The Geographical Evolution of the North Sea Basin.

By

L. Dudley Stamp,
University of London.

I. Introduction.

REGARDED from one point of view the basin occupied by the North Sea is geologically very ancient. When the Armorican earth movements brought to a close the long quiet period during which the Coal Measures were deposited, they resulted in the formation of lines of mountains across what is now the northern part of Central Europe and left to the north a wide, shallow basin. Though closed to the north by the Caledonian mountains which stretched from Scotland to Norway, the desert-girt basin thus occupied by the Permian Sea included practically the whole of the area now lying beneath the waters of the North Sea, though stretching far beyond the present limits of that sea.

The great structural units which limit the North Sea basin thus date from the periods of the Caledonian and Armorican earth movements and the basin has persisted, though in varied forms, as a physiographic unit from that time to the present.

From another point of view, however, the North Sea is a very recent, almost a modern phenomenon. There is little doubt that man, who had already advanced beyond the use of primitive stone implements, wandered on dry land all over the southern half of the basin and built his primitive homes amongst the forests of the Dogger Bank, finding as the principal obstacles to his wanderings the lower, marshy, courses of the Rhine, the Thames and the Ouse. It is only very recently that it has been recognized that the topography of the floor of the North Sea is that of a submerged plain and that the sediments of the sea-floor have undergone but limited changes since the submergence. It is within the last ten years also that the discovery of human artefacts in beds interstratified with the glacial deposits of East Anglia has permitted at least a partial solution of the longstanding mystery of the relationship between the climatic pulsations of northern Europe and the cultural evolution of Stone Age man. The time would seem to be opportune, therefore, to attempt in the light of these recent discoveries to trace the geographical evolution of the North Sea Basin. The reconstruction must, in any case, be tentative for many major problems await solution. For example, though the four glacial periods of the Alps have long been known and clearly demonstrated, and though there is increasing general agreement that eastern England was similarly affected by four main glacial periods, the apparently obvious correlation cannot be directly made and would, indeed, appear to be a wrong one. Although the attempt is here made to trace the history of the Basin in true sequence, a note is made where possible of divergent views. It has proved out of the question to append full references to the relevant literature because of the immense number of writings involved. The footnotes refer, therefore, to but a few papers of outstanding significance.

II. The North Sea Basin from Carboniferous times to the Miocene.

In Coal Measure times there existed a great continent to the north linking Scotland and Scandinavia and built up of mountains of Caledonian age. From this continent rivers drained southwards and had built up, in Britain, the great delta of Millstone Grit — a delta which later became the home of Coal Measure forests. The old land-ridge of St. George's Land stretched across central England from east to west and to the south of this island also grew Coal Measure forests.

The Armorican or Hercynean earth movements defined much more clearly the North Sea Basin. The *massif* of Wales was further enlarged; the Pennines of England arose to form a natural western limit of the basin; the Amorican mountains of the Ardennes, Central and Southern Germany defined it to the south. The Basin itself became occupied by the 'Germano-British' sea of Permian times and later by the varied desert lake areas and the Muschelkalk Sea of the Trias. Throughout Jurassic times the basin persisted; the Cretaceous seas occupied it and in the heart of the basin (Danian of Denmark) we find the least disturbed transition from Cretaceous to Eocene beds. When the gentle earth movements of Eocene and Oligocene times culminated in the great Alpine storm of Miocene times, the ancient blocks of Highland Britain and Scandinavia remained but little altered and so continue to form the natural limits of the North Sea Basin. Along the southern margins folding movements were more marked and important changes occurred in Southern England — in the further uplift of the Weald and the folding of the Isle of Wight. The story of the early North Sea can be traced in the works of several geologists[1]) and it will suffice to begin this study with conditions as they were in the Miocene, after

[1]) See especially M. Gignoux, Géologie Stratigraphique, 2nd Ed. 1936. L. D. Stamp, An Introduction to Stratigraphy, 2nd Ed., 1935. L. J. Wills, Physiographical Evolution of Britain, 1929.

the last great period of earth-building movements. The accompanying map, based on that of G i g n o u x, modified by M o r l e y D a v i e s[2]) illustrates the geography of the North Sea Basin at that time.

III. The North Sea Basin in Pliocene Times.

L o w e r P l i o c e n e (D i e s t i a n) T i m e s.

The great Alpine storm of Miocene times had spent its force before the end of that period. The effect of the great upheaval in Central Europe had been, as already shown, to restrict the Miocene North Sea

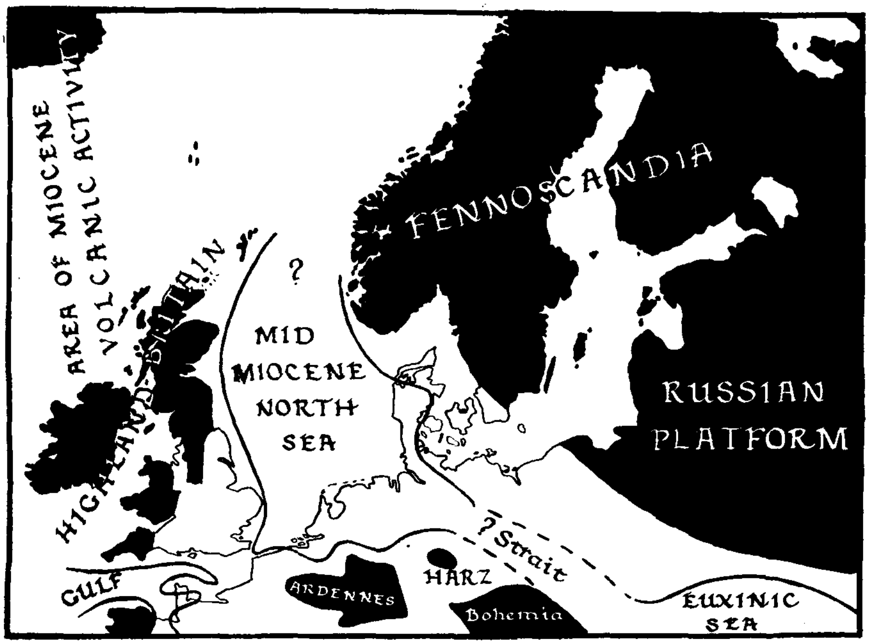

Fig. 1. The Middle Miocene North Sea, showing in black the hosts or ancient blocks by which the basin is naturally bounded (after G i g n o u x and M o r l e y D a v i e s).

to the centre of the Basin with the result that Miocene deposits, except for certain possible representatives, are unknown in Britain[3]). The Alpine earth movements, though their power was almost exhausted before they reached as far north as the south of England and the North Sea, resulted undoubtedly in intensifying the pre-existing trough of the London Basin and the existing anticlinal arch of the Weald and

[2]) Tertiary Faunas, Vol. II, 1934, p. 166.

[3]) The 'Boxstones' or sandstone pebbles with a Miocene fauna found at the base of the Crag in East Anglia show that Miocene beds were formed in the North Sea.

caused severe folding in the Isle of Purbeck and the Isle of Wight, as suggested in Fig. 2.

Since Miocene times it is important to remember that, although there have been no major folding movements, earth movements of three types may have, and probably have all, occurred. These three types are:—

a) renewed folding along Alpine lines, i. e., an intensification of anticlinal or synclinal structures of Miocene date,
b) tilting, or differential upheaval or subsidence over large areas — some of the tilting possibly isostatic and due to the weight of great masses of ice,
c) vertical or eustatic movements of elevation or depression resulting in changes in the relative level of land and sea.

The earth movements of later Miocene times, which threw the sea of the Wealden ridge were of the first type but there appears to have followed a general subsidence — a movement of the third type. The marine waters of the Diestian North Sea thus invaded the London Basin syncline and have left traces of their former presence in patches of ferruginous sand with marine fossils high up on the North Downs — the Lenham Beds. In an important paper, Dr. S. W. Wooldridge pieced together the fragmentary evidence and traced the shorelines of this sea[4]. Whilst the Diestian age of the Lenham Beds of East Kent is admitted, it is claimed by some palaeontologists that similar beds further west at Netley Heath and on the northern side of the basin at Rothamsted (Hertfordshire) have a later Pliocene (Red Crag) fauna[5]. The evidence is slight, but this would simply mean a persistence of the Pliocene Sea for longer than Dr. Wooldridge imagined in the London Basin, or even a westward extension after Diestian times.

The fauna of the English Diestian includes a considerable percentage of warm-water species and there is a marked affinity between the faunas of the East Anglian Pliocene and the St. Earth beds of Cornwall (deeper water Mio-Pliocene). It is accordingly probable that the Diestian North Sea was connected with the warmer Western Sea. This connexion may have been through the western end of the London Basin to the Bristol Channel or, as Dr. Wooldridge believes, further to the south through a synclinal trough west of Basingstoke[6]. That an arm of the Diestian Sea extended south of the Weald is evidenced by the discovery of a Diestian fauna near Beachy Head[7].

[4]) The Pliocene History of the London Basin, *Proc. Geol. Assoc.* vol. XXXVIII, 1927, pp. 49-132.
[5]) A. Morley Davies, Tertiary Faunas, Vol. II, 1934, p. 207.
[6]) *Op. cit.* p. 95.
[7]) F. H. Edmunds *Geol. Mag.*, 1927, p. 287.

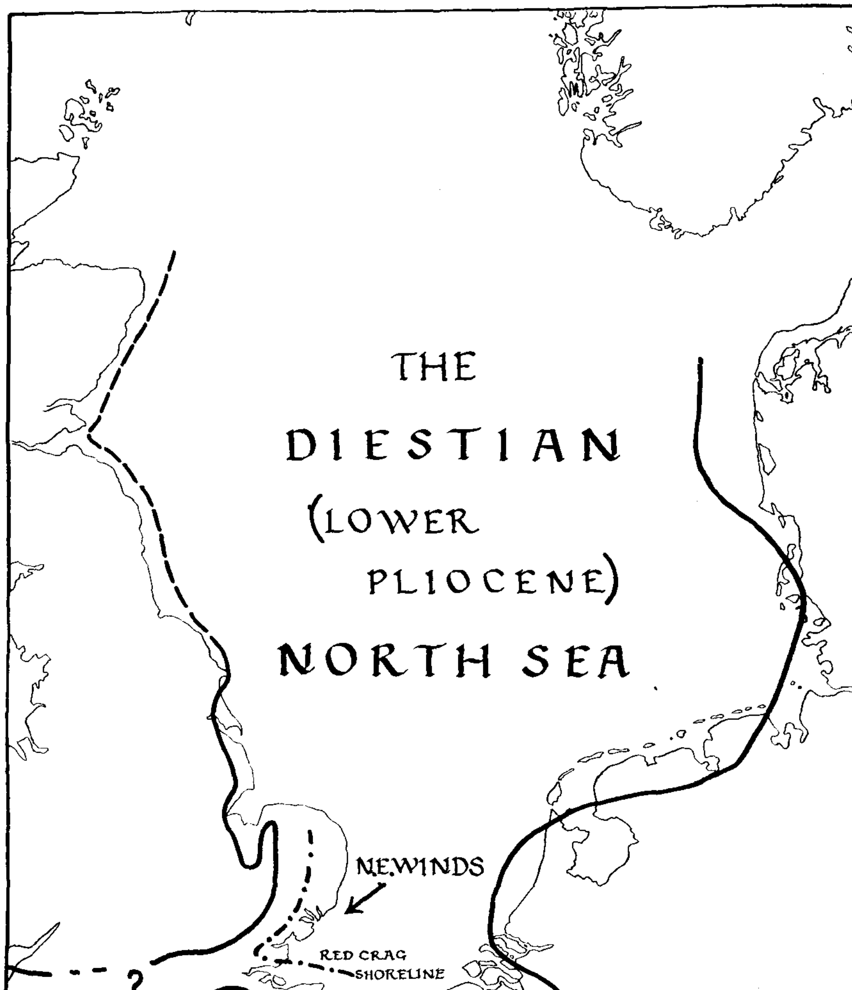

Fig. 2. The early Pliocene geography of the North Sea Basin.

Middle Pliocene (Gedgravian or Coralline Crag) Times.

Wherever or whatever may have been the connexion between the Diestian North Sea and warmer waters, later in the Pliocene the connexion was severed. It may still have been open at the time of the deposition of the Coralline Crag of East Anglia and the Casterlian of Belgium, but from that time onwards the Pliocene deposits round the North Sea show a steadily decreasing percentage of southern forms. If it had not already been breached, the Caledonian mountain ridge between the Scottish Highlands and Scandinavia was now severed and communication established with the cold waters of the Northern Ocean. Blocks of rock with Casterlian fossils have been dredged from the North Sea east of the Orkneys, so the sea probably extended to that latitude. In the south there seems to have been renewed, if slight, warping along the Alpine fold lines. The Wealden-Artois ridge was slightly raised, the London Basin Syncline slightly deepened. The Casterlian deposits of Belgium thicken northwards. At the same time the Pliocene North Sea had retreated from Germany, where the only Pliocene known is from the island of Sylt in the extreme north-west (see Fig. 2).

Middle Pliocene (Red Crag) Times.

As the Pliocene time wore on, the sea retreated from the London Basin, retreated northwards from Belgium (where the Scaldisian and Poederlian are equivalents of the Waltonian or *lower* horizons of the Red Crag only), and the Upper Red Crag North Sea occupied an area approximating to that of the present-day sea, though overlapping the present-day coast-line in East Anglia and Holland, (Amstelian). Again the Red Crag fossils must occur on the floor of the North Sea as far north as Aberdeenshire, as they are found in the North Sea Glacial drifts of the coasts. Apart from the increasing number of northern forms amongst the Red Crag *mollusca* there is other evidence of oncoming Arctic conditions. Boulders of foreign rock, some of Scandinavian origin, sometimes exceeding a foot in diameter, are found both at the base of the Red Crag, and scattered through the deposits. There is little doubt that these were dropped from melting icebergs which drifted across from the Scandinavian coast and they bear witness to the early formation of glaciers or an ice-cap over Norway. There are some who believe that this cold phase is equivalent of the Günz glaciation of the Alps.

The three sub-stages which have been recognized in the Red Crag (from the oldest to youngest, Waltonian, Newbournian and Butleyan) are nowhere found superimposed on one another. Their arrangement with the oldest beds in the south-west and the youngest to the north-east bear out the conception that the shelly Red Crag is a shore deposit left by the sea retreating to the north-east, and Harmer long ago attributed the accumulation to the work of easterly gales. The fossils are usually abraded or broken.

Mr. J. Reid Moir claims that flints found below the Red Crag show evidence of human workmanship. If so, this is the earliest evidence of man in Britain[8]).

[8]) See the long series of papers in the *Proc. Prehistoric Society of East Anglia*, *Proc. Royal Soc.*, and elsewhere.

Upper Pliocene (Norwich Crag) Times.

The Norwich Crag occupies a large area to the *north* of the Red Crag and affords evidence of the continued retreat of the Pliocene North Sea in that direction. The fauna is not only more modern but is markedly more northern in character so that the climate would seem to have been becoming steadily colder. The Norwich Crag is more extensive in East Anglia than the earlier crags and thickens to the

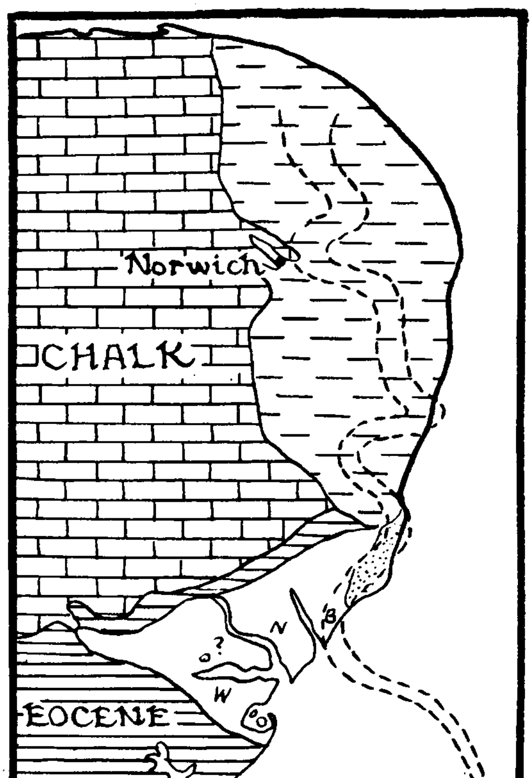

Fig. 3. The "Chillesford River" according to F. W. Harmer. The solid geology of East Anglia is also shown:— dotted = Coralline Crag; blank = Red Crag (W, Waltonian; N, Newbournian; B, Butleyan); interrupted lines = Norwich Crag. (From Stamp's "Introduction to Stratigraphy" by permission of Murby & Co.).

north and east — that is towards the centre of the North Sea Basin — and its sands and clays with occasional pebble beds are more clearly bedded than the shore deposits of the Red Crag.

Upper Pliocene (Chillesford Beds) Times.

The Chillesford Beds of Norfolk and Suffolk rest irregularly on either the Red or Norwich Crags and consist of fine, micaceous sands sometimes full of shells, often overlain by estuarine clays. The outcrop can be followed along a sinuous course from south to north and Harmer believed that they were laid down in a distributory of a delta — the delta of the ancient Rhine. It is important to remember that the retreat of the sea from the Wealden uplift and the London Basin must have synchronized with the development of those consequent streams and the advancement of the Wealden drainage pattern which has remained the classic example of such development since it was first described by W. M. Davis. The Chillesford Beds may represent

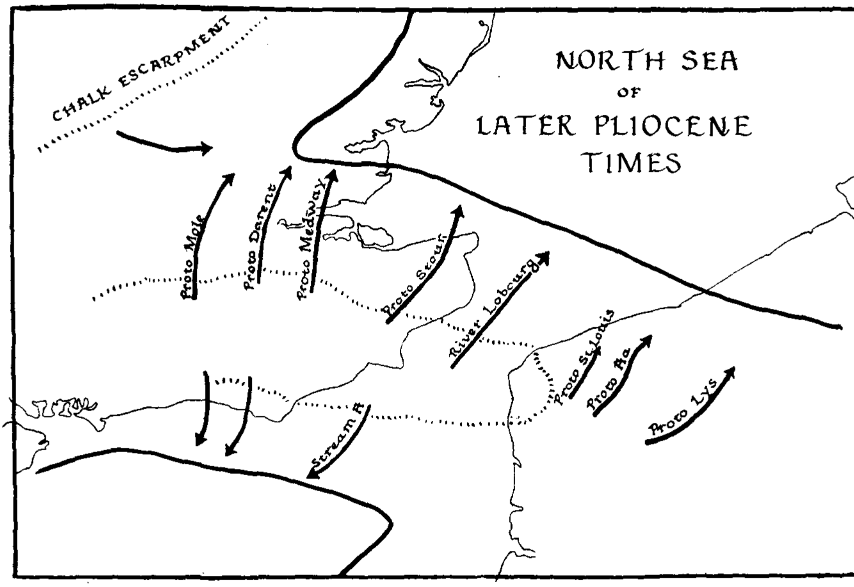

Fig. 4. The later Pliocene geography of south-eastern England (after Stamp, Geog. Journ. LXX, 1927 and Wooldridge, Proc. Geol. Assoc. XXXVIII, 1927).

the estuarine deposits of these Wealden rivers. On the other hand although the "Chillesford Beds" have long been accepted as a distinct group, they do comprise isolated or separated patches of sands which may be of different ages. It is interesting that the sands show varves or seasonal laminae.

Upper Pliocene (Weybourn Crag) Times.

The Weybourn Crag is found only on the Norfolk coast. Amongst the fossils there are less than 10 % of extinct forms; no southern forms survive but there is a further influx of "northern" forms including *Tellina balthica* which suddenly becomes extremely abundant. Seventy per cent. of Weybourn Crag fossils are of species still living in British seas and the deposits suggest that conditions in the North Sea were not markedly different from those of the present day. It is claimed that the old shore-line of buried cliffs with accompanying beach deposits, running from Hessle on the Humber, inland to Beverley and to the coast again at Sewerby, is approximately of this date.

Upper Pliocene (Cromerian) Times.

The interesting Cromer Forest Bed Series is only seen on the Norfolk coast, where it is overlain by Glacial Deposits. There is an impersistent Lower Freshwater Bed, succeeded by the Estuarine layer or Forest Bed proper. The Upper Freshwater Bed lies in erosion hollows on the surface of the Forest Bed. The whole has been regarded, as with the Chillesford Beds, as having been formed in the delta of a river which was possibly the ancestor of the Rhine. The Forest Bed is particularly interesting in that it consists of clays with sandy and lignitic seams and yields the stools and boles of trees and other plant remains of which no less than 135 species of flowering plants alone have been recognized — largely from seeds[9]). These are nearly all species living in Britain now and the inference is that climatic conditions must have been almost the same as those of the same area to-day. The fact that the few associated marine molluscs are northern forms merely indicates that the only open sea connexion was to the north. The freshwater shells, on the other hand, have a more southern aspect, as one would expect, with free land or freshwater communication with the south.

Roaming over the land which thus linked England with Holland and Germany were such mammals as *Elephas antiquus, E. meridionalis, Hippopotamus amphibius, Rhinoceros etruscus, Ursus spelacus* and some sixty others whose remains have been found in the Forest Bed and show that clearly there was uninterrupted communication by land between Britain and the Continent. It was formerly thought that because this land fauna is a *southern* one that it indicated a return to warmer conditions and that it might represent a first 'interglacial' period. But the associated land flora shows that the climate was the climate of to-day — perhaps slightly more Continental with colder winters and warmer summers as one would expect with Britain part of the Continent; the associated marine fauna is a northern one. The explanation is afforded by the distribution of land and sea — free land and freshwater communication with the south, free sea communication with the north only. Although this was realized by Clement Reid in his great work on the Pliocene Deposits of Britain (1890)[10]) it was rather overlooked till recalled by Boswell in 1931[11]). Only recently has evidence been collected that man himself was among the denizens of the Cromerian forests or plains. The

[9]) E. M. Reid. In this important paper Mrs. Reid traces the effect of the general increase of cold throughout the Pliocene in causing the southward migration of warmth-loving species, with the result that the Lower Pliocene flora of Western Europe survives to-day mainly on the Himalayas and mountains of Western China at heights of 5000 to 6000 feet, having migrated south against the cold and then migrated *upwards* on mountain slopes against increasing heat of post-glacial times. *Quart. Jour. Geol. Soc.*, LXXVI (1920) 1921 pp. 145-146.

[10]) *Mem. Geol. Survey.* — See also "Submerged Forests" (1913).

[11]) *Proc. Geol. Assoc.*, xiii, 1931 pp. 89-90.

implements discovered in association [12]) with the Forest Bed are of Pre-Chellian Types, so that the users of the Strepyan implements of Belgium or the eoliths of the North Downs may have been contemporaries of the dwellers in Cromerian forests.

The Pitdown skull *(Eoanthropus dawsoni)* though apparently occurring in Pleistocene deposits of the Weald, is associated with derived Pliocene mammalian remains and it would seem that before the close of the Pliocene man himself was widespread in Britain.

The Cromer Forest Bed is succeeded by the *Leda myalis* bed of the Norfolk cliffs. Its cold water marine molluscs show the nearer approach of Arctic conditions but the old statement that it shows a *return* to cold conditions after the 'milder' Cromerian must be discounted. It is frequently grouped with the Pleistocene.

Summarizing, during the whole of the Pliocene conditions seem to have become steadily colder. There is little evidence of a distinct glacial period, though icebergs seem to have drifted across the North Sea from an ice-cap in Scandinavia, which may have been the contemporary of the Günz glaciers of the Alps.

IV. The North Sea Basin in Quaternary Times.

The First British Glaciation — the advance of the North Sea Ice.

There can be little doubt that the first accumulation of ice in Northern Europe was on the lofty Scandinavian mountains. At an early stage valley glaciers from the central mass must have stretched down into the Norwegian fiords and have given birth to icebergs which drifted across the North Sea. It was probably these bergs which dropped the erratic blocks of Scandinavian origin found at the base of the English Pliocene Crags[13]. This early glaciation of Scandinavia may have been contemporary with the Günz of first glaciation of the Alps. If so, its effect in Britain is limited to the gradual lowering of temperature seen throughout the Pliocene.

In East Anglia the *Leda (Yoldia) myalis* Bed with its cold marine fauna is succeeded by the Arctic Freshwater Bed — a bed of limited extent but great interest. It is usually taken as the oldest of East Anglian Pleistocene deposits and indicates a widespread elevation of the sea-floor and the corresponding extension of the land surface. The Arctic Freshwater Bed leaves no doubt as to the Arctic conditions then prevailing on land — with such present-day plants of the tundra as *Betula nana* (Arctic Birch) and *Salix polaris* (Arctic Willow). The elevation which thus changed part of East Anglia from the floor of the North Sea to a willow-birch swamp forest was probably that which

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[12]) Not actually found in the bed, but in a gravel believed to be that at the base of the Forest Bed.

[13]) An elevated ice cap would give rise to strong out-blowing winds which would drive the icebergs across to Britain. *Cf.* Antarctica — F. Debenham Report Brit. Ass. Adv. Sci. Norwich 1935.

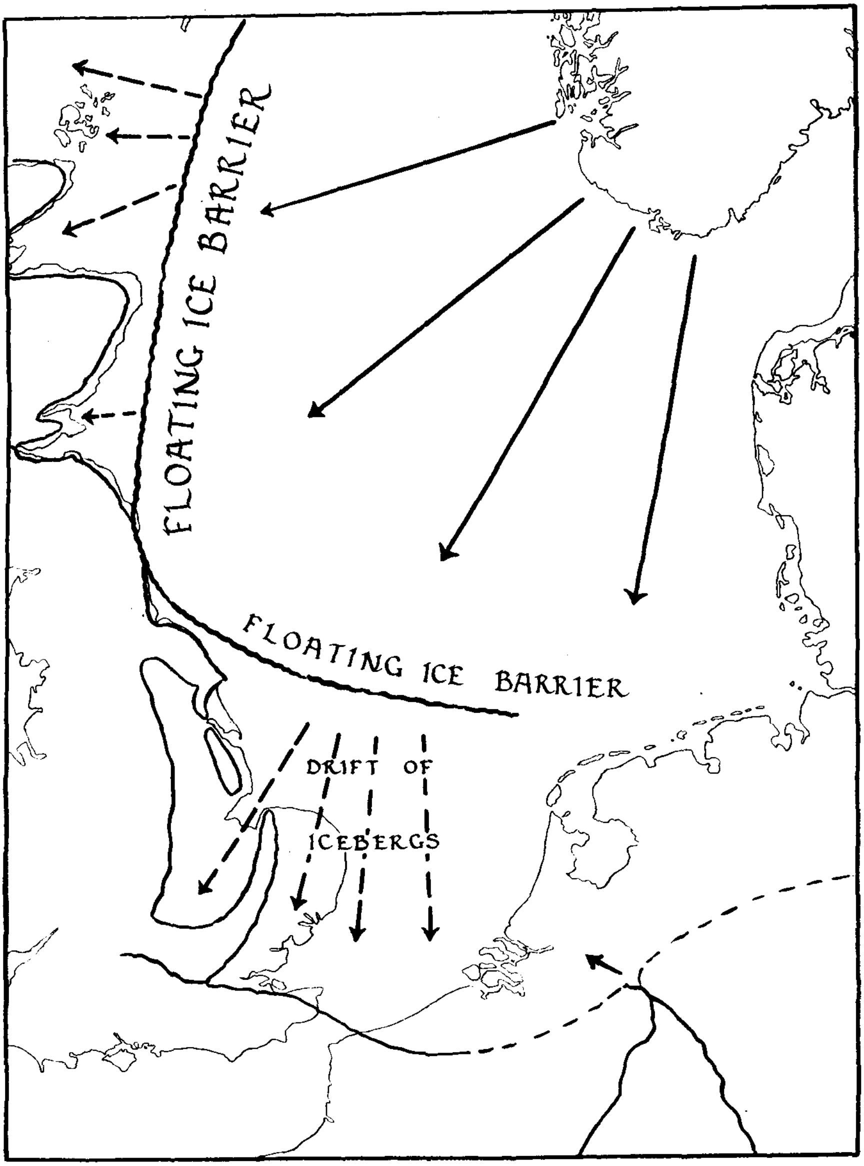

Fig. 5. The North Sea at the time of the First British Glaciation.

also caused the elevation of the well-known pre-glacial raised beach found along so many parts of the British coast, now about 12 feet above sea-level. If one accepts the idea of a rather delicate isostatic balance it may be hazarded that the increasing weight of ice over Scandinavia at first caused a compensatory upward tilt in Britain, followed, as the area covered by the ice-cap and its weight increased, to a general and widespread depression. Whether that is so or not, the continued accumulation of ice in Scandinavia was accompanied by a general submergence of the land of Eastern England. We can picture a great ice-barrier generally spreading westwards across the North Sea (floating as does the Ross Barrier of the Antarctic at the present day) and giving off huge icebergs which deposited their load of debris over the submerged low ground of eastern Norfolk and Suffolk. In this way was formed the Norwich brick-earth and probably the Cromer Till — unstratified deposits with scattered Scandinavian erratics which have every appearance of having been deposited under water and not by the melting of a glacier *in situ*. Icebergs seem to have drifted up the submerged Wash and far into the southern Midlands[14]).

British—North Sea Pleistocene Chronology.

Solomon [15]) 1932	Boswell [16]) 1932	Cultural Stages [16])	Possible correlation with J. Geikie's European [17]) Glaciations	Correlation according to Baak [18]) 1936
	? Fifth Glacial			
	? Fourth Interglacial			
Hessle Glacier	Fourth (British) Glacial	Magdalenian etc.	Mecklemburgian Glaciation	
	Third Interglacial	Aurignacian Mousterian		
Little Eastern Glacier	Third (British) Glacial	Mousterian	Polandian Glaciation	Würm
	Second Interglacial	Achenlian	[Elmian]	Elmian
Great Eastern Glacier	Second (British) Glacial	Chellian	Saxonian or Great Glaciation	Riss
	First Interglacial	Chellian		
North Sea Glacier	First (British) Glacial	Pre-Chellian	Scanian Glaciation	Mindel

Icebergs similarly drifted across to Scotland and deposited their debris around the Orkneys and in the Moray Firth and it is possible

[14]) Boswell *op. cit.* see also F. W. Harmer Proc. Yorks. Geol. Soc. XXI 1928 pp. 79-150 (with coloured map of erratics).
[15]) J. D. Solomon, Proc. Geol. Assoc. XLIII, 1932, pp. 241-271.
[16]) P. G. H. Boswell, Report Brit. Ass. Adv. Sci., York 1932; Proc. Geol. Assoc. XLII, 1931, pp. 87-111.
[17]) Jour. Geol., III, 1895, pp. 241.
[18]) *Vide infra.*

that, at least at one stage, the ice-sheet itself impinged on the shores of Durham and Yorkshire. At the same time there was a feeble accumulation of ice in Britain itself, the evidence for which is not very clear.

During this period there is every reason to believe that the Thames and Rhine drained northwards into the North Sea which was *not* completely blocked by an ice-sheet. Clearly the Thames must have been at a high level above its present valley and some of the 'plateau gravels' may date from that period.

In East Anglia the Norwich brick-earth — the subaqueous boulder clay of the Scandinavian ice — is succeeded by the well-known glacial sands and gravels. These afford the evidence of the first 'inter-glacial' period and are attributed to the meeting of ice and the consequent deposition of out-wash in a North Sea Basin which was probably a shallow sea. It is well known that, as the ice-cap over Scandinavia grew, its centre (of maximum accumulation) shifted gradually towards the east until at a later stage it was over the Gulf of Bothnia. Again allowing a delicate isostatic balance, the surface of Britain (and with it the British shores of the North Sea) may have risen while Scandinavia sank. Thus the stage was set for the oncoming of the second British Glaciation.

The Second British Glaciation — the advance of the Great Eastern Glacier.

The oncoming of this period was marked by the growth of ice-caps on the Scottish mountains, the Lake District and the Pennines. There is little doubt that the North Sea was largely filled with ice from Scandinavia but the British ice moving south from Scotland, joined by the glaciers from the Lake District and the Pennines, hugged the low ground of the east of England, swept out over the North Sea, and successfully kept back the Scandinavian ice. Thus was formed the wholly British Great Eastern Glacier which ploughed up part of the floor of the western North Sea before impinging on the coast of Norfolk and leaving there the Contorted Drift as evidence of its work. The ice stream of the Yorkshire Coast (which deposited the Lower Purple Boulder Clay) does not appear to have over-ridden the Lincolnshire Wolds. "On the west of this escarpment the Great Chalky Boulder Clay ice, augmented by the sheets which had flowed down the Yorkshire Plain (together with Lake District ice which had come over Stainmore) travelled up the valley of the Trent and down that of the Witham, fanning out across the low ground of the eastern Midlands. Part of the sheet, which crossed the Fen district, spread eastwards and southwards over East Anglia, reaching to Finchley in North London .... The ice which had descended eastwards from the Pennines seems only to have been sufficiently powerful to travel southward side by side with the Great Chalky Boulder Clay ice and thus to have been elbowed into the Avon Valley. At the same time ice appears to have advanced from the North Sea in a south-easterly direction on to the

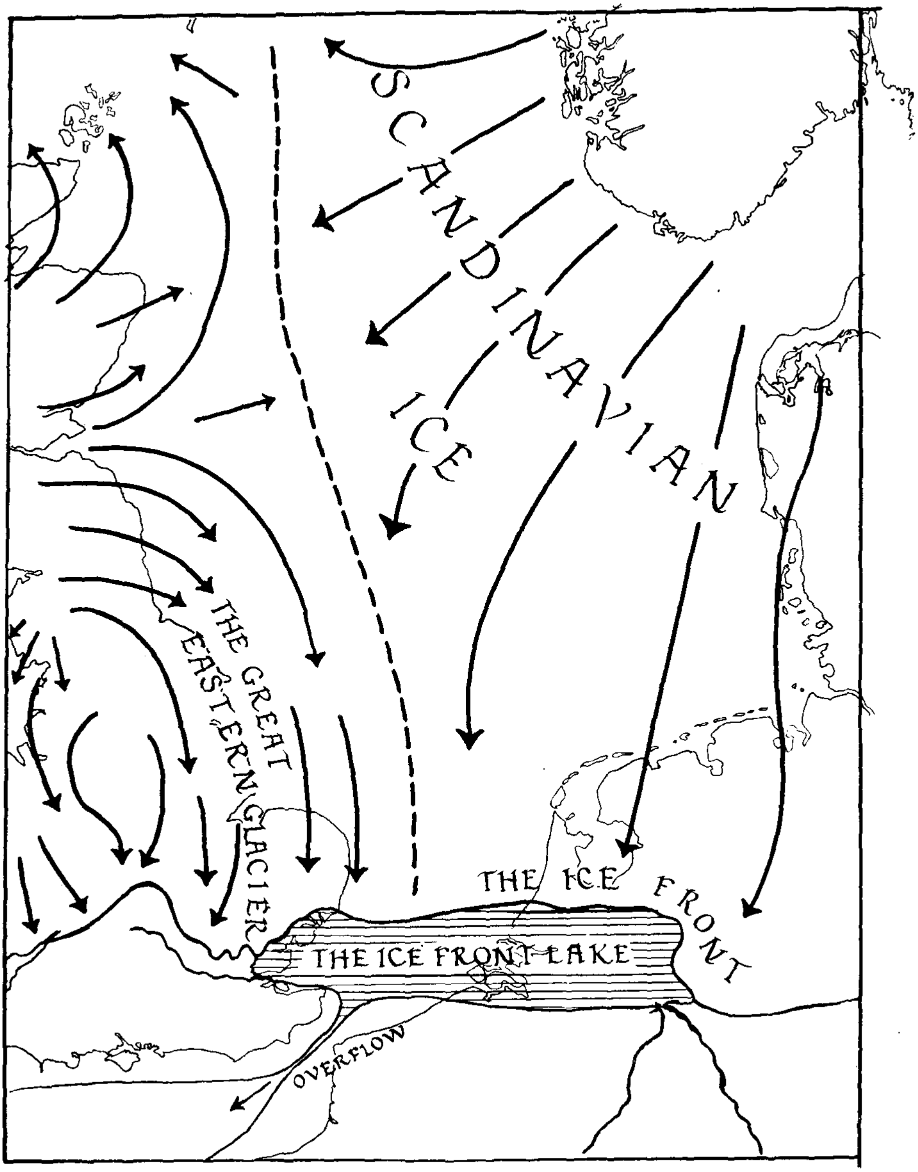

Fig. 6. The North Sea at the time of the Second British Glaciation (the period of maximum or Saxonian Glaciation of Europe).

Norfolk Coast, thereby influencing the course of the Chalky-Neocomian and Chalky-Jurassic glaciers"[19]).

This was, for Britain, the period of *maximum glaciation.* Only

[19]) P. G. H. Boswell, Pres. Address Section C, Report Brit. Assoc. Adv. Sci., York, 1932.

the south — south of a line joining the Severn and the Thames — remained outside the grip of the ice-sheets. There seems every reason to believe that it was also the period of maximum glaciation in northern Europe when the Scandinavian ice-sheet extended southwards as far as the mountains of Saxony, the Harz, Thuringia and the Carpathians. Because of its extent southwards to Saxony this was called the Saxonian or Great Glaciation by James Geikie. The term 'Saxonian' has been adopted by several geologists since, notably by Gignoux[20]), and seems safer than to assume a correlation with the Riss Glaciation of the Alps. The southern front of the ice stretched from Essex across the southern North Sea to Holland, the northern half of which was within the ice front. There seems no alternative to the view that the northern outlet for the waters of both the Thames and Rhine systems was blocked, more especially as the North Sea ice front must have 'grounded' on the Haisborough-Terschelling Rise where the North Sea to-day is only 25 to 30 m. deep. Thus the extreme south of the present North Sea Basin must have been occupied by a typical glacial lake, blocked by the ice on the north, and receiving the waters of the Thames and Rhine. This 'ponding back' of the waters was suggested long ago by Clement Reid[21]), and urged by the writer[22]), and has been accepted by the Dutch Geologist Faber[23]) amongst many others. What happened then is exactly comparable to that which happened in glacial Lake Pickering in Yorkshire and in many other well-known cases[24]). The water in the ice-front lake rose until a new escape was found. That escape was the existing valley of a Pliocene river[25]) in what is now the Straits of Dover. So the lake drained southwards to the English Channel, widening and lowering the valley which was later to form the Straits of Dover. The recent work of Baak[26]) has, from a new and comprehensive study of the sediments of the North Sea, confirmed that the Rhine thus drained southwards.

The retreat of the glaciers ushered in the very important second interglacial period of Boswell and other British geologists. The mingling of the Rhine and Thames waters permitted the spread of the temperate freshwater molluscan fauna characterized by *Corbicula fluminalis* (now restricted to the Nile and other warm rivers). Man returned to live on the river terraces and to shape Acheulian implements. These, like *Corbicula fluminalis* are associated with the 100 ft. Terrace of the Lower Thames Valley. Acheulian man was a big game hunter and he had the warm southern fauna of *Elephas antiquus*, *Hippopotamus* and *Rhinoceros leptorhinus* with which to contend.

20) M. Gignoux, Géologie Stratigraphique 1926; 2nd Ed. 1936.
21) See, *inter alia*, 'Submerged Forests' Cambridge 1913, p. 67.
22) L. D. Stamp, Geog. Jour., LXXX, 1927 p. 386-390.
23) F. J. Faber. Geologie van Nederland 1933.
24) See the map in 'The Pennines', British Regional Geology, H. M. S. O. 1936.
25) Named by the writer the River Lobourg, from the 'Creux de Lobourg' now occupying this position in the floor of the Straits of Dover.
26) J. A. Baak, Regional Petrography of the Southern North Sea, Wageningen, 1936.

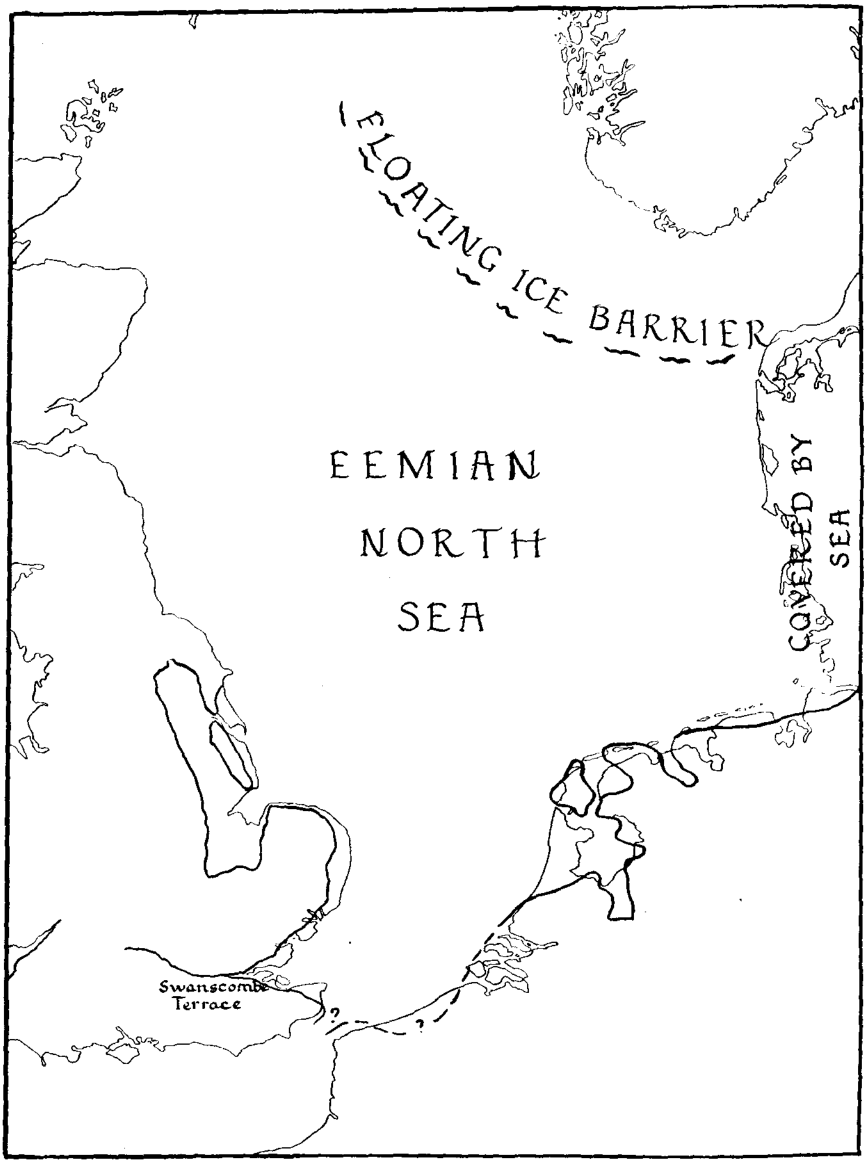

Fig. 7. The Eemian North Sea (at the time of the Second British Interglacial Period).

The retreat of the ice from Holland was accompanied or followed by a very marked marine transgression — the Eemian[27]). The Southern North Sea extended far over Holland and Denmark and the Eemian deposits, resting directly on boulder clay or outwash gravels, contain

[27]) The River Eem, south of the Zuyder Zee.

such warm water marine molluscs as *Tapes senescens* and *Bittium reticulatum* but also *Cyprina islandica.* In Holland these beds occur now at a height of 100 feet (35 m.) which is consistent with the level of the 100 ft. (Swanscombe) Terrace of the Lower Thames and with the position of the *Corcibula* gravels of East Anglia[28]).

It is not possible to say how the Eemian marine fauna reached

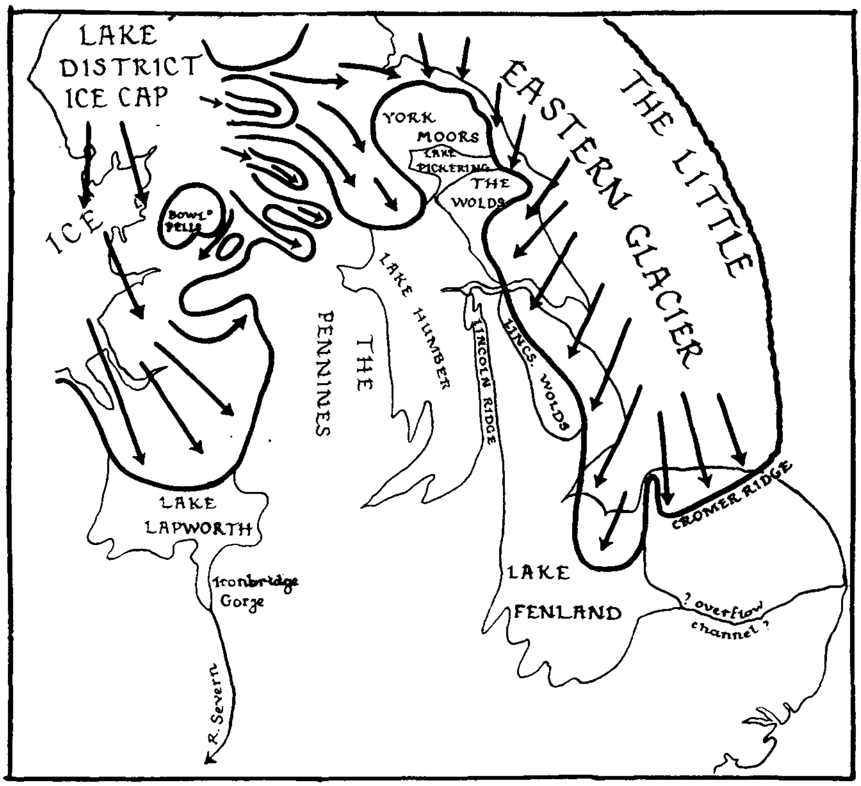

Fig. 8. Eastern England towards the close of the Third British Glaciation (after Raistrick and others).

Holland and Denmark. It *may* have come *via* the North Sea but its character suggests the temporary submergence of the Straits of Dover (after the warm land and freshwater fauna had reached Britain).

The Third British Glaciation — the advance of the Little Eastern Glacier.

Several interesting changes are to be noticed towards the end of the second interglacial period. Acheulian man gave place to Mousterian man and the climate became sufficiently cold to change rain washes

[28] For the classification of Belgian deposits see A. Rutot, Bull. Soc. Belge Géol. XXIX, 1919, pp. 31-42; pp. 151-196.

from hill slopes in southern England to movements of frozen sludge which have left the Combe Rock and trail.

In England the Third Glaciation was marked by a movement of ice from the Southern Uplands of Scotland and the Lake District across the Irish Sea to the Cheshire Plain and from the Lake District across Stainmore to the Tees Valley. In East Anglia the 'Little Eastern Glacier' invaded the north of Norfolk and the famous Cromer Ridge is probably the terminal moraine of this glacier. Elsewhere the deposits left by this Third Glaciation form what was long known as the Newer Drift.

On the eastern side of the North Sea, the ice no longer stretched far over the water. But the ice still covered the whole of Denmark, there frontal or terminal moraines stretch between Stade and Bremerhaven being found along the *right* bank of the Weser and the Aller, passing through Magdeburg, Spremberg to Plock on the Vistula. Behind this frontal or terminal moraine[29]), that is to the north and north-east, there is a succession of moraines which mark stages in the retreat of the ice. The rivers of Germany, flowing from Central Europe, were unable to make their way to the still ice-covered Baltic as they do to-day, and so flowed *parallel* to the front of the ice, receiving from its melting large volumes of water, and so towards the North Sea. These old marginal valleys, in large part unoccupied by rivers at the present day, form the well-known *urstromtäler* of German geologists.

The Period after the Third British Glaciation.

Whatever may be the reason, there seems little doubt that the area at present covered by the southern North Sea was at this time a low-lying plain with quietly meandering rivers. At first it had an Arctic or Tundra climate and may be compared with the low-lying plains of northern Siberia. *The present floor of the North Sea is essentially the buried landscape of this period.* Except in the south, it would seem that the sediments of the North Sea floor are those which covered this late Pleistocene land-surface though partly resorted by current action. Special interest therefore attaches to the researches of J. A. Baak, published in his 'Regional Petrology of the Southern North Sea' (1936) in which he incorporated the results of previous work on North Sea sediments. Essentially he finds the north-eastern two-thirds of the sea-floor covered with glacial and fluvioglacial deposits of Scandinavian origin, together with resorted Pliocene and probably with silt or other sediments from German rivers. The north-western third is similar material mainly of English-Scottish origin. Between the mouth of the Thames and the mouth of the Rhine is an area covered by sediments whose mineral composition suggests that they were deposited by the Rhine. Only along the Belgian-Dutch coasts has there been extensive *later* resorting of materials. This is Baak's view, but

[29]) This terminal moraine may be later than the Third British Glaciation as suggested by the table given above.

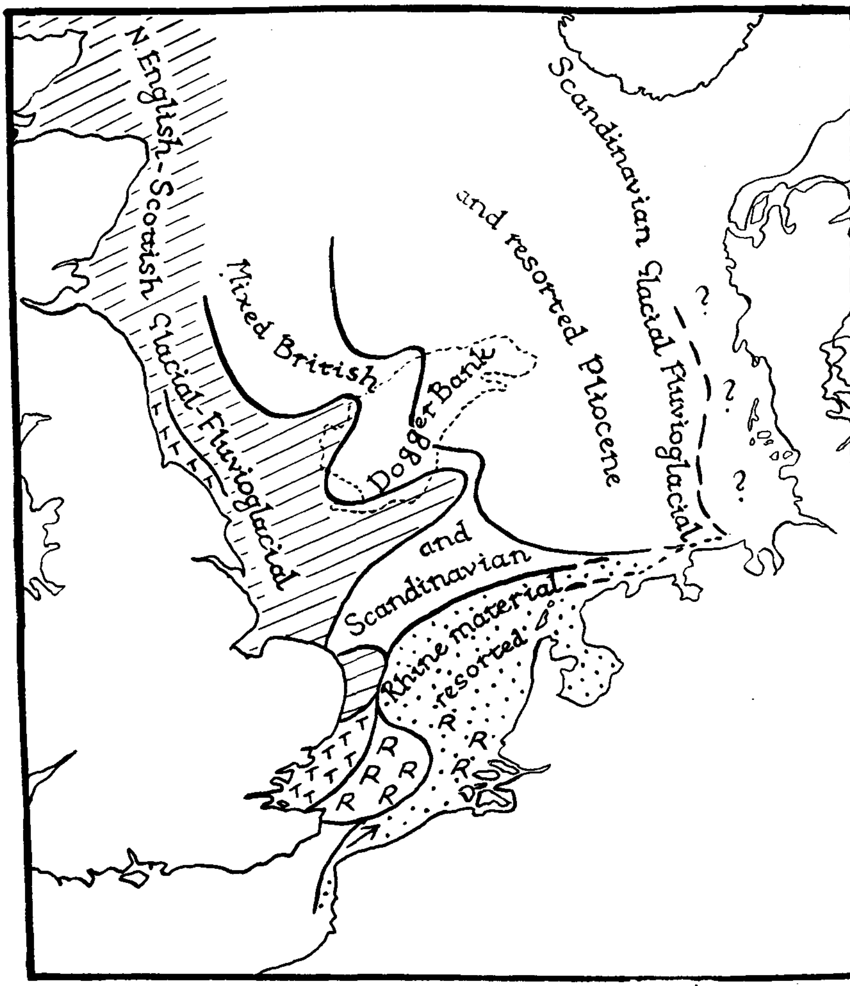

Fig. 9. The Petrographic provinces of the North Sea according to J. A. B a a k.

it does not entirely accord with the famous researches of J. O. B o r l e y (The Marine Deposits of the Southern North Sea. Min. of Agric. and Fisheries, Fishery Investigations, Ser. II, Vol. IV, No. 6, 1923). B o r l e y found that the existing distribution of material is largely the result of selective transport by current aided by wave action, and that wave action was operative down to at least 120 feet (20 fathoms). Coarse material occurs where current action is such as to prevent the accumulation of silt and finer materials. The North Sea is divided, however, into an 'English Channel' and a 'German Bight', on either side of the Dogger Bank. B o r l e y shows that there is little transport of material *across* the Bank from east to west and thus little mixing of the material of the two provinces determined by

Baak. For details of the conditions in the German Bight reference should be made to Otto Pratje's comprehensive work[30]).

The extensive and rapid movement of material along and near the coasts of the North Sea is, of course, well known[31]).

The late Pleistocene land-surface of the North Sea has long been postulated by geologists. Various authors such as Jukes-Browne[32]) (1888), Sir Halford Mackinder[33]) (1902), Clement Reid[34]) (1913) have published maps showing the Humber — Little Ouse — Thames systems joining up with those of the Rhine and Elbe and flowing across this plain to the sea far in the north. J. W. Gregory[35]), mainly for zoological reasons, is alone in believing that the Thames and the Scheldt joined to flow southwards (through a valley occupying the centre of the Straits of Dover) whilst the Rhine (which he shows passing through the Zuyder Zee) joined the rivers from the Wash and Humber and flowed northwards. Baak, to explain the distribution of certain heavy minerals in the North Sea and sediments, believes the Rhine joined the Thames and flowed southwards.

As the ice (which most Continental geologists regard as ice of the same age as the Würm glaciation of the Alps) retreated, the North Sea tundra plains with their *Elephas primigenius, Rangifer tarandus* and other Arctic animals enjoyed an amelioration of climate. The vegetation began to change gradually from that of an 'Arctic prairie' to forest with *Pinus sylvestris* and *Betula.* Sea-level may have been as much as 150 or 200 feet (50—60 m.) below its present level, (Tesch and Schutte). The forests of this period or slightly later are preserved to us as the famous 'submerged forests' found round the shores of Britain. What is now the Dogger Bank seems to have been occupied by a tract of fen in which fenland peat accumulated. Fragments of this peat-bed are frequently dredged and are known to the fishermen as 'morlog'. The peat consists of species common in the English Fens of to-day, but with such species as *Betula nana* indicating a distinctly colder climate. The Dogger Fen may have been bordered with sand-dunes, if the evidence of the beetles associated with the peat can be taken as conclusive[36]). The Dogger Bank peat occurs at a depth which suggests a greater difference of level than do the submerged forests of the English, Dutch, and German coasts where the forests occur at depths of 50 to 60 ft. below present mean sea-level, so that

[30]) Die Sedimente der Deutschen Bucht. Wissenschaftliche Meeresuntersuchungen Abt. Helgoland, Vol. 18, Nr. 6, 1931.

[31]) See *inter alia,* J. A. Steers, Scolt Head Island, Cambridge, 1935; papers by H. Muir Evans *(Mariner's Mirror,* Vols XV-XVIII, 1929-1932).

[32]) Building the British Isles, 1st edition, p. 294. See also Contemp. Review 1893 pp. 704-712.

[33]) Britain and the British Seas, p. 140-1.

[34]) Submerged Forests, p. 40.

[35]) Geogr. Journ. LXX, 1927, pp. 52-59.

[36]) For a discussion of the implications see Clement Reid, Submerged Forests, especially Chap. IV; also Essex Naturalist, XVI, pp. 51-60. On the molluscs see O. Pratje, Centralblatt f. Min., Jahrg. 1929, 56-61.

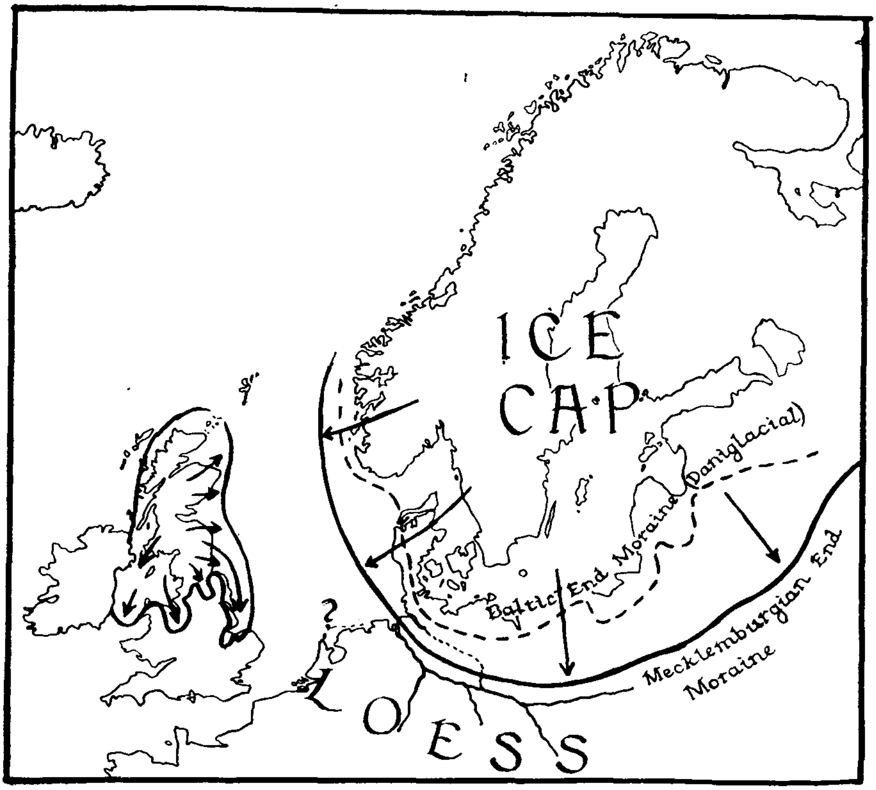

Fig. 10. North Europe showing the limits of the Mecklemburgian Glaciation, probably contemporary with the Third British Glaciation. This map also shows *the position of the next stage of retreat, the Daniglacial (Baltic End Moraines).* The rivers parallel to the ice front in Germany should be noted.

the land stood at least 70 ft., more probably 90 ft. (20—30 m.) above its present level. The submerged forests of Britain are mainly of oak but the flora and fauna associated are poor. Recent investigations in France, (D u b o i s) and Holland (by T e s c h and Mrs. V e r m e e r - L o u m a n) suggest that peats and submerged forest of several ages may have been confused in Britain.

The land phase of the North Sea came to an end by the steady southward advance — for the last time — of the North Sea. For most geologists this marks the end of the Pleistocene and the beginning of the Holocene — the Recent or Post-glacial period. In this sense the North Sea of to-day is essentially a recent phenomenon. B a a k points out that the renewed southern invasion of the sea from the north must have taken place along the lower ground of the North Sea Plain, leaving the higher ground of the Dogger Bank and the centre of the Harlsborough-Terschelling rise as land for a considerable period. He believes that the first connexion between the English Channel and the North Sea was made along the "Deep-Water" between the Dogger

Bank and the English coast and that a separate arm of the sea reached the Flemish-Dutch coast. He places the beginning of the 'Atlantic' period (see below) at the time when the connexion was first etablished. It is difficult to reconcile this reconstruction with Dubois' work, but it is supported in considerable measure by Borley's and Pratje's studies of the North Sea sediments, and by the investigations on the British flora by Woodhead, Erdtman and others mentioned below.

Late Glacial and Post-Glacial Chronology.

The late Glacial and Post-Glacial history of the North Sea Basin is closely allied with that of the Baltic Sea, where De Geer and his fellow workers have been able by a detailed study of the 'varved' or seasonally banded sediments, to work out a time-scale measurable in years[37]). G. Dubois[38]) working in the north of France has attempted to correlate events there with those in the Swedish area but in the correlation there are many difficulties. In the first place it must be remembered that the removal of the ice in Scandinavia led to an enormous regional uplift to the land — 700 or 800 feet — far exceeding any change of level along the British and southern shores of the North Sea. Thus the movements must have been differential and not eustatic.

Daniglacial. This period of ice-retreat from over Denmark has not been dated in years. We may presume it to have taken place during the pre-Boreal period (see below) when the North Sea Basin was occupied by tundra.

Gothiglacial. This period of ice-retreat across southern Sweden lasted from about B. C. 14,000 to B. C. 10,000. During this period the margin of the Scandinavian ice-sheet retreated across southern Sweden. Marine beds known as the Upper Senglacial were deposited in Denmark possibly from an extension of the deep waters now found in the 'Norwegian Deep', as well as Continental deposits with 'Dryas' or Tundra flora — the older Tundra flora (pre-Boreal). Dubois believes that a shallow and narrow arm of the sea occupied the Straits of Dover and stretched over Flanders, but that it was blocked by ice in winter so that mammoths and other large animals could cross to Britain, whereas in summer icebergs with erratics from Brittany drifted eastwards up the English Channel through the Straits to the Ostend Bay where marine sands (the Lower Flandrian) were being deposited. Again according to Dubois the younger limon (or loess of France) was being formed and about 10,000 B. C. there was a slightly warmer period; towards 9,000 it was again colder. The land continued to rise.

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[37]) See especially G. De Geer, C. R. XI^e^ Congr. Géol. Intern. Stockholm, 1910, I pp. 241-253; M. Sauramo, Fennia XLIV, 1924.

[38]) G. Dubois, Ann. Soc. Géol. du Nord, XLIX, 1924, pp. 120-130; Mem. Soc. Géol. du Nord VIII, 1924.

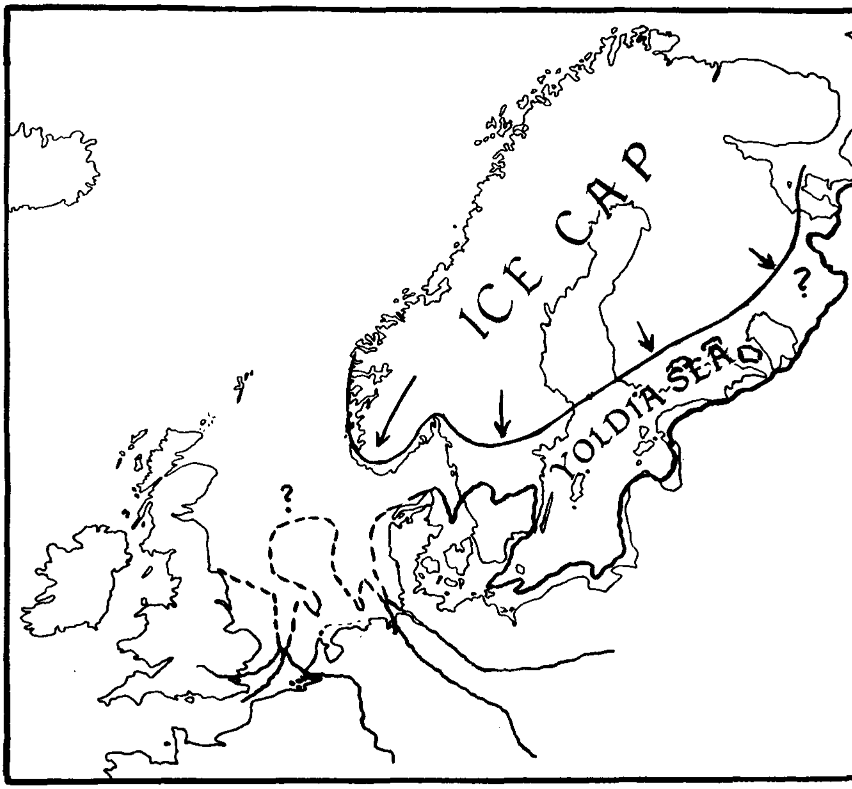

Fig. 11. Northern Europe during the Yoldia Sea Period — the beginning of the Finiglacial when the Scandinavian moraines and the Salpausselka of Finland were being formed. Ca. B. C. 9000 — 8000 (after Sauramo). The gradual emergence of the floor of the North Sea at this period is postulated.

Finiglacial[39]). This period lasted from about 8,500 B. C. to 6,500 B. C. In the early part of this period the climate was distinctly colder than at present, giving rise to the younger Tundra or Dryas flora. There was a pause in the ice retreat and the famous end moraines of Sweden and Finland (Salpausselka) were formed. In northern France, (Dubois), estuarine deposits yielding *Elephas primigenius* were laid down in the Calais Bay.

About 8,000 B. C. the Finiglacial Retreat commenced. A sea of Arctic temperatures (the *Yoldia* Sea) occupied the Baltic and may have been linked with the White Sea. The mammoth left north-western Europe, the reindeer and the other Arctic mammals left the southern shores of the North Sea and retreated northwards.

[39]) J. K. Charlesworth considers the last Highland glaciation was contemporary with the Finiglacial. Proc. Roy. Irish Acad. XL, B, 1931, pp. 27-83.

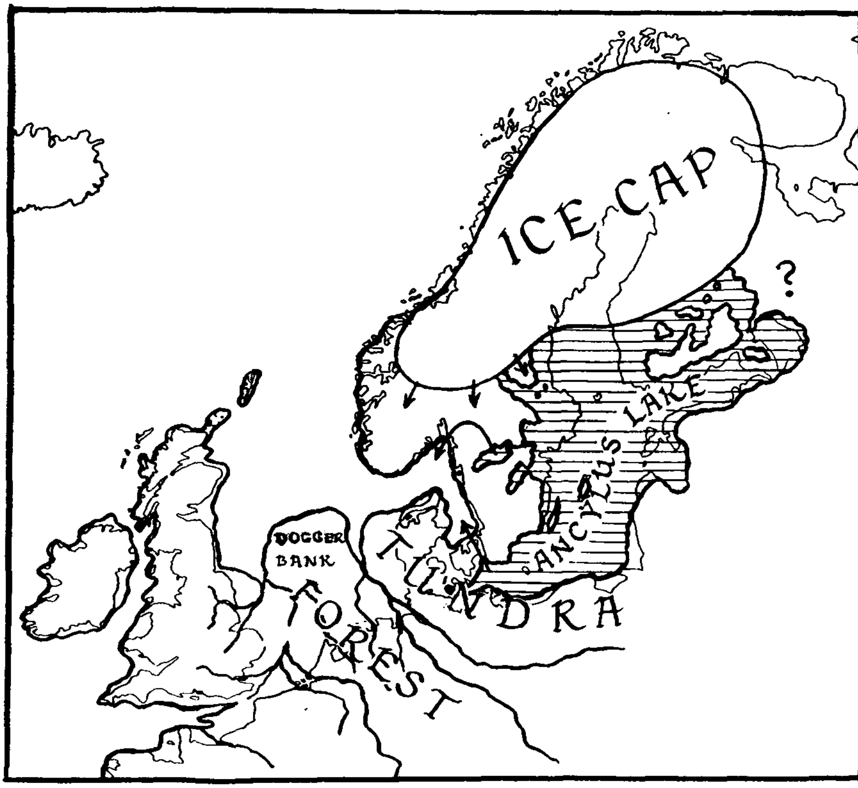

Fig. 12. Northern Europe during the Ancylus Lake Period (late Finiglacial, ca. 7500 B. C.) — the Boreal or Submerged Forest Period in Britain (after Pratje and Sauramo).

Later, the climatic conditions improved and, possibly as a result of the diminution of the weight of ice, Denmark rose and the Baltic was cut off from the North Sea and formed a lake (*Ancylus* Lake). Northern Denmark was occupied by tundra and became habitable by man, and the forest belt commenced to invade southern Denmark. According to Dubois, along the northern French shores of the North Sea, sea-level stood about 15 or 16 m. above the present, and men with finely chipped flint knives (Azilian) lived in Western Europe.

Postglacial. The postglacial period of Swedish geologists commences about 6,500 B. C. The Scandinavian Ice sheet was reduced to two masses and at first remained stationary, as did the sea-level along the southern shores of the North Sea. The Calais Bay was an area of peat formation. Dubois believes that the Straits were open, but shallow and narrow.

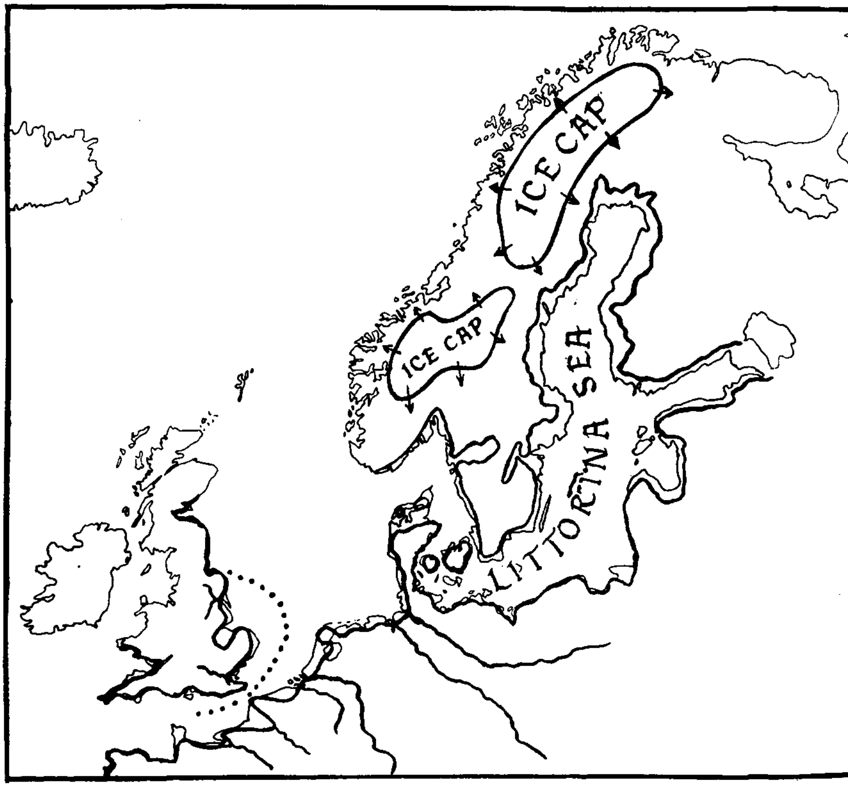

Fig. 13. Northern Europe during the littorina Sea Period (Atlantic Period ca. 4000 B. C.). This was the period of the 25'Neolithic Raised Beach of Britain and the Middle Flandrian Transgression in Northern France. The line of dots shows the probable line of the first sea connexion between the North Sea and the English Channel (after Sauramo, Pratje and others).

About 6,000 B. C. came the final retreat of the Scandinavian Ice sheet. This was accompanied by a remarkable transgression of the waters of the North Sea. The North Sea invaded the Baltic (as the *Littorina* Sea); beds with *Tapes* were laid down over Denmark and the Flemish plain was also invaded as was the Plain of Picardy (transgression of the Middle Flandrian) and the Straits of Dover assumed something of their present character, so that the movement of a land fauna between Britain and the Continent ceased. In northern France the sea was about 12 or 10 m. above the present level and the rivers, thus rendered sluggish, became areas of marsh and of peat formation. In Britain this period of marine transgression is marked by the well known Neolithic (25 foot) Raised Beach, about 4,000 B. C. Neolithic man was living in Denmark and building his "Køkkenmøddings". Britain was definitely and finally cut off from the Continent.

During this period the sands and other sediments which had been transported from the southern North Sea to the English Channel by the overflow channel of the old Glacial Lake and possibly by the Rhine, were swept back by the strong tidal current. There was a strong tidal scouring and the Straits were rapidly deepened (Lobourg trough) and widened. This was during the Atlantic period (see below) and the opening of the Straits of Dover to the influence of warm waters from the North Atlantic may have been largely responsible for the change in the character of the climate. From the projecting Cape Gris Nez (west of Calais) a sand-bar grew out and behind it accumulated clays and silts. Similar sand-bars to the north-east form the "Oude Duinlandschap" (Old Dune Formation) of Holland and the silt behind the "Oude Zeeklei", (Old Sea Clay). Later tidal marsh or swamp and heath vegetation spread over the sea clay (in the sub-Boreal period) and it is believed that the Romans knew the Dutch coastal area as a belt of swamps bounded on the sea-ward side by the Old Dune Formation[40]). With the opening of the connexion between England and the Dogger Bank, there would be initiated the system of tidal currents which characterize the area to-day[41]). It was not, therefore, until this period that the resorting of the materials on the floor of the North Sea, shown by Borley's investigations, was begun and, at the same time, the whole present-day trends in coast erosion and coastal accumulation.

De Geer's chronological scale was based on the actual counting of the seasonal layers or varves of the post-glacial sediments of Sweden. It is an absolute scale of years and may be linked exactly with the stages of ice-retreat in Scandinavia and with the evolution of the Baltic Sea. An attempt, using the work of A. Blyatt[42]) by R. Sernander[43]) was made to draw up a scheme of post-glacial chronology. This work in Sweden can be linked with De Geer's scale. The correlation given by Pratje[44]) for *southern Sweden* and the neighbouring parts of the Baltic is as follows:—

[40]) On the effect of currents off the Belgian Coast see C. J. van Mierlo, Bull. Soc. belge Géol. XIII, 1899 pp. 219-265.

[41]) See J. O. Borley, *op. cit. sup.*, O. Pratje, *op. cit. sup.*, also Atlas of Tidal Streams of the North Sea (Hydrographic Office of the Admirality, 1899), C. H. Brown, Report on the Deep Currents of the North Sea, (North Sea Fisheries Invest. Com. 4th Report, 1909. *Ibid* 2nd Report, Fishery Board for Scotland, 1914.)

[42]) Essay on the Norwegian Flora, Kristiania 1881; Wechsel continentaler und insularer Klimate nach der Eiszeit. Naturf. 1881; Bot. Jahrb. Pflanzengeogr. II.

[43]) The Swedish Peat Bogs as evidence of post-glacial changes of Climate C. R. Cong. géol. intern. Stockholm, 1910, Vol. II.

[44]) O. Pratje Die Tierwelt der Nord- und Ostsee: Einführung in die Geologie der Nord- und Ostsee, 1931.

	De Geer	Climatic Periods	Baltic Sea Stages	Cultural Periods
		Subatlantic	*Mya* Sea	Historic Times Iron Age
BC 1000		Sub-Boreal	*Lymnaea* Lake	Bronze Age
BC 2000	Post-			
BC 3000	Glacial	Atlantic	*Littorina* Sea	Younger neolithic
BC 4000				
BC 5000		Boreal		Older neolithic
BC 6000				
BC 7000	Fini-	Subarctic	*Ancylus* Lake	Oldest neolithic
BC 8000	Glacial	Arctic	*Yoldia* Sea Ice-covered	
BC 9000	Gothi-			
BC 10000	Glacial			
BC 15000				
BC 18000	Dani-Glacial			

The Arctic period is regarded by Pratje as having a July temperature increasing from 6°C. (43°F.) to 9°C. (48°F.) — and is essentially the climate of the tundra.

The Subartic period with July temperatures from 10°C. (50°F.) to 12°C. (54°F.) makes possible the growth of 'Arctic prairies' and Arctic trees such as *Betula nana.*

The Boreal period had a climate of continental type with short, hot, rather dry summers (July 17°C. or 63°F.) and long cold winters, and one which favoured the 'taïga' type of forest — with *Pinus Abies* and *Betula.*

The Atlantic period had a climate more marked by oceanic characteristics, not greatly different from that of Britain to-day, but warmer, i. e., resembling that of present-day Denmark or warmer, with a July temperature 18—18.5°C. (64—65°F.) and one which favoured broad-leaved, deciduous forests.

The Sub-Boreal period had a lower July temperature (17°C. or 63°F.) and was damper and cooler.

The Subatlantic period, lasting to the present day has relatively cool, short summers (16°C. or 61°F. in July).

It is important to note that these temperatures and periods refer to *southern Sweden.* It is probable that the same general sequence of climatic periods (with local modifications) followed the ice age in Britain, but what seems to the writer a fatal mistake is to regard them as synchronous in Britain and southern Sweden as Woodhead[45])

[45]) T. W. Woodhead, Jour. Ecology, XVII, 1929, pp. 1-34; Tolson Memorial Museum Handbook VIII, Empire Forestry Journal, VII, 1928.

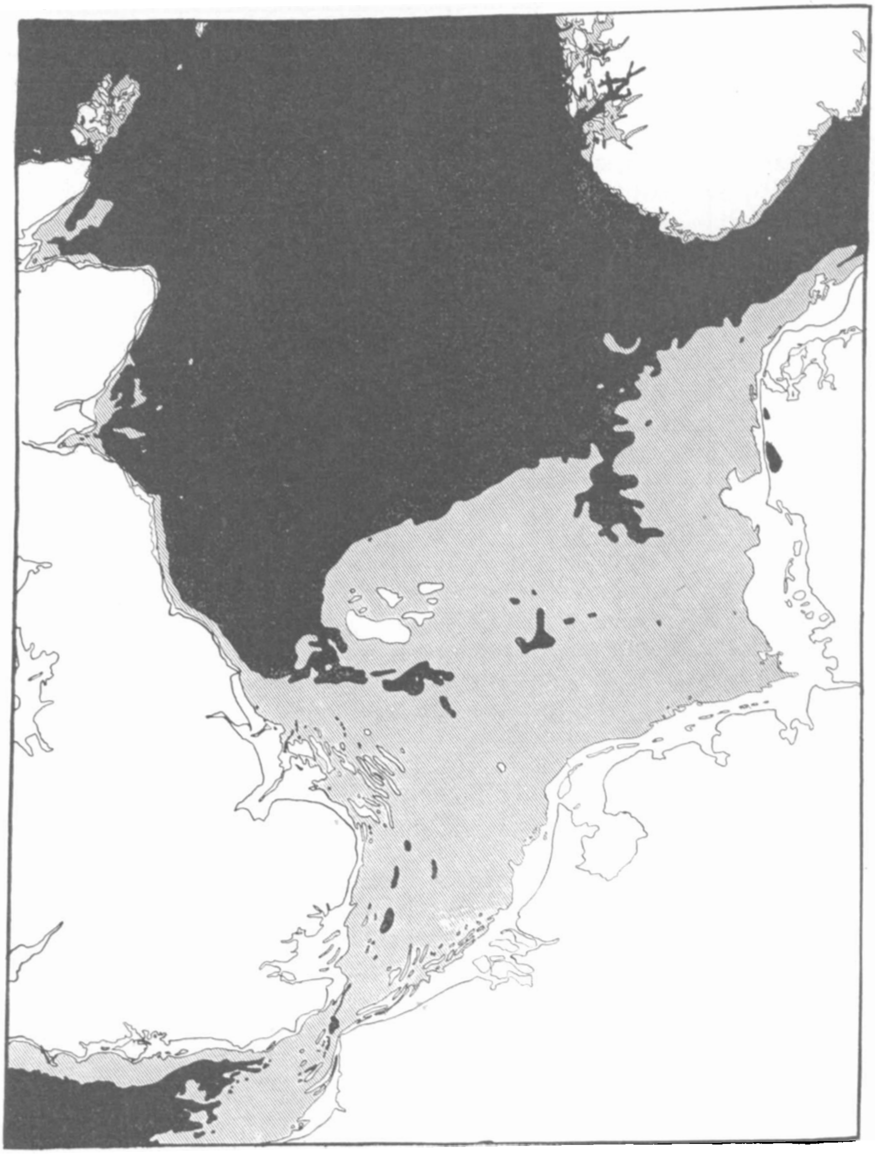

Fig. 14. The North Sea of to-day, showing the positions (in black) over 50 m. and which indicate the probable Channel of early Atlantic connexion between the North Sea and the English Channel.

black — over 50 m.; hatched — 50-20 m.; white — under 20 m.

has done. In view of the position of the British Isles, nearer the Atlantic, we may more rightly regard the corresponding climatic period as occurring considerably *earlier* than in Sweden and Denmark. With this reservation we may use the very valuable detailed work of Woodhead on the history of the vegetation of Britain (especially his work on the Southern Pennines) and the results obtained by G. Erdtman by his now famous methods of pollen analysis of peats. In the late glacial period (which Woodhead calls 'Würm' — presumably the third British glaciation of the scheme given above), it is probable that the high ground of the Pennines remained as a 'nunatak' above the ice and had a tundra flora with common moorland species. As the following Arctic period merged into the sub-Arctic, *Betula* appears and in the Boreal period there were forests on the Pennines — mainly of birch, but with hazel, alder and oak, later with occasional pine[46]) and elm. The ground flora was heath *(Calluna)* and during this 'warm dry Continental period' Tardenois man lived in the area. During this period the Pennine forest reached its maximum: with the coming of the damper, cooler Atlantic period the forest began to degenerate. Woodhead agrees that at this time Britain became cut off from the Continent; it is the writer's belief, as noted above, that the severing of the land connexion and the new circulation of water round the islands actually *caused* the climatic change, probably considerably earlier than in Denmark and Sweden. By a micro-analysis of the 'moorlog' of the Dogger Bank, Erdtman[47]) assigns an early Boreal age to it — which is consistent with the sequence of events already outlined. In the Pennines *Eriophorum* (Cotton grass) replaced *Calluna-Betula* in Atlantic times and the associated human tools are Neolithic. In the succeeding sub-Boreal time *Calluna* returned, with beech and fir *(Abies)* and Bronze Age tools are found. The final sub-Atlantic period brings the sequence to the Iron Age and the present day.

V. Conclusion.

Any attempt to trace the geographical evolution of the North Sea Basin from Miocene times to the present day is to be regarded merely as an attempt based on the state of knowledge at the moment. Perhaps a dangerously positive tone has been adopted; it is merely that the erection of an edifice with some definition does at least afford a target for others to attack.

[46]) Elsewhere the post-Glacial maximum for pine was reached.
[47]) Essex Naturalist XXI, 1925, pp. 107-112.