only 1 cm. From these data one might infer a northern origin. Another conspicuous bed is 18 cm. thick in the Limfiord, 13 cm. at Mariager Fiord, and only 12 cm. at Røgle Klint ; from which a north-westerly origin might be inferred. But these are the only beds that can be followed with any degree of certainty. In an attempt to calculate from the localities where the ash occurs, the distance from the volcanic centre, one is able to employ the varying thicknesses of the beds. But the data derived from these observations are not sufficiently precise to justify the drawing of an inference. One condition furnishes, however, a method of estimating the distance from the centre of the eruptions and that is the coarseness of the particles of ash. From certain observations Bøggild considers that the distance from Mors to the volcanoes approaches 100 to 200 kilometres, but nearly all the known Eocene volcanoes lie at greater distances than this, with the exception of Scania, which lies at only 160 km. from Refsnaes. If all the ash came from Scania it would be necessary to discover an ash notably finer in this locality (Silstrup at 340 km.) than at Refsnaes, but this is not the case. There are no marked differences by which one can infer the direction of the original source. Ussing's theory† appears to be the most probable, namely, that the ash was emitted from a chain of volcanoes which were situated along the coast of Fenno-Scandia, also from others in the Skager-Rack and the Kattegat, possibly aided by the Scanian eruptions.

In the Moler 179 beds of ash are distinguishable (plate 8A), but as neither the base nor the summit of the deposit is known

* "Den vulkanske Aske i Moleret samt en Oversigt over Danmarks aeldre Tertiaerbjaergarter," *D.G.U.*, II. Raekke, Nr. 33, 1918.

† "Danmarks Geologi," *D.G.U.*, III. Raekke, Nr. 2, 1899.

a central band has been taken as the zero and those beds above it are numbered with the positive sign and those below with a minus symbol. The positive series numbers 140 beds, which fall into two groups, of which the lower has a total thickness of 19.3 metres, containing 130 beds of ash of a combined thickness of 3.6 metres, whilst the upper section attains a thickness of 7.26 metres and contains 10 beds of a combined thickness of .07 metres. The negative series has a thickness of 29.47 metres and comprises 39 beds with a total thickness of .62 metres. The ash consists of andesite, dacite and liparite.

In each bed of ash the largest grains lie at the base, while the size diminishes steadily upwards. The size of the grains at the base is about .5 mm. in the thickest beds and .2-.3 mm. in relatively thin ones. Specific gravity varies from 1.5 to 1.6. The beds often show converging streaks of differently coloured material. There are frequently twin beds of ash without intervening moler, from which it may be inferred that two eruptions occurred with a very brief interval between them. The beds are divisible into six groups according to their petrographical nature. Beds numbered 20 to 140 consist purely of amorphous basaltic fragments, and among these the greater number are black, nearly all opaque, and scoriaceous, whilst the remainder consist of diaphanous, brown glass. The amorphous grains are often rather pumiceous. The crystalline particles which do not exceed 1/50 of the mass are composed for the greater part of basic plagioclase, closely related to labradorite ; there is also a small amount of augite. There are beds that are nearly free of crystalline matter, and others that consist almost entirely of it, and of these some are mainly composed of augite and others of felspar.

The second group comprises beds which are not as purely basaltic as the main mass, for they contain a sufficient amount of the more acid felspars, oligoclase and albite, and rarely also orthoclase, to be separately classed.

Group three contains specimens which lie between basalts and andesites with both oligoclase and albite and also labradorite. Some notable examples have a particularly characteristic composition, consisting of highly refractive glass, all sorts of plagioclases and also orthoclase, quartz and green hornblende.

Group four consists of beds containing clear glass of which the refractive index is from 1.53–1.54 (Basaltic glass being 1.6). *i.e.*, oligoclase. These are andesites.

Group five consists of fragments of clear glass with refractive index of 1.51 ; chiefly albite and orthoclase of the dacites.

Group six is composed of liparite ash and uncoloured glass with a refractive index of 1.5.

The different classes of eruptions are mixed one with another with a nearly complete irregularity. Generally speaking, the beds have mainly the most acid rocks in the basal layers.

There are four beds in which the cementstones are richly developed.

Ussing says that at Hanklint on Mors, and at Silstrup Klint in Thy, are found beds of dark plastic clay under the moler, but the sections are so much disturbed and irregular on account of the action of ice masses (plate 8), and partly also because of the slipping of the plastic clay, that the evidence of succession cannot be relied upon, and therefore the stratigraphical position of the moler is still uncertain. Moler may have been deposited in shallow water, whilst the plastic clay was laid down in deep water, *i.e.*, at Strib.

The Oligocene and Miocene deposits. The deposits of these periods are called the Glimmer Sand, Glimmer Clay and Brunkul, or the Mica Sand, Mica Clay and Brown Coal. They cover a considerable part of South Jutland, where they lie beneath glacial deposits, and extend eastwards into Fyen on the north-west and the south of the island. Their distribution is shown on map, fig. 6, by dots, while the Brown Coal is indicated by crosses.

The deposits occur as alternate beds of sand and clay and together attain a great thickness as proved in many boreholes.

Mica Sand consists essentially of white quartz grains in which numerous small scales of muscovite occur, but the appearance of abundant muscovite is deceptive, for in reality it forms only a very small part of the total mass. It is notable that the Mica Sand consists almost entirely of the two minerals quartz and mica ; the rarity of felspar indicates the deposition of the beds in shallow water. Lime is also rare, but occasionally layers of gravel of strongly rolled quartz pebbles are found, and not uncommonly mica is absent and the sand becomes a purely quartz sand.

Mica Clay consists of very sandy clay containing numerous scales of mica, small quantities of fine grains of iron pyrites and tiny black particles of coal. It is brownish to black in colour. Where there are larger quantities of pyrites and coal the clay becomes "Alunjord" or alum-earth, which in past times has been exploited for the manufacture of alum, but without much success. Decomposition products of the pyrites give rise to crusts on the alum-earth, and when lime also is present small colourless crystals of gypsum are formed. Lime occurs as round concretions (Kalkbolle) in which shells of mollusca and crustacea are often preserved, but these are uncommon. When the Mica Clay does not contain too much sand it supplies an excellent tile and pot clay, and especially is such clay developed in the region between Holstebro and Esbjerg in Jutland ; it is from this clay that the familiar "Jydepotter" is manufactured.

The age of these deposits has been determined by means of the fossils which, however, are of rare occurrence. The principal fossil localities are Skyum and several other places in Thy, also in the neighbourhood of Aarhus, at Albaekhoved, east of Veile, by Middelfart, Esbjerg, Sandfeld Gaarde and at Skjaerum Mølle, west of Holstebro. The localities are thus distributed inside the district covered by these formations. The fossils belong to two periods : those from the north-east and part of the eastern district are of Oligocene age, whereas the remainder are Miocene species. The principal Oligocene form is *Aporrhais speciosa*, while *Cassis saburon*, *Astarte reimersi* and *Isocardia forchammeri* are common Miocene mollusca.

The full thickness of these deposits is unknown, but several hundred feet have been proved in boreholes without the base having been reached. The following figures give the thickness in feet at several of such boreholes. Skovby, 181 ; Horsens, 205 ; Veile, 61 ; Varde, 280 ; the formation is seen to overlie the Plastic Clay at both Viborg and Frijsenborg.

The Brown Coal is either black or brown-black ; the inferior qualities are slaty, sooty and full of clay, while the better varieties contain trunks of trees so perfectly preserved that the woody tissues are clearly seen.

Brown Coal always occurs in layers, but unlike coal elsewhere not in a series of adjacent beds. Their thickness is seldom more than a foot or two, and when worked, the incoherent sand of the roof has to be excluded by timbers from the workings, and this so much adds to the cost that it renders exploitation unprofitable. Near Silkeborg an attempt was made, in 1861, by the Government to work the coal by means of a level driven into the hill. The seam was up to four feet in thickness, and was dug to a length of 208 feet, but only 1,000 tons (Danish) were obtained, of which 400 tons were dust. The coal was friable, damp and porous, and a sample, after having been preserved in a dry place for five years, contained 20 per cent. of moisture.

The mode of origin of these coals appears to have been marine, and in a shallow sea.

The presence of pot-holes or " marmites " is usually attributed to the activity of falling or swirling waters in carrying around stones which drill out the holes. In Denmark, on the north of Fyen, at Røgle Klint, similar effects have been produced by the activity of the wind causing sand and stones to fall down the cliff-face in incessant streams. The streams cut grooves in the solidly-bedded sand, and where more resistant beds occur proceed to drill out basin shaped cavities. On a day in June, 1925, when a northerly gale was blowing directly on the face of the cliff, masses of sand poured downwards and swirled round and round in large eddies in the " pot-holes," while subangular stones up to 2 inches in diameter were spasmodically jerking round when extra heavy gusts of wind reached the cliff. The general effect is striking and characteristic, and is shown on plate 8B.

IV. THE GLACIAL DEPOSITS.

Nearly the whole of Denmark is covered with glacial deposits, among which several different types can easily be recognised,

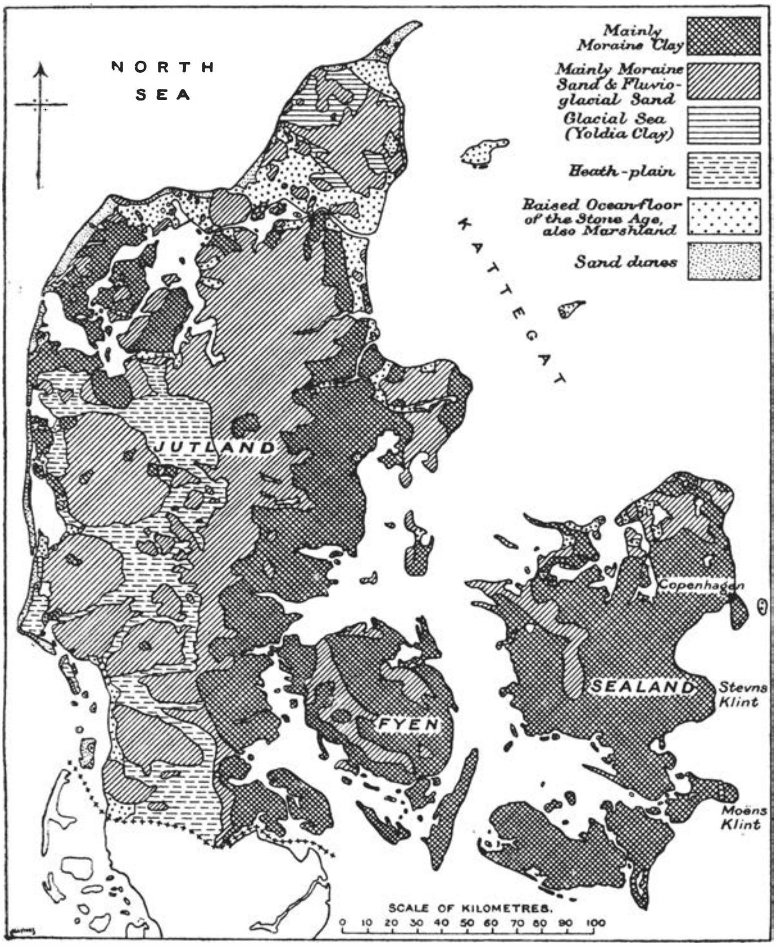


FIG. 7.—GEOLOGICAL SKETCH MAP OF DENMARK. SHOWING DRIFT DEPOSITS. (*After Dr. V. Madsen.*)

but all have arisen either from moraines or from waters resulting from melting ice. The deposits of the moraines are characterised by their unassorted condition, whereas those derived from the melt-waters are stratified or current-bedded. Lithologically they both may consist of clay, sand or gravel. Moraine deposits cover about two-thirds of Denmark, and are especially well developed in the islands of Sealand and Fyen, where boulder clay forms the richest agricultural land. The melt-water deposits cover the remaining third of the land, and the great outwash sand-plains constitute the barren " heaths " of Jutland (map, fig. 7).

The moraine clay is blue at depth but weathers to a rusty-red colour ; it is thickest on the islands. Stones of all sizes up to the large boulders called " Kampsten " are mixed with the clay, *i.e.*, such well-known stones as the " Hessellagerstone," the Tirslundestone, the Dybbølstone and others. All of them are striated ; some are derived from the solid formations of Denmark, while others have been conveyed from Fennoscandia by ice.

By the petrographical characteristics of these rocks the direction whence the ice-masses came can be precisely inferred. Erratic boulders of rocks derived from the south of Norway occur especially in north and west Jutland, such, for example, are the boulders of rhombporphyry, while numerous rocks from the lands adjacent to the Baltic are found principally on the islands. The well-known red granite of the Aaland Islands and the Silurian limestone from Gothland are common in the moraines of Sealand and Fyen.

There are convincing evidences of at least two glaciations and one interglacial period in Denmark. Madsen and Nordmann, however, consider that there were three glacial and two interglacial periods, which they classify as follows :—

(1) Post Glacial time.

Mya arenaria deposits : recent, boreal-Lusitanian fauna	emersion period
Littorina deposits : Lusitanian fauna	submersion period
Ancylus deposits : Freshwater deposits	emersion ,,
Zirphaea deposits : Boreal fauna ..	submersion ,,

(2) Late Glacial time.

Upper marine sand : Arctic fauna ..	emersion ,,
Yoldia clay ,,	submersion ,,
Lower marine sand : ,, ..	,, ,,
Allerod oscillation : *Dryas octapetala* flora.	

(3) Glaciation III.

The surface moraines of the Danish islands and north and east Jutland.

(4) Interglacial II.

The marine series of Skaerumhede and Vendsyssel.

Zone of *Portlandia arctica*. Arctic fauna	emersion period

= Older Yoldia Clay.

Zone of *Abra nitida* : boreal-Arctic fauna .. .. emersion period

Zone of *Turritella terebra* : boreal fauna .. .. ,, ,,

Eemian Deposits = (Cyprina Clay) in south Jutland and the Danish islands. Their total extension from Holland to East Prussia : Lusitanian fauna.

The Brørup Bogs.

(5) Glaciation II.

Older moraines and surface moraines of the "hill-islands" in West Jutland.

(6) Interglacial I.

The Vognsbol deposits with boreal and boreal-Arctic fauna.

The *Tellina calcarea* clay (Arctic fauna) in the cliffs of Røgle near Strib (Fyen) and the diluvial marine deposits called "Esbjerg Yoldia Clay" : boreal and Arctic fauna.

(7) Glaciation I.

The older moraines of the hill-islands.

These glaciations* are thought by the Danish geologists to correspond to the Mindel, Riss and Würm glacial periods of the Alps as desciibed by Penck and Brückner.

The Great Ice Age was marked by the advance from Norway of an enormous ice-sheet which forged its way across Denmark, obliterated the Baltic and invaded northern Germany for many miles. At its maximum the ice represented so much of the oceanic waters in the frozen state that the deep sea deposits appear to have been elevated to a height of at least 2,600 metres above the present sea-level.† The effect upon the comparatively non-resistant rocks of Denmark of this ice mass is marked by the great overthrusting and overfolding that is now seen in them ‡ (plate 8). The thrust of this huge mass was irresistible and the rocks were pleated, telescoped and ultimately comminuted. It is unfortunate that the soft beds could not retain the striae that are preserved on the crystalline schists and igneous rocks, but sufficient are preserved to prove that the direction of movement was southwards in Jutland. The previously mentioned boulders of rhombporphyry, moreover, supply further evidence of the source of the ice-sheet. When this ice-sheet had retreated beyond the northern boundary of Jutland an interglacial period ensued which is marked by the Eem Clays. For example, there is in a cliff on Langeland a

* V. Nordmann, "Det marine Diluvium ved Vognsbøl," *D.G.U.*, IV Raekke Bd. 1, Nr. 14, 1922.

† W. C. Brøgger, "Om de Senglaciale og Postglaciale Nivaforandringer." *Norges Geologiske Undersøgelse*, No. 31, 1900–01, pp. 89–96; 683.

‡ *D.G.U.*, IV Raekke, Bd. 1, Nr. 2, 1916.

marine clay that is overlain by moraine clay; it contains mollusca characteristic of temperate seas. A similar clay with the same fauna occurs at Ribe and Tønder resting on moraine clay. One must therefore conclude that these clays are interglacial deposits. Similar conditions are known about some freshwater formations found, among other places, at Fredericia and various localities between Kolding and Esbjerg in Jutland, where the finds prove that fir trees, yews, beeches and other plants were growing in Denmark in an interval between two glaciations, and the presence of the skeletons of the Red deer shows that beasts had had time to immigrate into Denmark. Transported masses of these Eem clays are found in eastern Denmark and also in North Germany, but in west and south Denmark they occur in the place that they were first formed. The line of separation between the disturbed masses and those *in situ* does not, however, coincide with the termination of any of the large ice-sheets. The shells of this clay have been incorporated into the ground moraine of the Baltic glacier for an area of at least 50 miles across, but the change of climate indicated by the shells is such that the retreat of the ice must have been very much greater than this distance indicates. Some of these shells are now limited in their distribution northwards to the west coast of France, such *i.e.*, as *Mytilus minimus* and *Syndesmya ovata*, while *Mytilus lineatus* is to-day not found beyond the Mediterranean. Some of the species, however, have a northern range, *i.e.*, *Mya truncata*, *Zirphaea crispata* and *Cyprina islandica*, but it must be admitted that the assemblage can only be regarded as a temperate group.*

Western and northern Jutland were not again invaded by ice; but the eastern parts of the peninsula and the islands were entirely buried beneath an ice-sheet which swept westwards along the Baltic. In the Mid-Baltic the line of advance was south-south-west, but instead of continuing over eastern Germany, a part was diverted westwards and followed the basin of the Baltic across Bornholm and spread out towards the west and north-west parts of the islands and eastern Jutland, almost as far as the Grenaa peninsula. The marginal deposits of this sheet extend from the Mariager and Randers fiords south-westwards, and then south, and give rise to the lovely lake scenery around Silkeborg and the Himmelbjerg. The ground moraine of this ice-sheet renders Fyen the richest agricultural land in Denmark. The terminal moraines completely diverted the former drainage of Jutland and gave rise to a new watershed which now determines the drainage of the eastern parts of the peninsula (map, fig. 7). The former deep fiords and straths are truncated by the hill-country, while westwards the drainage

* Madsen, V., Nordman, V., and N. Hartz, "Eem-Zonerne," *D.G.U.*, II Raekke, Nr. 17, 1908.

which should enter them flows north along the Gudenaa dale. This was the last advance of the ice, but each period was subdivided into a series of advances and retreats, often leaving traces in moraines and other deposits.

It is to the Baltic Glacier that the scenery of Denmark is due. The surface features are divisible into (1) heath-plains, (2) hill-country, (3) undulating moraine-plains and (4) the wide valleys terminating in fiords. The heath-plains occur, as shown on fig. 7, typically in eastern Jutland, where they extend for mile after mile as flat, featureless stretches of arid and sparsely-covered sandy heath. Locally a slight elevation marks the place where the underlying moraine deposits protrude through the sand, and such sites have often been chosen for the erection of a church, a windmill and normally a " Kaempehoi " or barrow. These heath-plains consist of the melt-water sand, and, where exposed, are seen to be horizontally bedded.

(2) The Hill-country forms the most picturesque part of Denmark and consists of both large and small hills lying close together without any dominant alignment, and separated by flats and deep valleys. These hills are old marginal moraines of the ice-sheet, and from their western margin the outwash plains of the heathland extend to the North Sea.

As already mentioned, the lake-country of Silkeborg and the beautiful stretches by Veile and Horsens are the best examples of these land forms.

(3) The moraine-plains represent the bottom moraines of the ice-sheet and form slightly undulating surfaces diversified with long flat-topped ridges. Typical of such scenery is the country between Roskilde and Copenhagen, and that around Kjøge in Sealand.

(4) The Valleys. These flat broad areas are now drained by only tiny " Aas " which are obvious misfits. Thus Gudenaa, the largest stream in Denmark, is only a rivulet which flows through a valley two kilometres wide and flanked by hills rising to a height of 400 feet. A special form of valley is the tunnel valley. These resulted from erosion under the ice by subglacial rivers which flowed under pressure. If the thalweg of these valleys is plotted it shows that beneath the long lakes (langsø) the base is lower than the sea-level. Where the valleys are submerged they give rise to the beautiful blue fiords such as the Veile, Horsens and Randers Fiords of Jutland, so clearly described by Poul Harder.*

But perhaps the most characteristic features of Danish scenery are the long rounded sinuous ridges formed by the Aase, or Eskers. Consisting for the most part of stratified or current-bedded sand and gravel, the beds slope downwards from the centre of the hill, so that in section the surface is seen to follow the slope of the beds (plate 9). Moraine clay often covers,

* " En Ostjydsk Israndslinje," *D.G.U.*, II Raekke, Nr. 19, 1908.

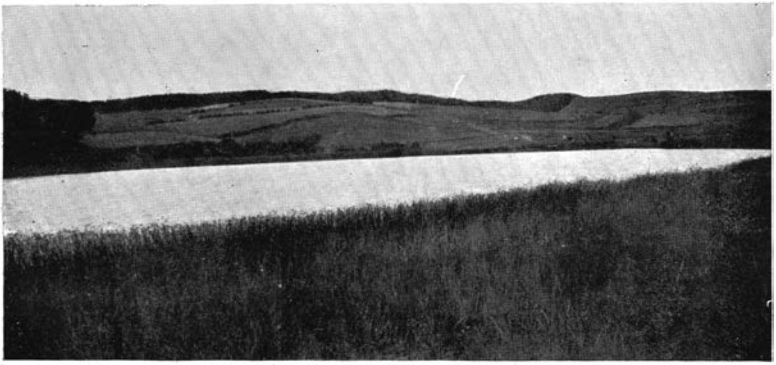
and also very frequently underlies the sand. In some localities, *i.e.*, Grindløse, the clay was pushed up into a vertical position against which the sand is banked. The boulder clays were the bottom moraines of an earlier glaciation and are conspicuous in all sections of the eskers on Fyen.

The origin of the eskers had long puzzled the Danish people, and curious traditions still exist in the country relating to their supposed origin through the activity of giants. A difficulty presented itself when the ice-sheets were supposed to be marine and not land ice, but recent studies have established the fact that the eskers originate from englacial and subglacial streams. The trend of the eskers is in the same direction as that of the movement of the ice-sheet and often crosses water-divides at right angles to them. Some of the larger eskers have tributaries joining them in much the same way as tributaries unite with a main river. They are distinguishable from the great sandy out-wash fans and plains that were washed from and through the front of the ice-lobes as these melted away. The melting of the ice was not confined to its margins but took place over the whole surface, and streams and sheets of water poured through and under the ice, leaving stones and boulders on the surface which in time united with the masses of detritus that had accumulated in the lower parts. Such masses compose as much as 50 per cent. of the ice and at the final melting give rise to sheets of boulder clay. Where distribution of the débris was irregular, drumlins were formed; where stream courses were established in the ice the mud was washed away and only the sand and stones left, while the angular fragments became rounded by mutual attrition in the water as they were carried along under pressure. At the edge of the ice they built up deltas, and as the ice receded these ridges extended backwards without regard to the original topography, and so formed eskers. The ridges parallel to the ice-front are called by the Danes the Moraine-landscape, and many are beautifully preserved in Jutland.* The most typical eskers in Denmark are the following:—the Naestved or Mogenstrup Aase, S. Sealand, which for a distance of four miles forms one long even ridge up to 125 ft. in height, and is considered to be the finest in Denmark†; the Kjøge Aase on Sealand, which trends westwards for a distance of eleven miles, though several breaks interrupt its complete continuity; the Grindløse Aase, in Fyen (plate 9). Others occur at Strø Bjerge, Sealand, south of Arresø, and at Højby, south of Odense.

Varve clays are clearly exposed in the tile works at Allerød, near Frederiksborg, Sealand, where they have been studied by K. Jessen. Overlying the laminated clay is a seam composed of plant remains and especially of those of *Dryas octapetala*.

* See P. Harder. *Op. cit.*

† V. Milthers, "Nordøstsjaellands Geologi," *D.G.U.*, V Raekke, Nr. 3, 1922.



VAEHR LAKE AND MORAINES, JUTLAND.

THE GRINDLØSE ESKER, SEALAND.

[To face p. 142.

These laminated clays were formed in a glacial lake; their alternate beds of sand and clay represent seasonal variations of temperature giving rise to more or less water which could suspend sand or only clay. The classical researches of De Geer in the Swedish Varve clays enabled that observer to calculate the duration of time since the retreat of the ice from southern Scania. This amounts to 12,000 years.*

The post-Glacial submergence, or the Epoch of the Yoldia Sea.

A period of submergence followed immediately after the retreat of the Baltic Ice-sheet, and left its traces in the Scandinavian peninsula up to a height of 200 metres above the present coast-line. Denmark also was affected by this submergence, but only the northern part of Jutland. The district of Vendsyssel was submerged to a depth of 150 feet and was divided into a group of islands. The distribution of these late Yoldia clay-beds is shown by horizontal lines on fig. 7, principally in the north of Jutland. Icebergs coming from the Baltic and Norway deposited beds of clay in this arctic sea and various species of mollusca thrived under these conditions. The type-shell is *Yoldia* (*Portlandica*) *arctica*: other forms being *Tellina loveni* and *Tellina tarelli*.

Subsequent elevation raised the whole of this sea-bed so that it now forms dry land. The marginal formations of this ice-sheet are found also in the Mariager Fjord, on the island of Anholt and on Bornholm. The greatest elevation occurred near the town of Frederikshavn, where it approaches 58 metres. Traces of the former level of the glacial waters slope rapidly towards the south-west until in the islands of Gjøl and Øland, in the eastern parts of the Limfiord, they are only at 11 metres. In Mariager Fiord the Yoldia deposits are so intermixed with more recent marine beds, or are completely hidden by them, that it may be assumed in glacial times the land rose here above sea-level. In the isle of Anholt traces of glacial margins are found at an altitude of 28.5 metres. The figures above cited do not indicate the maximum depth of the glacial sea, but the highest limits of wave action. Under present conditions the upper line of sea-level (*Varech*) is found both in Vendsyssel and in Bornholm at an altitude of 2½ to 3 metres for open coasts, and it may, therefore, be accepted that a similar height obtained in the glacial seas. The actual elevation since the maximum submergence would therefore be about 55 metres for Vendsyssel, and 19 metres for Bornholm.†

The remainder of Denmark at that period had been raised above sea-level and marine deposits are therefore not represented.

* " A Thermographical Record of the Late-Quaternary Climate," International Geological Congress, *Compte rendu*, 1910.

† E. L. Mertz, " Oversigt over de Sen—og postglaciale Niveauforandringer i Danmark," *D.G.U.*, II Raekke, Nr. 41, 1924.

The post-Yoldia elevation raised nearly the whole peninsula and the archipelago so high above sea-level that they formed a

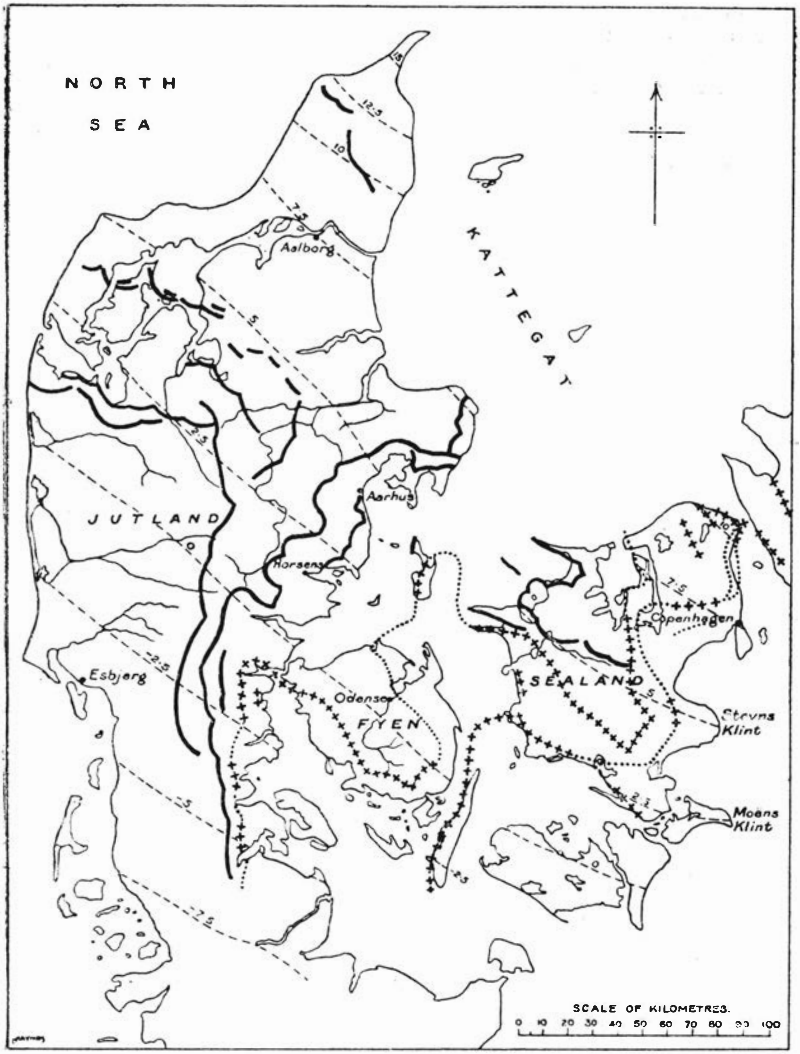


FIG. 8.—SKETCH MAP OF DENMARK.
Thick lines *indicate deposits of ice-edge during its first retreat.*
Crosses *and* **dots** *indicate new advance of the ice.*
Thin broken lines = *Altitude in metres of Littorina Sea deposits.*
(*After V. Madsen, in "Geologi for Gymnasiet."*)

continuous land-mass, and were united with Sweden. Big rivers flowed through what are now the Little Belt, the Great Belt and the Sound, and their submerged valleys are still traceable under the sea. Several have yielded from their deposits relics of early man, to which further reference will be made.

This Continental epoch is that of the Ancylus lake when the Baltic became an inland sea of fresh water.

Evidences of the elevation are found in the form of peat-bogs, beds of rivers and coastal formations, which, as a result of subsequent submergence, lie below the sea-level. There are many facts which show that the land of Ancylus time was much more elevated than the existing land. But observations are difficult to make because of the submarine position of the deposits, and still more difficult is it to determine the different levels of the coasts of the two periods. This difference is, however, more pronounced in the southern than in the northern part of the country. In the north of Vendsyssel proofs have not been found that the district was more elevated than it is at present; whereas the south of Vendsyssel was raised by more than 6 or 7 metres. Numerous observations of beds of peat and tree trunks in the isle of Samsø and near the towns of Bogense and Nyborg in Fyen furnish indices of a greater elevation, but do not indicate what is the difference between the sea-levels at the two periods. On the other hand, peat beds have been proved at a depth of 6½ metres near Fynsvang in the Little Belt, which indicate that during the period of formation of this peat the country was at a higher level than to-day.

The submarine river valleys in the Little Belt* are 20 metres below sea-level; if the land were raised by this amount South Jutland would be united with Fyen. For South Jutland a similar depression, 20 metres, is indicated. W. Wolff inferred from this fact that the area around the Kiel Fiord was then united with Tønning, and that the land was even higher, by 10 metres, than it is to-day.

With regard to the coasts of East Sealand, Milthers† records submarine peat beds at a depth of 13 metres, and according to Anteus‡ the submergence in the Sound between Copenhagen and the Swedish coast near Malmö attains a depth of at least 24 metres. Traces of a similarly deep submergence have been recorded by De Geer in South Sweden.§

The Zirphaea Subsidence.

After the maximum submergence of the Yoldia Sea a period of elevation followed, interrupted, however, in the north of

* *D.G.U.*, Raekke I, No. 12, p. 79.

† *D.G.U.*, Raekke V, No. 3, p. 156.

‡ *D.G.U.*, Raekke IV, No. 18, p. 14.

§ "Om Skandinaviens niva förandringer," *G.F.F.*, No. 128, vol. 12, fasc. 2, p. 107.

Vendsyssel by a relatively limited submergence called "The Zirphaea Subsidence."

From Frederikshavn to Hirshals one can recognise along the borders of the glacial plateau the presence of a series of marine deposits enclosing shells of a boreal fauna. The series has been called after the commonest shell, *Zirphaea crispata*, the Zirphaea deposits. The character of these deposits implies that they were formed at a sufficiently long time after the maximum submergence for the climate to have changed from Arctic to boreal, with a mean sea temperature of from 4 to 6 degrees.

It has also been found possible to show the presence of species of a passage fauna between the Arctic Yoldia sea and the boreal Zirphaea beds. At a little distance from Frederikshavn, at Raaholt and Borgbakke, beds of shells have been found belonging to a fauna which exists in a sea of an annual temperature of 0° and less, and which, in consequence, must be considered as more recent than the Yoldia fauna, but a little anterior to that of Zirphaea. Zirphaea indicates both change of climate and also change of sea-level, marked by alternations of beds of gravel and sand. Axel Jessen* says one finds on the ancient clay a bed of gravel with rolled fragments of shells, *i.e.*, a coast deposit; above it lie beds of sand, often clayey, containing complete valves, half closed, which give evidence of life in relatively deep water some distance from the coast. He concludes that the Zirphaea beds show an interruption of the general elevation, a subsequent sinking and a second elevation. The same period, a period of transition from the glacial to the post-glacial (Fini-glacial) is found in Sweden and Norway in some deposits which present the same alternation of beds, as at Uddevalla, in Western Sweden, and by Oslo Fjord, and therefore the Zirphaea sinking cannot be considered as merely local, but part of a widespread depression which affected the basin of the Skagerrack at the end of the Fini-glacial epoch. This submergence amounted to about 13 metres.†

The Littorina Submergence (Epoch of the Stone Age Sea).

After the prolonged period of dry land, marked by the Ancylus lake, the sea again broke through the barrier and salt water entered the Kattegat and the Baltic. It was one of the oscillations brought about by the Ice Age. The depth of the sea that then invaded the Baltic was greater than that of to-day, and the sea was also salter. Subsequent elevation has raised the deposits of this ancient sea-bottom and its adjacent shores to well above sea-level, and those parts of Denmark where such

* *D.G.U.*, Raekke V, No. 2, p. 170.

† See E. L. Mertz, *Op. cit.*, who gives a concise account of these beds, from which the above notes are derived.

deposits occur are shown on fig. 7 by large dots.* From this map it will be seen that North Jutland (Vendsyssel) then consisted of an archipelago, and that the sea extended south-eastwards over Sealand. Its ancient strand-lines form conspicuous features at many localities, and their height above sea-level is found to become less and less southwards along a line trending from Nissum Fiord south-eastwards to the northern part of Falstar. North of that line the land has been raised, while south of it depression has taken place. Ussing noted the following occurrences of strand-lines above sea-level: at Hindsholm, the peninsula in the north of Fyen, mounds of strand-gravel lie at 11 ft.; on Samsø there are numerous strand-lines up to 17 ft; at Grenaa, the eastern peninsula of Jutland, and at Helsingør, Sealand, mounds lie up to 23 ft.; on Anholt island similar formations reach 32 ft.; at Frederikshavn up to 50 ft. In Norway this rise continues in Oslo Fiord up to 200 ft. above sea-level. These levels mark the limit of storm waves, which may be taken at about 6–7 ft. above normal sea-level, and from the above figures this amount should be deducted. On map, fig. 8, the lines of equal elevation and depression of the Littorina Sea are shown by broken lines and from the map it will be noted that southwards they fall to 7.5 metres below sea-level at Kiel. This fact was recorded by Holst in a clearly argued account of the subject.† The beds are completely submerged in Holland on account of the enormous quantity of sediment that has accumulated there. Movement therefore occurred once again with this N.W. to S.E. line as a pivot.

Now De Geer pointed out that the submergence allowed the waters of the Gulf Stream access to the Baltic to a greater degree than at present, and this fact is proved by the occurrence of marine mollusca far in the Baltic. The principal species are the oyster, cockle, mussel and periwinkle. The oyster is now absent from the Belts, and the southern Kattegat, as the water there is not sufficiently salt; it thrives, however, at the Skaw, and in the western Limfiord. During the period of the Littorina depression it flourished in the Belts and the numerous fiords along the Danish coasts. Vegetable remains are of frequent occurrence in these shell deposits and numerous leaves of the oak, and even stumps of the trees, have been found in the mud and in the underlying peat, proving a subsidence of the land where the oak-forests grew. A splendid section at Snoder in Gotland shows the Ancylus gravel covered by peat, on which in turn the Littorina gravel rests.‡

The succession of beds laid down since the last Ice Age is

* See also "Stenalderhavets Udbredelse i det Nordlige Jylland," *D.G.U.*, Raekke II, Nr. 35, 19.

† "Kvärter-studier i Danmark och norra Tyskland," *Geol. Forenigens i Stockholm, Förhandlingar*, vol. xxvi., p. 433 (1904).

‡ L. von Post.

not commonly well exposed, but a section at Tversted Aa, north-east of Hjoring, shows the following sequence* :—

Blown sand	=	land surface deposit
Strand sand	=	ocean bottom ,,
Cardium mud	=	Littorina Sea ,,
Peat	=	Ancylus land surface
Strand sand	=	ocean bottom deposit
Yoldia clay	=	,, ,, ,,
Glacial beds		

This section proves clearly the oscillations of the land since the last glaciation. The Yoldia clays were laid down in an arctic ocean 200 ft. deep. The peat was a land formation of plants which grew in a warm climate after this clay had been elevated to a height of at least that amount. This elevation was succeeded by a depression that allowed the invasion of the Littorina Sea, and the land next steadily rose until recent times.

At numerous localities on Sealand the peat beds have been found under the Littorina clays, and similar conditions hold for the south of Denmark, except that the Littorina beds are submerged. Submarine peat bogs are known in nearly all the waterways from Esbjerg to the Sound, and were laid bare at a depth of 20 ft. below the sea when the Free Harbour of Copenhagen was excavated, while at the King's Deep in the Sound a submerged peat bog was proved at a depth of 40 ft. This fact is of importance with regard to the relative periods of the humanly made implements found in the peat, and in the shell-heaps, and a discussion of this question follows.

V. STONE AGE PERIOD.

Man appears first to have entered Denmark when the Ancylus elevation had united the three Scandinavian kingdoms. The Baltic then was a fresh-water lake in which the small snail *Ancylus fluviatilis* flourished, while the elk, but apparently not the reindeer, roamed the land. The average temperature had increased and the climate improved so much that birch, aspen and fir trees covered the land, and grew around the numerous lakes. Men lived near the lakes and lived by fishing and hunting; their weapons and implements after dropping into the water became covered with peat growths, and it is from peat bogs that the evidence as to this culture has been obtained. Two of these deposits have been examined in a systematic manner, namely, that at Maglemose near Mullerup, in western Sealand, which was investigated and described in 1900,† and the other more recently at Svaerdborg, about nine kilometres north of

* Ussing, N.V., " Danmarks Geologi," *D.G.U.*, III Raekke, Nr. 2, p. 241, 1899.

† Sarauw, G. F. L., " En Stenalders Boplads i Maglemose ved Mullerup," *Aarboger for Nordisk Oldkyndighed og Historie*, 1903, p. 148, etc. ; and also " Maglemose ein steinzeitlicher Wohnplatz im Moor bei Mullerup auf Seeland," *Prähistorisch Zeitscrift*, 1911, p. 52, etc.

Vordingborg, in South Sealand.* The following remarks, which give a brief account of the work at Svaerdborg, are abstracted from the above-mentioned reports.

The Svaerdborg prehistoric deposit occupies a constant position in the series of alluvial beds, *i.e.*, with few unimportant exceptions, exclusively in the lower part of the " green marsh " peat. It extends as a thin cover above the mud and follows exactly the contours of that deposit. Exceptionally, large bones, and also bone implements, have been found buried deep in the mud surface, or entirely below that surface, and notably at the margins of the " moss."

A vertical section of the deposit shows the soil with grass on a thick mass of brownish-black peat, resting in turn on a thin, clear grey, streaky mud overlying light-coloured sand.

The prehistoric layer is very thin, up to 15 cm., and lies about 10 cm. above the mud. It is characterised by a great abundance of flints, both worked and in the form of débris, those discovered during the seven weeks in the 404 square metres systematically explored numbering about 110,500. The deposit contained also a great quantity of mammal's bones and deer's antlers ; from this site 720 worked objects were found among a total of 13,786 pieces, most of them being small flakes of broken bone. There were, however, but very few antlers, and of those most were small fragments of tynes. Many were more or less carbonised, and powdered carbon occurred throughout the deposit. The dimensions of the dwelling site were proved to be approximately 140 m. from N. to S., and 110 m. from W. to E., of which only a small part has been explored. Wherever the site was tested prehistoric remains were found, but their number was extremely variable, and it is evident that the flints were worked only at certain spots and not in the intervening areas. Flint and bone were not equally common, for where flint was found in abundance, bone was rare, and *vice versa*, and the finest worked bone and horn implements were found apart from the best flints. There was no order or plan among the finds ; they lay as they fell, and for the most part rested horizontally on the mud.

The fact that great fires had been lighted upon the sites is shown by the burnt bones, and more especially by the calcined condition of the flints. Of all the flints discovered about 5 per cent. were observed to have been calcined, but although most often the percentage was appreciably less, in certain fields it was notably higher.

At one part of the field there was a remarkable abundance of remains of bones and pieces of flint. In addition to 325 blades

* Johansen, K. F., Knud Jessen and H. Winge, *Aarboger for Nordisk Oldkyndighed*, 1919, pp. 106–235 ; also " Une Station du plus ancien age de la Pierre dans la tourbiere de Svaerdborg." *Mem. Soc. Roy. des Ant. du Nord*, 1918–1919.

and 142 other worked bone and flint objects found in 4 square metres, 5,949 pieces of flint and 4,001 of bone, mostly very small, were collected. Out of this number 25 per cent. of the flints were strongly calcined. Where these occurred, the earth presented an unusual character, and was not entirely the humid black peat of the marsh, but composed partly of a grey substance of fine grain, mixed with some sand, and rich in small fragments of carbon. Analyses proved that this material consisted mainly of fine particles of bones of vertebrates and scales of fish, strongly carbonised, and derived undoubtedly from a pyre or burning place. In another field a hearth was discovered ; it consisted of stones as large as the hand, blackened by fire and arranged in files strongly pressed together and open to the air. K. Jessen gives a generalised section of the deposit as follows :—

(A)	Grass, etc.	15 cm.
(B)	Peat, sombre brown, derived from Alder growth ; horizontal bedding ; trunks, branches, and remains of *Alnus glutinosa*, and a certain number of herbaceous plants : at the base of the peat lay *Phragmites communis*	47 cm.
(C)	Peat of the green marsh : sombre brown, strongly oxidised, clearly distinguishable from the overlying bed by its richness in remains of *Carex* spp. Also a great abundance of *Mariscus cladium* and *Phragmites communis*, also *Coronis flos cuculi* ..	13 cm.
(D)	Mud, clear grey, shelly. Numerous shells of *Bithynia tentaculata*, *Valvata cristata*, *Planorbis stroemi*, *Limnaea ovata*, etc. Several branches of *Pinus silvestris* ..	3 cm.
(E)	Mud, elastic, brownish-green, containing several water-plants, among which are *Nymphaea alba*, and *Najas marina* ..	3 cm.
(F)	Sand (Diluvial).	

While the two beds of mud D and E were deposited at the bottom of running water, the peat of the green marsh marks the stage of invasion of the lake by vegetation formed at a geological horizon between the levels of the deepest and the shallowest waters of the lake at this period.

Examination of the burnt wood showed that there were 32 instances of pine, 6 of hazel, 4 of alder, 3 of birch, 2 of elm, besides some wood of indeterminable trees. One sees by this that of the trees of the (Skovmose) " woody peat " used as fuel, the alder and birch were hardly touched, but that the pine forests of the surrounding high land were mostly drawn upon.

Jessen examined the pollen found on the prehistoric site and is thus able to state authoritatively that the period was that of

Ancylus, and that *Pinus sylvestris* reigned almost exclusively in the forest. V. Nordmann arrived at the same conclusion as to age by examining the mollusca, and states that the fauna belongs to the Zone of *Bithynia tentaculata—Planorbis stroemi*. This fauna corresponds with that found at Mullerup. The animal life of the two ancient lakes of Svaerdborg and Mullerup, also the vegetation of the neighbouring forests, were comprised of the same elements, and in consequence one is able to attribute the same geological age to the deposits—*i.e.*, the period of *Ancylus*.

From this it can be seen that the men of the time lived between the pine forests and the alder swamps on prairie land that was dry in summer, but submerged in winter. That they lived only on the dry firm ground is proved by the fact that their implements are not found in the peat. The lake was large. The animal remains were identified by M. Herluf Winge and include those of the pike, turtle, whistling duck and wild duck, red bill swan, merganser, goose, grouse, grebe, crane, black-backed gull, heron, bittern, cormorant, osprey, fish eagle, water rat, beaver, squirrel, wild cat, fox, domestic dog, wolf, brown bear, martin, badger, otter, roe-deer, stag, elk, urus, and wild boar. Characteristic of this and the assemblage at Mullerup is the abundance of the elk and the urus, in which respect these deposits differ from the rest of the Stone Age. There was a great abundance of beaver remains, the locality being much richer in this animal than anywhere else in Denmark. Remains of roe-deer and wild boar are the most abundant. Some of the bones were gnawed by mice. One striking fact is the rarity of the metatarsal and metacarpal bones of the large ruminants, because these had been used for instruments.

The numerous bones of young grouse indicate almost certainly that it was summer-time when the sites were occupied; the same conclusion may be drawn from the number of fully developed antlers of roe-deer and remains of young wild boar.

The only domesticated animal both at Svaerdborg and Mullerup was the dog. Small pieces of human skull have been found. A great and varied collection of humanly fashioned implements was obtained, which in all respects resemble those found at Mullerup, but differ from those of the Kitchen Middens except in a few characteristics. The stone implements play a much more important part than they do at Mullerup; all are made of flint, a material which is abundant locally and was fashioned on the site. Over 102,402 pieces were collected in 404 square metres. None of them showed the least trace of polish. Over 8,300 worked pieces are preserved in the National Museum, mostly of a few types.

Flint blades were extraordinarily abundant, the longest being 15.5 cm.; while pieces of over 8 cm. were numerous. But by far the largest proportion were tiny, thin, graceful blades varying between 2 and 5 cm. in length. Nearly all the large strong blades show evidence of rough usage along both edges, whereas the little ones remain sharp. The special grattoir, or scratching knife, on a blade, is very rare, only 11 having been found, and only six beautifully fashioned knife blades.

An arrow with a transverse edge (petit tranchet), strongly calcined, was discovered in some peat nearby, but its exact provenance is unknown ; it is the only one of its kind occurring at either Mullerup or Svaerdborg, whereas this kind of arrow occurs in hundreds in the Kitchen Middens.

Numerous pygmy implements are characteristic of this site, the predominant type being the triangular point worked carefully along one side and at the end, leaving a knife edge. Some resemble gravers. Nuclei are common. Of axes and chisels (tranchets) there were only 22 in a complete state and 2 broken, and in this respect again Svaerdborg agrees with Mullerup and differs from the Kitchen Midden industry. Picks are characteristic and resemble the Campignian and Thames picks in form. There were also numerous tools of horn and bone, comprising harpoons and the like fishing and hunting tackle. Some harpoon points are grooved for the inclusion of flint barbs.

As the period of Ancylus was drawing towards its close men appear to have modified somewhat their habits of life, but unfortunately very little is known of the people who next appeared. Discoveries at Brabrand, however, throw some light on this period, and more or less supply a link between the Svaerdborg and the earlier shell-mound people. Brabrand lies east of the lake of that name and three miles west-south-west of Aarhus in Jutland. The site was investigated by Drs. Thomsen and Jessen,* and the following section was disclosed :—

Gravel.
Sand, deposited in shallow water—Littorina-Tapes-Oak period.
Dark mud containing shells, laid down in deep water.
Lower gravel.
Peat : Ancylus period. Fir trees.
Glacial deposits.

The shore deposits all contained implements of early Neolithic age. Oyster, mussel, cockle and periwinkle occurred in their natural positions in the dark mud ; while remains of Aurocks were common, those of elk were rare. Flint implements were separable into two kinds, the commonest being characterised by the large "skivespalter," while only a few transverse arrow-heads occurred. Bone and horn implements were common, mostly axe-heads, one bearing an engraved lozenge ornament. A bone comb with five

* *Mem. de la Société royale des Antiquaries du Nord*, 1904, p. 162 ; and Hans Kjaer, "Vor Oldtids Mindesmærker," Copenhagen, 1925.

teeth formed an interesting discovery, but what are of even greater interest are the wooden "boomerangs." A vase, 10.2 in. high, with a pointed base, was made of pottery and consisted of a series of spiral whorls. There was no sign that these Brabrand folk lived on rafts or pile-dwellings ; it would appear rather that they occupied dwellings on the dry ground between the lake and the fir-woods in much the same way as their predecessors, the Svaerdborg people, had done. The land was then sinking, or the sea rising, and soon after, much of the coastal area was depressed below sea-level, and the people of the Kitchen Middens or shell heaps appeared.

These shell-mound people were not nomads, but lived the whole year round and for many generations in the same localities. Their remains have been found at numerous sites around the fiords and are especially abundant on the shores of the Roskilde Fiord. The mounds consist for the most part of the shells of mollusca used as food, the principal forms being oyster, mussel, cockle and periwinkle. They form vast mounds, often several hundred feet long, 25 ft. high and 100 ft. wide. They have long been known, but were not adequately examined until 1893, when a committee of scientific experts thoroughly investigated the great shell-mound at Ertebølle,between Thisted and Aalborg in Jutland, and since then that locality has become the type. The shell-mounds were gradually built up at the time of the maximum depression of the Littorina sea. The characteristic type of implement is the "shell-mound axe," or in Danish "Skivespalter." This implement was produced by only two blows upon a block of flint ; the first blow formed the front of the implement, while the second not only detached it from the block (skivebloc), but was so directed that the edge cut obliquely across the flake to form the cutting-edge of that and also of the adjacent implement. A whole series of such implements were struck off in, as it were, concentric courses, and such series were found again and again at Ertebølle. The Danish antiquaries are able by inspection to say whence each specimen came from the block and describe the implements as the

Første Yderskive	=	First Outer Slice
Anden Yderskive	=	Second ,, ,,
Tredie Yderskive	=	Third ,, ,,
Første Inderskive	=	First Inner Slice
Anden Inderskive	=	Second ,, ,,
Tredie Inderskive	=	Third ,, ,,

In addition to these slice-implements others have been found on which more careful work has been expended. The "skivespalte" is usually of nearly the same width from end to end, but some widen towards the flake-end. During the period 1893 to 1897 the enquiry unto the shell-mounds was continued at eight different places situated respectively in Jutland and Sealand, but it was mainly the heap at Ertebølle that furnished the material for these investigations, and 314 square metres were excavated. The results are recorded in a magnificently printed and illustrated monograph.* In all 8,608 antiquities were collected: also 20,300 bones of animals and much wood charcoal.

At the other sites the operations were not so extensive and were stopped when it was found that the results were similar to those at Ertebølle. These shell-mounds belong to the early Neolithic age of Denmark, a period well-known in France under the term Campignien. They represent true stations, and numerous fire-places were found. Two burial places were also unearthed but the investigators hestitated to call them sepulchres.

Bones of wild animals were extremely numerous; the only domestic animal, however, was the dog. The great majority of the artefacts consist of flint, and bones and antlers of stag, while the pottery is similar to the early Neolithic ware of the West of Europe. These objects characterise a people who were huntsmen and fishermen, and who, in Denmark, represent the earliest (but one) race of human beings.

The lowest beds of the mounds yielded the same type of culture as did the higher ones, and no advance is shown during the prolonged period of many centuries represented by these vast masses.

One of the most interesting finds is the small transverse flake or arrow-head. These were fashioned in precisely the same way as the skivespalter, and closely resemble that tool except in size. They were carefully chipped at the sides to form a waist and were tied to a shaft in such a way that the edge projected, and must have been an effective weapon.

Less characteristic among the finds are the picks, which are strictly comparable with the Campigny "pic," the Spiennes "pic" and the Thames pick. They are not so common as the skivespalte, but are contemporaneous with that tool.

Some of the shell-masses in their upper layers become less shelly and consist more of clay material, and nearly all of these occur farther inland than the principal mounds; they also contain a slightly later culture represented by implements resembling the Dolmen type.

These three periods together are included under the Older Stone Age by the Danish archæologists, but belong in reality to the Neolithic Age. They are definitely associated with geological periods marked by characteristic deposits and changes of sea-level. Other great groups of implements have been

* "Affaldsdynger fra Stenalderen i Danmark," by A. P. Madsen and others, Copenhagen, 1900.

found either upon the surface of the land or in graves. Burial of the unburnt bodies of the dead in great stone-built tombs was an early institution, and formed part of the ritual of a cult which affected a people that occupied various parts of Europe, bordering the coasts, who gradually advanced from the eastern Mediterranean to Brittany, England and Scandinavia. Such

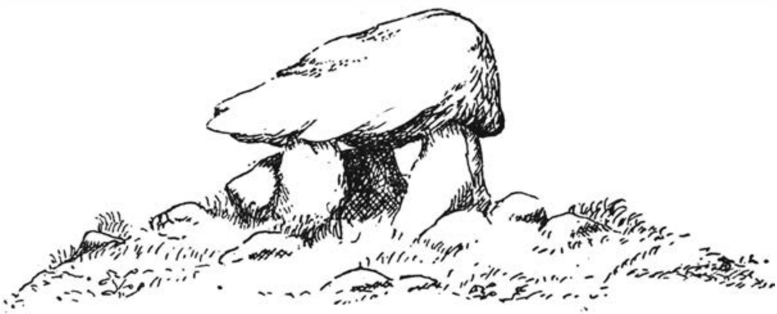


FIG. 9.—A DYSSEKAMMER OR DOLMEN.

tombs are of three principal forms, and each one shows sundry variations. The first is a tomb built up essentially of four upright stones enclosing a rectangular space and covered by a fifth block, usually a large boulder weighing many tons. Such tombs are called by the Danish archæologists "dysse" and by the French "dolmens" (fig. 9). Many are surrounded by a

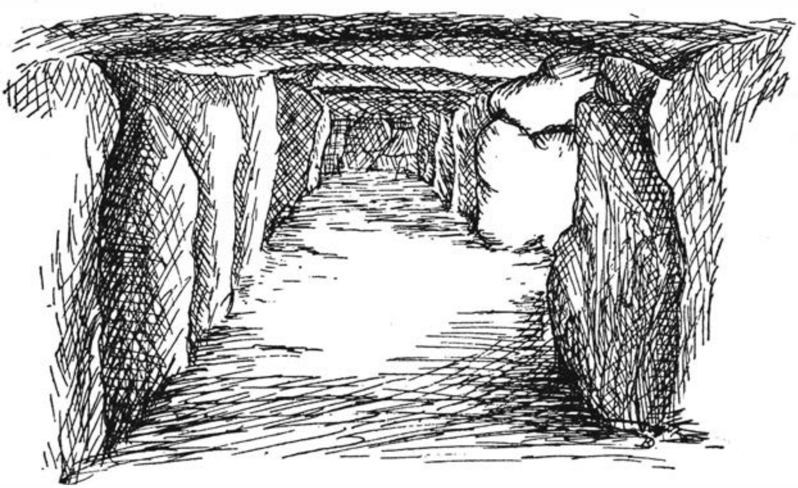


FIG. 10.—A JETTESTUE OR PASSAGE GRAVE.

FIG. 11.—A HELLEKISTE OR CIST.

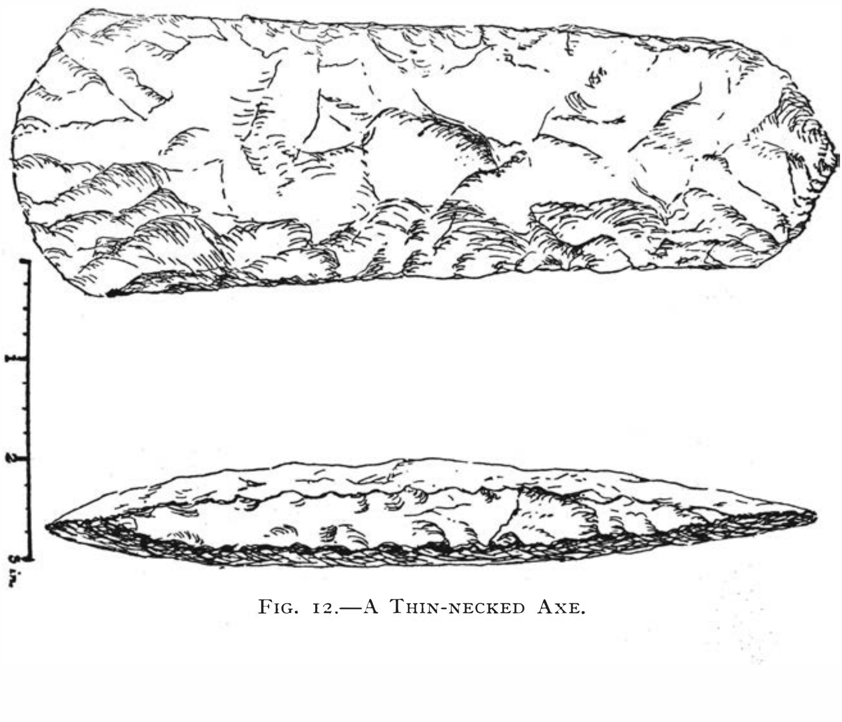


FIG. 12.—A THIN-NECKED AXE.

ring or an oval of large stones, when they are called round and long dysse respectively. Another kind of tomb consists of a large chamber either square, oval, or rectangular in plan, and approached by a covered avenue of stones, all being buried with earth. Many burials were made in these chambers, possibly all belonging to one family or clan. These are the "Jettestue" of the Danish and the "Allé couverte" of the French archæologists (fig. 10). A third kind is partly buried and consists of four or more large stones covered with a top stone and called an "enkeltgrav" or cist (fig. 11).

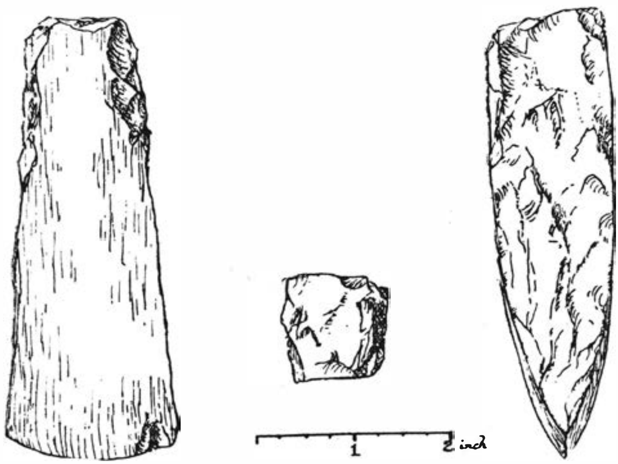


FIG. 13.—A THICK-NECKED AXE.

It has long been observed that each kind of tomb is characterised by its furniture, and axes and daggers were the principal articles buried. In the dolmens the axes are long and rectangular in plan (fig. 12) with thin necks and are convex in both directions with squared angles. Both polished and unpolished examples occur. They are termed by the Danes "tyndnaekked øxe" or thin-necked axes. The daggers are in the form of long and narrow blades, many having rippled surfaces where long parallel flakes were pressed off in manufacture.

In the jettestue the axes have square necks, are rectangular in plan (fig. 13), and nearly flat, but convex from the neck to the edge. Both polished and unpolished forms were placed in the tomb. These are the "tyknakked øxe" or thick-necked axes. The daggers in these tombs have well-formed handles, usually trigonal in section and the blades are broader.

In the cists the axes spread out at the sharp end (fig. 14,) are square in section and nearly flat on the sides ; the daggers have broad blades and lozenge shaped or square handles beautifully fashioned in flint with imitation stitches in stone at the edges.

These three groups extend into Norway and Sweden, where they are related to changes of sea-level, the earliest forms being found at higher levels above the sea than the later ones.

Montelius* classified them as in the following table :—

4. Stone Cists (enkeltgrav) ; celts with thick neck and spreading edge.

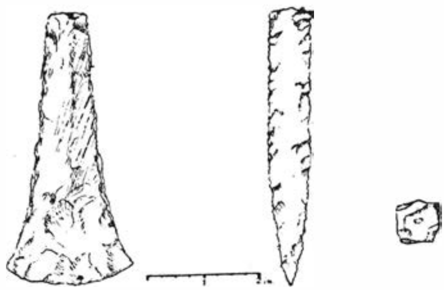


FIG. 14.—A THICK-NECKED SPREADING-EDGE AXE.

3. Passage graves (Jettestue, gangbygning) ; celts with thick neck = the tyknakke øxe.
2. Dolmens (Dysse) ; celts with thin necks = the tyndnakke øxe.
1. Form of sepulture unknown ; celts with pointed oval section = the spidsnakke øxe.

Later, the Swedish archæologist Lindquist† investigated the subject in the Nerike district between Lakes Wener and Hielmer. He found that the sea in the early Neolithic period was 200 ft. higher than at present, 133 ft. higher in the Dolmen period, and 100 to 83 ft. at the time of the Passage graves, while the cists are found at present sea-level.

The rise of land was continuous, in Norway, Sweden and North Denmark, from the emergence after the Littorina depression until the Middle Ages. Its rate has been investigated by Professor W. C. Brøgger,‡ whose results are shown in the annexed table :—

* *Temps préhist en Suede,*" 1895, pl. 1 to 11 ; *see* Déchellette, "Manuel d'Archéologie préhistorique," vol. i., p. 334, 1908.

† *Prähistorische Zeitschrift*, iv. (1912), p. 405.

‡ "Strandliniens Beliggenhed under Stenalderen," *Mem. Norges Geol. Undersøgelse*, Nr. 41 282, 1905.

Period.	Type of Axe.	Actual Time.	Fall of Sea-Level near Oslo.
Norway's Middle Stone Age (Older Tapes Time with an Atlantic climate.)	Blunt necked round axe, also pointed necked axe.	circa 4900 B.C. to 3900 B.C.	metres 67 to 55 = 1.2 metres per 100 years.
Norway's Younger Stone Age			
Older part	Pointed necked axe	3900 to 3400 B.C.	55 to 44 = 2.2 metres / century
Younger part Middle Tapes Time. (Sub-boreal climate.)	Thin necked axe	3400 to 2400 B.C.	44 to 23 = 2.10 metres / century
Norway's Youngest Stone Age (Copper Age). (Younger Tapes Time. Sub-Atlantic climate).	Thick necked axe, also perforated (shaft hole) axe	2400 to 1900 B.C.	23 to 14 = 1.8 metres per century

Burials under earth-mounds continued until the 11th century in Denmark, and two of the largest and finest of these "Kampehoie" are those of King Gorm, the Old, and of Thyra, his queen, at Jellinge in Jutland. An impressive account of the funeral ceremony at such an interment is preserved in Beowulf: "Then the people fashioned for him (Beowulf) a mighty pile upon the ground, all hung with helms and war-shields and bright byrnies, even as he had entreated them; and in the midst of it the sorrowing men laid their great king, their beloved lord. Then the warriors began to kindle the greatest of funeral fires upon the mound. Uprose the wood smoke, black above the flame; blazing fire roared, mingled with a sound of weeping when the tumult of the wind was stilled, until, hot within the breast, it had consumed the bony frame. . . . Then the . . . people made a mound upon the cliff, high and broad, to be seen afar of seafaring men, and ten days they built it, the war-hero's beacon. They made a wall round about the ashes of the fire. . . . Within the mound they put rings and jewels, all the adornments which the brave hearted men had taken from the hoard . . . hid the gold in the ground, where it still remains as useless unto men as it was of yore."*

VI. ECONOMICS.

The Chalk is Denmark's most valuable mineral substance, for it is used (1) as a building stone, (2) in the manufacture of Portland Cement, and is burnt for lime. The principal source of the material used for Portland Cement is the chalk near Aalborg, and in the Mariager Fiord respectively. Building stone is obtained from Stevns Klint and also at Faxe, where the Bryozoa Chalk and the Coral Chalk are carefully sawn and trimmed into a variety of shapes according to demand. Much chalk from Stevns Klint has been used in the dignified interior of the Raadhus at Copenhagen, and its appearance is effective. Chalk is dug for lime at most of the quarries, but those parts free from flint are carefully selected.

Denmark is poor in other building stones and recourse has been had to collecting the glacial erratics of Norwegian and Swedish granites and porphyries. These are often piled up without previous dressing to form the foundations of walls of churches and larger structures, but they are sometimes roughly trimmed into rectangular blocks and set as masonry. They form an extremely handsome wall, a very fine example of which can be seen in the new palace (Christiansborg Slot) in Copenhagen. In some of the older churches and cathedrals these boulders were used, and Viborg Cathedral is almost entirely built of them. Massive columns of partly chiselled granite were used by the medieval builders in Roskilde Cathedral for the arcading behind the choir, and the dignity of these huge monoliths must be seen to be truly appreciated.

Apart from these stones and the Chalk, the other building material used is brick. Most of the bricks are much larger than the standardized English "stock," and are of better manufacture ; some medieval bricks called "Monkebrick" are as hard and clean to-day as they were when first made. The bonding is also different from that employed in our country.

Many of the churches are severely plain, a result which is partly due to the material employed being granite which cannot easily be carved, and when ornamented, lacks grace and charm.

In Fyen the boulders are not large ; they were collected and set in irregular courses without trimming or dressing. On the mainland they were well squared and laid in regular courses. Elsewhere the towers of churches consist partly of boulders and partly of brickwork. Unhewn boulders are commonly seen in Jutland forming the foundations of walls of farm buildings as

* Translated by Chauncey B. Tinker : *Select Translations from Old English Poetry* in "The Cambridge Book of Prose and Verse," p. 18, 1924.

well as churches, and houses consist of a wall of boulders on which brick and timber rest.

About the middle of the 15th century brickwork was again employed, and numerous examples are to be seen both in Fyen and Sealand. These bricks are of a warm red hue, and unlike those used two centuries before, which are rather harsh yellow in colour. At Uth near Horsens the church displays a magnificent tower built of such red bricks.

The commonest form of church tower is that capped by the crow-stepped gable where red bricks are frequently set obliquely to the vertical, while narrow panels often of great length and terminated by circular recesses, diversify the flat surface of the wall. The church at Store Hedinge in Sealand is a fine example of such work. The Cathedral at Roskilde is covered largely with similar panel-work. Where chalk occurs it was employed to form alternate courses with the red brick with a charming result. Many churches in Sealand show such workmanship.* Most of the bricks and tiles are manufactured from the Mica Clay and the Moraine Clays.

* See P. Købke, "De Danske Kirkebygninger"; also A. Heales, "The Architecture of the Churches of Denmark," 1892.