Chapter 1.

INTRODUCTION.

The development of Glacial Geology has been a most rapid one. It began practically within the memory of many living men, or at least during the last century. Since the study has commenced however an enormous amount of time has been given to it, and a huge bulk of literature has sprung up.

Playfair at the beginning of last century pointed out the importance of glaciers as agents of transport for blocks of stone of all sizes.

After this however the study was dropped for a time until Venetz & Charpentier took it up anew, and traced the dispersal of the crystalline rocks of the Central Alps outwards across the Swiss plain to the flanks of the Jura mountains and so demonstrated the former great extension of the Swiss Glaciers. However, it was Agassiz who really first realised the significance of these facts and brought forward the theory of a Great Ice Age which involved much of the Northern part of our hemisphere.

As far back as 1836 he was induced to visit the glaciers of Diablerets & Chamounix and the great moraines of the Rhone Valley, under the guidance of Charpentier whose views on the subject he had previously doubted.

After his tour however he was convinced that the phenomena were more important and far reaching than Charpentier had asserted. After careful examination of the erratic boulders and striated rocks he was led to conclude that the Alpine Glaciers, now restricted to the higher Valleys, once extended into the central plain, crossed it, and even mounted to the southern summits of the Jura Chain. Further he realised that this phenomenon was no accident, but was due to some general lowering of temperature. He believed that the glaciers did not advance from the Alps into the plain, but that the ice covered the whole area but finally retreated into the mountains. After a long study of the phenomena in his own country he visited Britain and examined a considerable part of Scotland, the north of England, and the north, centre, west & south-west of Ireland.

Agassiz showed that the phenomena in England were identical with those of Switzerland, and claimed that not only glaciers existed in the British Isles, but that the surface was covered by large sheets of ice.

The work of Agassiz gave a great impetus to glacial work, and although his ideas were at first strongly opposed by the leading geologists of the time, one by one they became converted to his way of thinking later.

Among his many converts in Britain Buckland was the first. He published a series of papers proving the presence of ice-sheets in Scotland, North England, and North Wales.

Lyell, too, about the same time was won over to the new way of thinking, and in 1841 published a paper on the Glaciers of Forfarshire.

A few years later (1845) James. D. Forbes gave an account of glaciers that nestled among the Cuillin Hills of Skye, and Charles Maclaren found glacier moraines in the valleys of Argyleshire, a few ~~later~~ years later still, important service towards the ultimate acceptance of Agassiz's complete views of the glaciation of Europe was rendered by Robert Chambers, from 1852 - 1855, by a series of papers on the superficial deposits and striated rocks of Scotland, and the results of a trip to Norway.

In 1851 Ramsay showed that in North Wales there must have been severe glacial conditions occuring both before and after the suggested Marine submergence of many of the older geologists. Ramsay too extended his work over Northern England & Scotland, and he came to the further conclusion, that effects of submergence (if it really took place) were very small compared with the effects of the widespread glacial action. He finally gave his adhesion to Agassiz's theory that the more striking drift phenomena of the British Isles could only have been brought about by a continuous ice-sheet, or by a series of confluent glaciers.

Above the old rocks of any district we always find 2 layers which are known as

1. Soil:- A black layer, whose formation is due to decayed vegetable matter. It is only a few feet thick.

2. Subsoil;- Not black, but varying in colour. Only a few feet thick. It is formed by the changing of the rocks below.

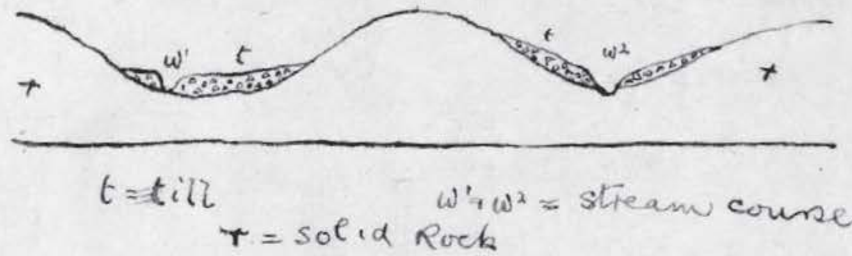
In many parts of the World between these layers and the older rocks we find another layer varying greatly in thickness, and which is known as "THE DRIFT".

The drift consists of a heterogeneous mixture of clay, sand, gravel, pebbles, subangular stones of all sizes, unsorted, unstratified, unfossiliferous - of all sorts of materials, wholly unrelated to the underlying rock, and therefore universally shifted. not so/

The lowest part lying in immediate contact with the subjacent country rock is often a stiff clay inclosing subangular stones, i.e.rock-fragments with the corners and edges rubbed off. This is known as Boulder-Clay or Till. When the till or boulder-clay appears in the same vertical section with any of two the other superficial deposits mentioned it invariably lies on the bottom. underneath Thus it may be inferred that the Boulder-Clay is the oldest of these three accumulations. not a sound inference

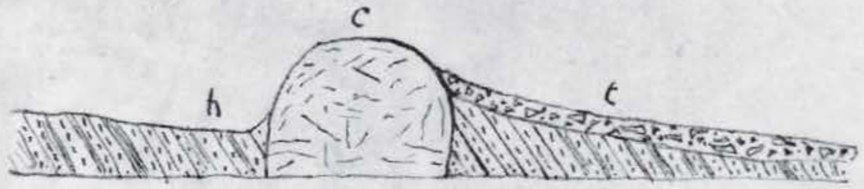
It is only now and then, however, that the lowest lying or oldest superficial accumulations are overlaid by these later formed deposits. Throughout wide areas stony clay alone occurs, just as in other regions heaps of sand and gravel form the only covering to the solid rocks.

Till or Boulder-Clay:- is usually a firm, tough, tenacious stony clay which sometimes gives us evidence of having been subjected to great pressure. Often of course the clay becomes coarser & sandier, when water can run through it and it loses its consistent toughness. Sometimes the stones in the till are so numerous that hardly any matrix of clay is visible, and on the other hand the stones may be only sparsely scattered through the clay. As a rule it is difficult to say whether the stones or the clay form the larger percentage of the deposit. Generally speaking,however, the stones are more numerous in the hilly districts, and the clayey characters



Diagrammatic section across two upland valleys

ore pronounced in the lower lands.
he stones vary in size from mere grit and pebbles up to blocks everal feet or even yards in diameter; most commonly, however, he smaller stones occur.
he stones are scattered confusedly through the clay, and are not rranged with any reference to their relative specific gravities. They are most invariably of angular and blunted subangular shapes, and usually exhibit smoothed, polished and strated surfaces.
The Till is sometimes quite local in character, that is to say in districts where sandstones occur most abundantly, the stones in the clay consist almost entirely of sandstone; and similarly in regions where volcanic rock occur the overlying till is invariably crowded with fragments of the same.
Not only the stones however, but also the colour and texture of the clay are influenced by the character of the rocks in whose neighbourhood the till occurs. Thus in a red sandstone district the till is red and sandy, and in a coal and black shale district it is of a dark dingy grey or blue colour, and usually very tough.
The Till lies thickest in the lower lands, as it approaches the hills it becomes thinner and more interrupted.
In upland areas too the Till is often found in the form of terraces sloping gradually with the inclination of the valley. Through the terrace a stream generally cuts its way, and gradually undermining the Till may finally clear it away altogether. (See Figure opposite)
In the lowland areas the till never takes this terrace form, but is usually found in a series of broad undulations. The ridges thus



c - crag t = till h = hollow left.

'Crag & Tail'

formed are often spoken of as "sowbacks" and "drums" and they run parallel both to one another, and also to the principal valley of the district.

Often where crags stand out from the surrounding rock we find a long fairly thick layer of till on the lee-side of the crag. (see figure)

This phenomena is known as "Crag & Tail".

When the till has been removed from a surface we generally find that this surface is beautifully polished, and is probably marked with those peculiar scratches or striae that are so often found on the stones of the till. This is found more especially if the underlying rock is hard & fine grained. The direction of these striae usually is the same as the direction of the main valleys. In the uplands where the drift is found too we find that the hills viewed down the valley present a more or less rounded and flowing outline. On the other hand, viewed up the valley, this rounded appearance disappears, and we get the usual irregular crags and projecting rock masses.

On the slopes of many valleys we find large boulders perched. These boulders may consist of the same rocks as the rocks of the valley, but often they are quite foreign to the district in which they are found.

Thus on the slopes of the Jura mountains, which are made up of limestone, we find blocks of crystalline rocks from the Alps. These boulders are known as "Erratics" or [when isolated on high points as] "Perched Blocks". [not synonymous]

What we may call the upper part of the drift consists of plains of sand and gravel stretching out for a great distance, generally at the lower end of a valley. Too, across the plain at the bottom of a valley we may have a cresentic ridge of coarse rock material. The rocks in this ridge are of different sizes, and generally quite angular.

Lying along the slopes of the valley also we may have a line of similar irregular rocks. These ridges are known as "Moraines".

Theories of the Formation of the Drift.

It is evident, at the outset, that in point of geological age the drift is more recent than any of the underlying rock formations. Further it is evident that it has been formed from the lower rocks by some powerful mechanical agent.

By the older geologists it was first supposed to be due to Noah's Flood, and so was called the Diluvium as opposed to the Alluvium. It is found to occur in England only north of the Thames, and the Seine in France. The Diluvium view however was cast aside, and Lyell & Murchison brought forward the idea that it was laid down by the agency of the sea.

Opposed to this view were geologists who held that the Universal mantle of boulder clay with its included erratics and polished ground floor could only have been laid down by ice-sheets or glaciers.

As already pointed out the first man to really develop this idea was one of the Swiss Geologists named Agassiz, who had already discovered that Switzerland had once been wholly buried below a continuous sheet of ice which had scratched and polished the floor, had laid down the boulder clay of that district, and had carried huge erratics from the Alps to the Jura mountains.

Another suggestion that was made was that the deposits were due to Icebergs during a period of submergence. It had long been noticed that in the drift there were many marine shells whose presence it was difficult to account for. Of course their presence was quite natural if the drift was laid down by icebergs in a period of submergence.

The Norwegian geologists found that their country was similarly covered with drift and sometimes containing shells. They found however that ice had radiated from the centre of their country in all directions, as shown by striations, and by the positions of the boulders, and from this they drew up the Scandinavian Theory, namely, that 'A great ice sheet having its centre in Scandinavia had stretched out all across Europe, including Britain'.

Now there can only be two suggestions in this glacial theory to provide for the presence of the marine shells, namely:-

1. That they have been scraped up by the glacier from the sea-bed and carried along with the rest of the detritus and laid down with it. or

2. That there have been a series of glacial periods with interglacial submergent periods.

This too introduces another point of interest, and has led to the formation of two bodies of glacial theorists, namely:-

a. The multi-glacial or Inter glacial School.

b. The Uni-glacial School.

The Geologists of this school, impressed by the evidences of the existence of old land surfaces containing relics of temperate life and lying between layers of boulder clay believed that the Ice-Age was broken up into periods of alternate glacial & genial conditions They said that in the interglacial periods the ice-sheet disappeared from the land, and was replaced by rich vegetation.

This body of geologists was most impressed by the similarity of the layers of the glacial deposits, and so ignored the intermediate vegetable bearing layers.

The former school was supported by the astronomical work of Dr Croll who referred the Glacial Age to an extended period of eccentricity of the earth's orbit.

The views of the former school too have been supported considerably by the most recent work, especially by that of Penck & Brickner on the glacial gravels of Bavaria, where they have recognised 4 glacial periods and 4 interglacial periods represented by denudation layers.

Origin of The Till.

From what we now know of glaciers and glacier action we cannot fail to come to the conclusion that the Till has been formed in some way by land ice. In addition we may look where we like but we shall not be able to find any other agency which will account for the striations occuring on the stones of the boulder clay.

The boulders and stones of the Till undoubtedly owe not only their striations but also their shape to the action of the ice.

At first we might be tempted to look upon the drift as old terminal moraines, but by comparing the Till with terminal morraines of the present day we find that they are almost entirely different from one another.

Each boulder-clay stone gives evidence of having been subjected to a grinding process. Each fragment has been firmly held in the bottom of a glacier and grated along with the rocky surface underneath as the ice moved forward.

The stones naturally get arranged in the line of least resistance, and so we find that the most distinct striae are along, or parallel, to the longest axis of the stone. Often the stones will be forced over and compelled to change their positions, and in so doing their sharper edges are worn down.

We find all these characters in the stones of the Till.

We look in vain however amongst the glaciers of the Alps for a deposit similar to the Till, so we are forced to believe that the Till was not formed like any of the present day deposits of the glaciers of the Alps.

If we reconsider our Till we remember that the floor below the Till, just like the stones, is covered with striae, which usually runs in one direction, but occasionally we get a cross-hatching due to two or three series crossing. But scratched and polished rock surfaces do not only occur in till-covered districts, but they are met with everywhere at all levels throughout the country, from the sea coast up to the tops of some of the higher mountains.

From this and more detailed evidence, which I do not propose to enter into here, we are forced to believe that all the country where these striations occurs was at some very distant time covered r buried beneath one immence ice sheet through which only the ighest mountain tops peered.

he striations or scratches are found from sea-level up to a eight of 3.500 feet at least, so that at any rate the ice must ave covered the country up to that height.

t is not surprising therefore that such a mass gliding down to the sea during a very long period should leave such striations.

As the ice moved on it would crush and grind the stones on the underlying rocks. In this action much fine mud would be formed which would get mixed up with the stones and form a stony clay.

The subglacial streams would carry only a very small proportion of this fine mud away, so that both mud and stone would tend to collect under the ice.

As the great mass of ice moved on it would press down with so great a weight that the mud and stones would be compacted and dragged forward so as to become a confused mixture of clay and stone with here and there traces of water action in the form of gravel, earthy sand, and clay, which is essentially the constitution of the Till or boulder clay.

Such then would appear to be the origin of that remarkable deposit known as the Till or boulder-clay. It is what is now known as the ground moraine, or 'moraine profonde' of the old ice-sheet.

From this it must not be assumed that the Till gathered equally underneath every portion of the ice-sheet. On the other hand it would be found that wherever the slope of the ground caused the ice to flow more quickly the clay and stones would not readily collect, but on flat lands where the rate of flow of the ice would be slow they would tend to accumulate. That is to say the deposition of the Till would be regulated by the varying pressure and erosive action of the ice above.

We have previously mentioned a phenomenon to which we gave the name crag & tail. This formation can best be explained by comparing it with a large stone in the bed of a stream. We know that as the stream rushes on to the stone it causes turmoil in fromt of the stone, and digs out a hollow which extends round the stone for a short way on either side. On the other side of the stone however silt and stone speedily accumulate, until a lomg sloping tail is formed stretching away from the stone as far as the quiet water extends.

In the case of the crag & tail we get a similar action, but our stone is replaced by a large jutting crag in a broad valley, and our water stream is replaced by a deep current of land-ice. From the formation of the crag & tail then we can easily find the direction in which the old ice flow took place.

The next point to deal with is the formation of the moraines on the sides of the valleys, and also the positions of the erratics. We know that as a glacier moves along down a valley itx collects on its sides much disintegrated rock from the valley sides. This is carried forward with the glacier until the glacier melts, when it becomes deposited & forms a ridge which is known as a terminal moraine.

But now suppose the glacier begins to recede up the valley. As it does so it is bound to drop all the angular materials lying on its edges. This then is dropped on the slopes of the valley, and forms the line or ridge of angular blocks which has been mentioned before. The erratics have undoubtedly been deposited in a very similar manner. Huge blocks are often carried down long distances by land-ice, but as the ice began to disappear hills began to rise through it like islands in the sea, and just as the sea when retreating drops some of its burden on the coast, so the glacier or ice sheet dropped these huge boulders on the sides of the hills. When the ice has completely disappeared we find the boulders often high up on the mountain side.

Often these blocks have been brought great distances, and as a general rule we find that they have been brought from higher to lower levels. There are however exceptions to this where we find blocks which have been elevated in their journey. How this has occured is an open question, but it may be that after being introduced into the bottom of the glacier by friction they are forced up to the top by the action of the frontal resistance which will be explained later.

Besides the glacial deposits already referred to we have what are known as glacial sediments. These are deposits made by streams while yet confined by glacial ice and from some distance after escaping from its borders.

These sediments differ from the deposits in that their sand and pebbles are usually rounded, and by their more or less perfect stratification.

We will consider one or two of these sediments:-

OSARS. This is the name given to long gently curving and sometimes tortuous ridges trending with the direction of the former ice movement and generally composed of water worn sand and gravels. They vary in height from about 50 - 150 feet, and are often many miles in length. Where their internal structure is exposed it is found to be fairly well defined cross-bedding. They are believed to have been formed by streams flowing in channels beneath the ice sheets. Occasionally we find angular boulders resting on them, in which case they have been deposited when the ice melted, in a similar way to those on the Drumlins or Sewbacks already referred to.

KAMES. These are accumulations of water worn sand and gravel deposited in the form of irregular hills and knolls with undrained basins between. They differ from Osars only in their irregular shape with basins between instead of long winding ridges.
They are believed to owe their origin to glacial drainage, and to have been formed by the deposition of gravel and sand in cavities beneath the ice.

Sand & Gravel Plains. About the margins of regions formerly covered by ice-sheets and associated with Osars & Kames there are often broad plains of irregularly stratified sand and gravel.
They have been deposited by glacial streams on expanding when leaving the ice sheet.
These plains of sand and gravel are the most important of the glacial sediments, and much work is at present being done on them.

Typical Glacier of the Present Day.

The life of a glacier usually begins when a mountain summit passes above the points where the mean annual temperature is 32° F. /The snow line is not an isotherm/ The snow line is not an isotherm

Above the line joining these points, i.e. the snow line, the winter's snow is not completely melted during the summer, and so it accumulates from year to year. If the mountain has an irregular surface the snow is usually blown from the peaks and accumulates in the depressions. The snow towards the bottom becomes consolidated by pressure. Water is formed by surface melting, it percolates through and becomes frozen. Ice is thus formed in the lower layers, and we get what is known as a "Névé" formed. By surface thawing by day and freezing by night we get thin crusts of ice formed which become buried by the next downfall of snow and remain as a well defined strata in the névé. These layers too are often intensified by the dust blown on to them when they are at the surface. If we examine a névé we find that it moves slowly downwards more rapidly in the middle than the edges, and more rapidly nearer the bottom than at the surface.

As the névé increases in thickness, the motion of the deeper layers becomes greater, and at length a tongue of solid ice comes out from beneath its lower margin.

The glacier advances more rapidly in the summer than in the winter. Each summer the flow buries the portion left from the previous summer, so that morainic deposits left on the surface one summer become buried during the next summer and are added to the ground moraine. Into this glacier we see other streams of ice, decending tributary valley, enter, from either side of the valley rock masses, often covered with the snow in the higher regions, fall on to the sides of the glacier. Much of this morainal material becomes incloded in the snow and ice, but when the matrix in which it lies melts it becomes concentrated at the surface.

The glaciers advancing down lateral valleys , and joining one central one, do not unite and mix as do the waters of tributary streams. On the contrary they flow on with some slight change of form side by side. This is well shown by the moraines.

From the end of any young glacier we find a stream issuing which is heavily charged with silt & mud, while the streams it joins lower down, and which do not proceed from glaciers, are clear. Evidently the glaciers are wearing away the rocks over which they move, and the streams are carrying away the ground up products.

When the glacier receives the supply from the lateral ice streams it increases greatly in size and we may say that it has now passed from its stage of youth to that of maturity. It fills the valleys from side to side, and stretches for many miles from its original source. This vast river of ice has a depth of a thousand feet or more, and a breadth of perhaps one, two or three miles.

It is easy to distinguish between the clear white névé whose surface is renewed each year by fresh falls of snow and the black dirt-stained ice of the glacier proper where morainic material is concentrated at the surface.

The glacier continues to advance century after century, and increases in thickness particularly towards ~~its~~ the snow line terminus. This increase in thickness is due partly to the decrease in the gradient, and partly to an increase in the load of débris it carries. Each of these changes increases the friction of flow, but, as the flow of ice from above is continuous the lower and more sluggish portions must increase in thickness.

As our glacier comes to the mouth of lateral valleys it may act as a dam and stop up streams of water which are flowing down the valley. In this way lakes are formed . The accumulated water may escape over the surface of the ice, but more frequently it disappears beneath the ice, and finds its way downwards through sub - or en - glacial tunnels.

We find by closely watching the basins of these marginal lakes, as they are called, that the deposits of sand and clay are formed in them. Important deposits thus originate, and may remain as a part of the geological record after the glacier has disappeared.

We may reach a point in the course of our glacier where the land slopes very rapidly, and is probably very rugged and broken. Here the glacier will become very broken and falls in detached masses, forming what is known as an ice cascade. By this falling much of the débris on the surface of the ice becomes engulfed in crevasses, but some will escape these pitfalls and still darkens the surface. Too, much of what was engulfed soon returns to the surface because of the melting of the ice.

The surface of the glacier throughout its lower course is very dark with débris. The medial moraines, so prominent in its middle course, become less well defined and less definitely separated one from another. This is due chiefly to the more rapid cooling of the clear ice, for the rocks protect the ice below and soon are left on a ridge of ice. This ridge breaks down and the rock rolls away from its old position to another where the previous action is repeated..

Finally the valley of the glacier is left and the ice invades the plain below. It may continue as a stream of ice whose banks are formed by the lateral moraine material dropped from its sides, or it may expand and form a semi-circular terminus in which a constantly increasing area of surface is exposed to the sun and rain. In its motion over the plain it will sweep out of its path, or cover, all that lies in its way. It will mow a forest down as easily as a field of grass is cut down by a scythe. The streams that escape from the ice build up alluvial deposits about the margin of the ice.

At this point a critical moment in the life of the glaciers has arrived. Will it have strength to resist the increased warmth of the region it has invaded and continue to advance, or must it stop because the annual melting balances the flow of the ice from higher regions. The terminus of the glacier seemingly remains stationary for a time, but in reality is seldom at the same line for many successive years..

After a time, the glacier having passed its period of strength, it begins to retreat. The stones and dirt previously held in the ice becomes more rapidly concentrated at the surface, and clear ice is only seen in the crevasses. Vegetation springs up on the débris covering the stagnant ice,and a forest even may spring up on the débris of the ice which is itself resting on the relics of a forest.

While these changes are going on at the extremity since the supply of fresh ice is diminishing from above, the ice no longer fills the valley so deeply as before. The mountain slopes rising above its borders are either bare or covered with débris left standing as the current subsided. Thus the former height of the ice is marked on each side of the valley by a lateral moraine. The rate of retreat of the glaciers is by no means uniform. It may remain stationery for many years, so that the débris is concentrated at its extremity. When the glacier is again forced to retreat this accumulation of waste material is dropped and forms an embankment across the valley. This embankment is concave to the valley. Several such crescentic piles may be left by the retreating glacier, and these form dams above which the drainage of the valley is so retarded that lakes are formed but they are soon drained.

As the ice retreats too we get other lakes formed in rock basins where morainic material is entirely absent. These rock basins have been formed solely by the abrasion of the rocks by the glacier. Generally these rock basins are formed at the bottom of steep slopes.

The last stages in the decline and death of a glacier are generally very slow. The blue ice visible below the margin of the white névé contracts more and more until finally it is concealed completely by a covering of snow.

It would be as well here to give an account of a typical ice-sheet, and for this purpose I propose to describe that of Greenland. From the most reliable sources it is estimated that the area of Greenland is approximately 750,000 square miles, of which 600,000 are covered by ice and snow.

During more recent years it has been proved by explorers to be covered completely by a featureless mantle of snow. So deep is the snow on the central part that not a single mountain stands out from this monotonous plain.

The snow is highest, and probably deepest, in the central area, and decends towards the coast, giving the island a convex surface. A few mountains stand out from the surface nearer the coast, that is about 50 to 70 miles from the sea. These risings like dark islands in a white sea are known as Nunataks.

No life of any kind, animal or plant, is found on this desolate plain. The snow and ice are nevertheless continually being renewed. They flow away towards the sea from the centre just as they flow in the Alps. Fast as the snows deepen and harden into ice in the centre, that ice creeps away to the coast forming innumerable glaciers which pour themselves into the fiords. One of the grandest of these tongues of ice is the Hümbolt glacier which forms a wall of ice 40 miles long and from 200 to 300 feet above the sea.

Only a narrow strip of land along the coast line is left uncovered by the snow-field and ice-sheet - all the rest is snow and ice.

It is very difficult to estimate the depth of the ice since the land surface in all probability varies greatly. In the central part where the covering is probably deepest it has been ~~been~~ judged as being about 8000 feet.

Under these circumstances we can only partly imagine the eroding power of this ice sheet, and as Dr Nansen pointed out the buried valleys of Greenland are undoubtedly being widened and deepened by the grinding of the ice-sheet, or the ice streams that are making their way to the sea.

Most of the glaciers from the central ice sheet go right down to the Ocean, one or two however stop short and give rise to rivers. Here it may be remarked that the fine sediment washed out from the bottoms of glaciers by subglacial water discolours the sea for large distances.

The glaciers often push their way along the sea bottom for considerable distances down the fiords, but finally they are broken up and ice-bergs are formed.

By the advance of the glacier into the fiord much sub-morainic material is dropped opposite to and underneath the ice front. It has been noted by explorers that very little material is carried down in the glacier itself, as is the case of Alpine Glaciers. Thus really very little material can be carried away by ice-bergs.

In general appearance the glaciers of Greenland do not differ, save in size, and their comparatively rapid motion, from those of other countries.

In summer the artic glaciers are traversed by streamlets and large rivers. Also beneath the ice large rivers flow, sending up through the crevasses large clouds of mist. The whole by which a river decends to the bottom of the ice is often bored by the river itself. Nansen however says that right in the centre, so small is the surface-melting of the ice, that no streams are met with there.

The surface of the great ice sheet is practically destitute of any morainic material on its surface. There are no hills exposed from which by weathering rocks can be broken off to form the moraine. There are only occasional nunataks standing out from the surface, and the weathered material from these are practically nil compared with the large surface of snow and ice exposed. Lower down, as the glaciers enter the wide fiords they may get a narrow layer of moramic material on their flanks, but the whole of the middle parts will remain as pure as above.

Underneath however we get the same grinding action as goes on in the case of the small Alpine Glaciers. Rough crags and bosses of rock are smoothed whilst even the mountain tops are rounded off and dressed and heaps of striated & polished stones will accumulate and be dragged on underneath by the larger subglacial rivers which slowly make their way down to the sea.

Thus then in Greenland we get these ground-moraines occuring. When the glaciers push themselves down the fiords to the sea, large masses become broken off. These masses that are broken off and float away are known as icebergs.

Those that are formed from glaciers which enter the sea by narrow fiords and inlets are usually of irregular shape.

However where the great inland ice-sheet of Greenland comes at a gentle angle to the coast, the icebergs formed are more or less cubical in form, and are known as floe-bergs.

These have a remarkable stratified structure, consisting of thin layers of snow and ice, with here and there very thick layers of clear ice between. This structure of course is similar to that of the Alpine Glaciers.

Ice-bergs must carry away in their lower parts portions of included moraine, but the amount of material transported in this way is relatively very small.

Occasionally ice-bergs may run aground. As a general rule when this happens however their progress is immediately stopped, until by gradual melting, or by breaking up into small pieces, they are again floated off and swept on by the currents.

Now and then, however, a berg may be propelled by the tide up a gentle sloping beach, but only to a very small distance. Of course by the force of the tide a berg may be driven into a mass of soft mud or sand, or may pound up any hard rock mass against which it is driven.

Although many careful observations have been made on rocks, yet nothing has been observed to show us that parallel markings like those made by glaciers have ever been made by ice-bergs.

Chapter ii.

The GLACIOLOGY of the British Isles.

GLACIOLOGY

of

SCOTLAND.

Throughout the whole of Scotland the rocky regions exhibit the peculiar rounded and moulded outline which, as was pointed out in Chapter 1., is characteristic of ice-action. This is especially well seen on the slopes which rise from the central lowlands. Wherever, too, the smoothed surfaces of the rock have been protected from atmospheric influences, they exhibit the striations and groovings left by the passage of ice-borne stones. Such striated surfaces occur not only on the summits and flanks of lofty mountains but also along the shores of the lochs and firths, and are often seen to pass beneath the level of the sea.

Covering the whole of the rocks of Scotland too we find, layers of till or more recent glacial deposits described in Chapter 1. Of course these deposits vary in thickness, being relatively thin on steeply sloping land, and thick on the broad lowland districts. In short the distribution of the till was regulated by the varying pressure and erosive action of the ice.

Thus on every hand we have abundant evidence of a great ice sheet in Scotland.

From the tops of some of the highest mountains down, and even below the present sea-level the country has suffered abrasion. Even the islands which lie off the coast show by striations that they have been at one time traversed by a huge ice-sheet. Thus then the great ice-sheet of Scotland did not remain only on the mainland, but crossed over what now forms the sea bed to the islands beyond.

We get a striking example of this in the case of the Outer Hebrides.

Here we have evidence of ice, having traversed these islands, and which came from Skye and the mainland. This ice sheet was sufficiently deep to fill up the Minch and to cover most of the mountains of these islands. The smaller islands were completely swept over like so many boulders in the bed of a stream.
In like manner the Island of Bute has been smoothed from end to end by an ice stream proceeding from the ~~inland~~ Highlands of Argyleshire. This Scottish ice sheet must have advanced over the bed of the North Sea to join the ice sheet from Norway which came forth at the same time. This united Scoto Scandinavian ice sheet overwhelmed the Orkney and Shetland Islands.
It is due to this and similar great ice sheets that the till has been formed throughout the length of the country.
As we pointed out in chapter 1 there are two series of till which we spoke of as Upper and Lower deposits. When we get a section of rock showing both these deposits as a rule we find them separated by intervening layers of sedimentary materials which vary from very thin to layers many feet or even yards ~~wide~~. thick
These intervening layers are of two classes

1. Marine, containing broken marine shells which too may be striated just as are the stones in the Till.
2. Gravel, sand, clay, silt and peat which are of fresh water origin, and which are associated with till in which no marine organisms occur.

Of these 2 is the more important as a general rule and it is with this class that I want to deal now.
Throughout the extent of the till in Scotland we get places where we find these beds accompanying the till. I do not intend to

enumerate cases of this but I might here quote one instance. Thus at Hailes Quarry two miles west of Edinburgh a good cutting showed the following succession of deposits. Starting xx from the bottom we get

1. The Lower boulder-clay as found in that district, with the usual dark greyish blue colour.
2. Above the boulder-clay came an irregular bed of coarse earthly sand with a few large boulders.
3. A foot to 18 inches of peat, containing fragments of wood, principally birch.
4. Above the peat came 2-4" of sandy clay often crowded with débris and in some places attaining a thickness of five to six feet.
5. A coarse sandy clay charged with boulders and stones.
6. A mass of normal till from a few feet to several yards in thickness, forming the uppermost member of the series.

Similarly Mr John Henderson has described the occurance of a bed of peat with associated deposits of sand and gravel, that lay between two masses of till at Redhall Quarry near Edinburgh. From the peat Mr Henderson obtained the fruit and seeds of upwards of fifty ~~flowering plants~~.

(continued on next page

With the opium-poppy, a weed of cultivation a weed of cultivation

flowering plants, most of which have since been identified. Associated with these are beetle remains and caddis cases.
Again near Beith in Ayrshire a bed of clay resting on and covered by till was observed to be full of roots and stems of the common hazel, which had evidently grown in situ long before the upper till was laid down. These are not unique cases but are common throughout the till covered country, and wherever these aqueous beds occur we find relices of a varied temperate fauna and flora. The aqueons beds intercalated with the till not infrequently, in fact I may say often, lie in the basins or saucer-shaped hollows or depressions.
We have already come to the conclusion that the till has been formed by the action of a great glacier but no one will doubt that the intercalated beds of silt, sand and gravel have had a very different origin. They occur in such layers as could only have been spread out by running water.
It is certain too that these intercalated beds must have been formed at a time when the production of the till must for a time have ceased, and since they are found in almost every part of the country it is reasonable to assume that there were times when the ice-sheets receded and permitted the accumulation in the forsaken regions, of water arranged clay, sand and gravel.
From this line of argument too it follows that after a time the ice returned and covered up the aqueons strata with thick deposits of till again.
When the ice-sheet returned, as we should expect it not only crumpled

but cut through and carried away large portions of these intercalated aqueons beds.

These aqueons beds are in many cases probably of lacustrine origin and we often find them in old river valleys, that is, the old river valleys have been partially filled up by these beds. This is really only what one might expect, for whenever the ice-sheet retired an irregular surface of glacial drift would be exposed in the hollows and depressions of which lakes and pools would gather. In some cases too the mouths of the small lateral valleys would be closed up with detritus,and thus streams being dammed back sheets of water would be formed in which fine sediments would accumulate. In like manner the glaciers themselves might act as barriers to the drainage of small lateral valleys and in this way true glacial lakes would come to exist. Hence we need not be at all surprised that old lacustrine beds occur in the valleys.

In cases where there are no fossil remains in the intercalated beds there must always be some doubt as to whether these were laid down in glacial or interglacial times, that is whether they are subglacial or subaërial accumulations.

More often however where we find the beds crowded with fossil remains there can be no doubt whatever of their interglacial formation.

As the interglacial fresh water deposits occur in places often far apart, it is impossible to be certain that they are geologically of the same age.

It is probable however that they represent the same stage, and they are the relics of the old land-surface which existed before the last advance of the ice.

Here and there we find scattered organic remains but it seems most reasonable to assume that they are relics of interglacial stage, rather than preglacial.

So far then we have only dealt with the fresh water interglacial beds. Besides these we have interglacial beds that are certainly of marine origin. In some places, as at Kilmaurs in Ayrshire we find beds of marine origin closely associated with beds of fresh water origin, which seem to point to the oscillation of the sea level during intergacial periods. In the south of Arran deposits of clay, sand etc, containing such arctic forms as Pecten islandicus, Modiola modiolus, Astarte borealis ets, were discovered to be resting upon and covered by boulder clay.

The shell beds were traced to a height of 200 ft. And many of the forms must have lived in a depth of 10 fathoms, so that at least the submergence must have been about 250ft at the least and probably much more.

Where we get a series containing both intergacial fresh water and marine deposits we may infer I think, that the succession of changes was somewhat like this:-

1. A period of very cold when the country was covered with ice.
2. A period when the ice melted away from the lowlands and when the streams flowed in the valleys, and the climate was temperate enough to support life

such as that of the reindeer and mammoth.

3. A period when the sea gained upon the land th a considerable depth, so that silt and sand containing cold water forms of life were deposited.
4. A period when artic conditions returned and another ice-sheet crept from the mountains and covered up the land again.

So far we have looked upon the till as devoid of all fossil remains. Now in many districts we find the till, especially near the sea coast, crowded with broken or crushed shells.

Thus in Caithness near the east coast we find the till crowded with crushed shells, but as we go to the north-west we get a gradual disapperance of the shells.

The occurence of broken shells in boulder clay has always been a puzzle to geologists.

Now however the generally accepted idea of the appearance of these shells is, that the ice-sheet whose ground morraine formed the till, had travelled over the sea bottom for some way, and in so doing carried in its ground morraine shells from the sea-buttom just as it carries stones on the land.

Thus take the case of the till of Caithness. It is probable that the ice-sheet that laid this down was part of the joined Scoto Scandinavian, which crossed the North-Sea bottom in a north-westerly direction. Thus when it reached the land it would be carrying with it shells which would be laid down after a time in the ground

morraine to form till. This would account for the gradual disapperance of the shells as the till is continued to the north-west i.e. as the ice-sheet gradually dropped its marine ground--stuff and took up terrestrial material in its place.
From an examination then of the stratified deposits that occur intercalated between layers of till on boulder clay, we find that the glacial period was interupted at least once by an epoch of milder conditions at the climax of which Scotland enjoyed a climate not less temperate than the present.

We must turn now shortly to consider some of the deposits with which the till is in parts overlain, thus these deposits include,

1. Åsar or ridges of gravel which coincide in direction with the trend of glaciation, i.e. they follow the path of the ice-sheet.
2. Terraces and irregular ridges and banks of gravel and sand etc, which fringe the slopes of hills that overlook the lowland tracks.
3. Kames of sand and gravel which are typically developed in Lowlands opposite the mouths of mountain valleys and which pass when traced up the valleys into ordinary morainic material.
4. Morainic débris and erratics sprinkled over the tops and slopes of the Lowland heights, but occuring at all levels down to the sea-coast.

It is certain that these deposits belong to the time when, the great Mer de Glace which formed the upper boulder-clay, was wasting away. They are of glacial and fluvio-glacial origin undoubtedly. On looking at the map of Scotland we must be struck by the large number of lakes.

Most of these lakes rest in hollows of solid rock. These lake hollows are what Ramsay has termed rock-basins. He pointed out in addition that these rock basins abound in every region which is known to have been subjected to the grinding action of glaciers. The formation of the rock basins has been explained in this way.

That as the glacier comes down on to a flat plain from a steep incline its velocity becomes suddenly reduced and so it digs down as it were, into the flat plain and scoops out these rock basins, for as the glacier comes down the slope it must exert tremendous pressure on the plain trying to stop its downward progress and so carves out these basins.

In addition to these we find that in practically every fiord round the coast of Scotland we have sub-marine rock basins, exactly the same as those found on the land, but now covered ~~with snow~~ by the sea. These have undoubtedly been formed by ice-actions. As the glacier came into the fiord its width would be diminished and so it would crowd up to a greater thickness and so exert greater pressure on the land below, and thus form a rock basin.

In all probability these valley basins have not been ground out by a general ice-sheet but by local glaciers.

At what stage did these local glaciers appear is the next question which we are forced to ask. These local glaciers may have preceded each great ice-sheet, but if they did it is probable that the basins would have been filled up with morainic material of the mèr de glace which followed, as we find has happened in certain parts of Bavaria which we shall deal with in a later chapter.

On the other hand, it is most probable that they have been carved out by local glaciers after the last general ice-sheet had disappeared. These may have been remnants of the last great ice-sheet, but James Geikie believes that they formed quite a different stage of the glacial period.

These local glaziers always flowed in a direction with the actual inclination of the surface whilst the older ice-sheets flowed in quite different directions, generally with the average slope of the land. Too the roches moutonnées of the local glaciers are fresher or better preserved than those of the ice-sheets.

Now for a short time let us refer to Scandinavia. We know that durin the formation of the Upper boulder-clay the Scottish and Scandinavian ice-sheets joined on the floor of the North-Sea. This Scandinavian ice-sheet reached as far south as Saxony. After the retreat of this, we get a return of milder conditions. Eventuall this intergacial period passed away and we get glacial conditions again. From Scandinavia streamed forth a great mer de glace which was however not so large as the previous one. It flowed as far south as Berlin and the valley of the Elbe and joined in the North-Sea the ice that streamed out from Britian. Underneath this ice-sheet the till of the Elbe Valley and low grounds of Britian were accumulated.

Again these glacial conditions disappeared and we get interglacial deposits found round the Baltic coast and again another ice-sheet formed whose ground moraine covered these Baltic interglacial depos deposits. This later ice-sheet was by no means so extensive as the previous ones and in fact did not invade the North-Sea.

Now it is with this Baltic ice-sheet that we correlate our local glaciers in Scotland, so that after the laying down of the upper boulder-clay there was an interglacial period and then a renewed

glacial which was represented in Scotland by the local glaciers, but in Scandinavia by this fairly large Baltic glazierz .
So far no beds have been discovered in Britian which are of this last interglacial period, but probably some of the postglacial beds may include some belonging to this epoch.
Besides these deposits already refered to, there are many which are generally put down as postglacial and which J.Geikie calls the younger deposits of Scotland. At any rate these are of later origin than the upper boulder-clay. However I do not propose to deal with them here, but now to simply to sum up shortly what appears to have been the general succession of geological changes from the advent of the Ice Age.
First of all we have the period represented by the Lower Till or Boulder-Clay. In this period the whole of Scotland was probably covered up to a height of about 3.500 feet, so that only the highest mountains peered out from the great ice-sheet. The Scottish ice was confluent with the inland ice of Scandinavia on the bed of the North-Sea. By these united masses the islands of Orkney and Shetland were overflowed. Similarly the Outer Hebrides was covered up by ice coming from the mainland.
Following this was a period of temperate climate, represented by fresh water and marine deposits overlying the lower till.
Submergence followed to a depth of about 500 feet and the temperatu returned to an artic one.
This was a period of renewed glacial conditions. It is represented by the Upper boulder-clay immediately overlying the interglacial

beds of '2'. It is the ground moraine of the second general 'mer de glace' which was probably not quite so extensive as '1'. Representing the gradual wasting away of the ice-sheet of 3 we have the kames and åsars referred to earlier and probably to many large erratics and perched blocks. To this period too may belong a few lacustrine deposits of the Southern Uplands.

. Milder conditions returned during which probably the older alluvium of the Lowlands was laid down. This inference is drawn by comparing the deposits with similar ones on the continent, and which can be proved to be of this period.

Probably a third period of glaciation represented by Terminal and Ground moraines in the mountain districts where they have been produced by district ice-sheets and valley glaciers or local glaciers as we called them earlier. These were probably accompanied by a submergence of the land to about 100feet and which is represented by a few marine clays and arctic fauna.

A period of re-elevation of the land and a gradual return to temperate climate.

A return of colder conditions with perhaps a few valley glaciers which laid down terminal moraines on estuarine deposits and the raised beaches of period '7' probably.

A retreat of the sea with which the climate became more continental and forest growth took place (Represented by a series of upper buried forests, lower buried forests representing '7'.)

. Another submergence to about 25-30feet, colder conditions and format-ions perhaps of a few small valley glaciers in loftiest mountain are-as

Finally the sea retreated and the present conditions supervened.

N O R F O L K   C O A S T

and

E A S T   O F   E N G L A N D.   (Generally)

Norfolk Coast.

We find on examining the low-lying districts of eastern England, that those regions are more or less thickly mantled with superficial accumulations which are often exposed in fine sections along the coast.

The Norfolk Cliffs, at and near Cromer form one of the most interesting localities for the study of these deposits. In 1827 Mr R.C.Taylor brought the Cromer beds to the notice of the English geologists and since that time much literature has been published dealing with them.

Directly below the glacial deposits we have,

2. Leda myalis beds,

1. Forest bed series.

Let us deal with these very shortly

These consist of an upper and lower fresh water bed separated by estuarine beds which are often crowded with drift-wood and the stumps and roots of trees. All the plants found in this series are living species and with very few exceptions are still found in Norfolk. There is an absence of both arctic and south European forms, and in all probability the climate of the Forest bed time was very similar to that of the present day.

. This occurs in interrupted patches in none of which it attains a greater thickness than 20feet.

These Leda myalis beds are of marine origin. There are few fossil and from the character of these it appears as though the differen patches of these beds are of different ages.

Probably the different sections of these Leda-mylais beds are fragments of marine deposits belonging to a period of considerable length during which both the depth of water and climate changed. rior to the period of the Forest-bed group it is probable that the limate was very cold but that later more genial conditions followed n which the Forest-bed was accumulated. Ere long however the emperature again fell as indicated by the arctic molluscs in the eda Myalis beds. After the Leda Myalis there was probably an increase of coldness if I may so put it and we get deposited a series of boulder-clays with sands and gravels.

The succession is as follows, according to J.Geikie.

Should explain Reid and Harmer

7. Boulder-gravels and sands; unfossiliferous,
6. Sands and loams, containing shell fragments and a few perfect shells.
5. Boulder-clay or stony loam, usually highly contorted, about 30feet thick and contains fragments of shells.
4. Fine sands, false-bedded, unfossiliferous: reaching in places 40feet in thickness.
3. Till or boulder-clay, containing much chalk.
2. Intermediate beds: clays and marls, well laminated and ripple -marked, with seams of fine false bedded sands: unfossiliferous.
1. Till or boulder-clay, with many broken, crushed and striated marine shells.

First of all let us take the Till deposits 1 and 3. They are undoubtedly ground moraines of a great ice-sheet.

Occasionally we find that there is a kind of lamination throughout them but which is probably not due to any aqueons agency but due more likely to a shearing force of the ice pressing down on the matter below. On the other hand the intercalated beds 2 and 4. are probably of subglacial origin and have been laminated by water under the ice-sheet. In addition as already remarked '2' is traversed often by ripple-marks and false bedding. It may be argued that these intermediate layers are marine in origin but I think this is doubtful as they are quite unfossiliferous.

Leaving '5' for a minute, and turning to the sands and loams of '6'. They are similar to 2 and 4. and are probably sub-glacial in origin. But you may say, they contain shell fragments and even a few perfect shells. These however I think are probably derivative, having been brought up from the sea-bottom by the ice-sheet.

Now far and away the most interesting part of the series is the boulder-clay or strong loam represented by '5' and which also contains shell fragments.

In the first place this deposit of boulder-clay or strong loam differs from all the other drift deposits in that it is very highly contorted.

Again too, in many places we find large boulders of chalk up to 180 yards long, and which have apparently been derived from the Cretaceous deposits of the districts.

There has been much discussion as to the origin of these beds with their immense chalk boulders. The till itself does not differ much from those underlying it, at any rate as far as its composition is concerned, except that it contains shells which however as we said with regard to those in '6' , ~~they~~ are probably derivative.

In the lower parts, Mr T.M.Reade says, the Cromer till (19) is in places stratified. Below it often passes down directly into semistratified beds. Upwards we get the contorted drift separated by a distinct line of erosion.

The contorted drift is a confused folded up mass of sands, gravel and mud which have been somewhat stratified and afterwards bent up in a most renarkable manner.

At first it was supposed that these phenomena of the contorted drift were due to the floating ice and that the contortions were due to the grounding of icebergs.

It was recognised by most Geologists at the outset that the lower till was the ground-moraine of an ice-sheet.

In 1880 C.Reid stated that after having made a most careful study of the district he thought the contortions in the drift were due to the pressure of an ice-sheet. He attributes the drift to the great ice-sheet which came in a south-westerly direction from the confluent ice-streams of Scotland and Scandinavia. This is substantiated by the presence of erratics of Norwegian rocks found in the drift, and by the strike of the larger folds in the drift which indicate a force acting from the north-east.

Now to turn to the included chalk masses which are as a general rule very irregular in shape. They have by various observers been attributed to,

1. Diluvial currents

2. Icebergs

3. Land-ice either as a glacier or ice-sheet.

Of these the last is the most generally accepted idea. Mr C.Reid points out that most of them need only have been carried a few yards, at most about 100 yard for they are all found in districts where solid chalk is at a sufficiently high level, to be acted on by the ground moraine. He further goes on to suggest that the chalk was at first forced into folds by the ice-sheet, that these folds were gradually bent over in the direction of flow and finally the tops was sheared off and the detached masses forced into the ground moraine.

In the Quart Journal for 1882 Mr T.M.Reade says, that he thinks the masses of chalk are detritus material, from the sea cliffs, and which became frozen into the shore-ice. This combining with the ice-floes would form a raft sufficiently strong to float these boulders. Thus when summer came and the ice-sheet broke up, the incline of the shore aided by the rise and fall of the tides would be equal to launching into the sea, the entire raft and so the chalk rocks would be transported.

To me this seems rather an extravagant idea and quite unnecessary to explain their transport and when we realise the immense power of an ice-sheet I think that Mr C.Reid's theory is the more acceptable one. Now if we exanine the sands and loams of '6' we find that they share the contortations of the drift (5) and therefore must be of the same date, and it is probable that all these Pleistocene formations (1-7) exposed in the Cromer Cliffs are of glacial and subglacial origin and belong to one and the same epoch of glaciation. Overlaying 5 and 6 we have what we have called Boulder-gravels and sand (7). This series however may be better divided up into the two

(2 Plateau Gravels.
(1 Chalky Boulder-Clay

In this district.

The Chalky Boulder-Clay is a stiff bluish gray clay, containing an abundance of ground up chalk and striated chalk stones, together with flints and a variety of other rocks.

It takes its clayey material probably from the underlying Lias, Oxford and Kimmeridge clays and occasionally we find specimens of the Lincolnshire oolites in its mass. Sometimes too we find derived fossils but this is very uncommon.

This series extends over a very large area. Thus we find it in Lincolnshire South-Norfolk, Suffolk, Essex, Cambridge, Herts and Middlesex. Over this area it maintains a fairly uniform character. In this series too we get the remarkable phenomena already referred to in this essay (Chapter 1.) of pebbles which have been carried to a much higher level than their source.

This series varies much in thickness, from a few feet up to 100 or 150 feet. Its base line is very irregular and often forms valley-like troughs filled with clay.

Plateau Gravel This is the last and highest glacial deposit in this district. It consists of a flint gravel which forms isolated plateaux.

It consists mainly of large rolled and battered flints with pebbles of quartz, quartzite, granite etc,

It varies in thickness from about 20 to 40feet and generally rests on the upper boulder-clay and never on the underlying chalk formations. Harmer shows by study of matrix the course of the C.B.C. ice to have been in Norfolk due W -> E

Harmer shows by study of matrix the course of the C.B.C. ice to have been in Norfolk due W -> E

Lincolnshire and Yorkshire.

Although much has been written upon the glacial deposits of Lincolnshire And Yorkshire there still appears to be much difficulty in fixing the relative ages of the deposits which occur on the eastern and western sides of the Chalk Wolds. The boulder-clays which occur on each side are quite different and of course the difficulty arises because the two are nowhere found in apposition.

First of all it will be best to give a short general description of the deposits found on either side of the Wolds.

The Western Type In Lincolnshire

The boulder-clays which is found on the west of the Wolds is identical with that Chalky Boulder-Clay which has been described as occuring in Norfolk and Suffolk, and extending through the Eastern Midlands. This chalky boulder-clay can be followed throu Cambridgeshire, Huntingdon, Northampton and Rutland into South Lincolnshire, and it has apparently formed a continuous sheet over this country.

The boulder-clay between Stamford and Grantham is remarkable for the huge blocks of Lias Marlstone and Limestone which it contains, and which must have been carried many miles from the west and north-west.

In addition to these blocks there are some such as the chalk boulders which have come form the north-east

It seems therefore probable that several ice-sheets or at least

two have met in this area.
This same boulder-clay appears also in the central parts of Lincolnshire spreading over the Jurassic clays east of Lincoln Again it is continued just to the south of Yorkshire and there disappears but it is probable that the gray boulder-clay found in the Vale of York is of the same sheet.

The Eastern Type.

To the east of the Wolds we get a boulder-clay which is generally of a purplish or reddish brown colour, This boulder-clay extends from the east side of the Wolds to the coast in Lincolnshire and in Yorkshire the corresponding area ~~and~~ which is known as Holderness. Although generally found at low levels in Lincolnshire we find it up to a height of 380feet on the slopes of the Wolds and to a height of 440feet on the Chalk of ~~the~~ Holderness.
In Loncolnshire the basement beds are not exposed. the clays which are visible are of two kinds.

2. An upper clay of a dull red colour, mottled with ashen gray, containing many small stones, bits of chalk and coal but few large boulders. This is known as the Hessle Clay.

1. A lower purplish brown clay, containing both small and large boulders.

   This is known as the Purple Clay.

Associated with these clays we get near the border of the Wolds patches of sand and gravel and at one place we find a bed of undisturbed marine silt. Both of these contain marine shells. In the case of the shells found in the sand and gravel most of them are broken but a few are found whole.

In Holderness the sea has cut back into the Glacial deposits and so we get good sections exposed. The deposits vary from 60 to 100feet in thickness and the succession has been worked out as follows:-

5. The Sewerby Gravels.
4. The Hessle Boulder-Clay.
3. The Purple Boulder-Clay
2. The Basement Boulder-clay.
1. Chalky gravels and buried cliff beds.

(Jukes Browne's)

ought to quote Lamplugh.

The chalky gravels appear to form a nearly contiouos basal bed but the buried cliff beds are only seen at Sewerby. & Hessle

These clays with their associated sands and gravels are banked up against what appear to be an old coast-line which in places presents the form of a buried line of cliffs.

The Basement Clay is of a greenish gray colour. It is nowhere very thick but varies up to 30feet. It includes layers of sand which contain marine shells.

(It must be very much thicker near Hornsea)

4 The Purple and Hessle Boulder-clays have the same characters as in Lincolnshire. The commonest stones have been derived from the Carboniferous rocks to the northward, but some have come from the Cheviot Hills, Others from Teesdale and Cumberland while a few are identical with rocks in the south and west of Norway.

Much important research work has been dome in this area by Mr Lamplugh and the Geological survey.

t is Mr Lamplugh's idea that the basement clay together with the purple clay and associated sands and gravels form the deposits of only one epoch of glaciation. The basement clay was in all probability laid down whilst the North-Sea was covered by an ice-sheet coming from Scandinavia. This is borne out by the presence in the ground moraine of parts of the sea-floor with its artic fauna which have been ploughed up by the ice as it approached the land or by the presence of erratics of Scandinavian rocks. Also we find that there are ~~few~~ many erratics of British rocks in the basement bed. Thus in all probability this great Scandinavian ice-sheet kept back the smaller British ice-sheets from reaching the coast. However when the great ice-sheet began to retreat towards the continent again the ice-sheets from the centre of England advanced to take its place and it was probably during this period that the purple clay was laid down.

This is borne out by the fact that whilst practically no British erratics appeared in the Basement clay yet in the Purple clay they are ~~fairly conspicuous.~~ very abundant.

After a time it is probable that even these English glaciers retreate and we get an epoch during which the climate was milder and there was a submergence of about 100feet.

This is borne out by the mammalian fauna which occurs in a series of gravels at Kelsea Hill and Hessle Cliffs, which underlie the uppermost (Hessle) boulder-clay. The age of these deposits however is open to question and so we cannot be sure of the changes that followed the laying down of the Purple-Clay.

Following this we come to the upper or Hessle boulder-clay, which is undoubtedly of glacial origin and in all probability represents the return of a great ice-sheet in the North-Sea.

This Mr Lamplugh says, can be deduced from the fact that the erratics brought down from the highlands of central England, came near the coast and were then carried southward i.e. the British ice-sheets were unable to reach the sea, being barred by the Scandinavian ice-sheets and so were forced to flow southward down the coast.

THE WESTERN CENTRE OF ENGLAND AND WALES.

The glacial deposits of the West of England and North Wales, can be divided into two groups.

An older set of tough blue boulder-clays and coarse gravels which however only occur in the neighbourhood of mountains.

A newer set of red and brown boulder-clays with interclated beds of sand. these beds resemble the Holderness beds of the East and Mr Reade has called them the "Low-level boulder-clays".

Number 1. in all its essential characters resembles the till of the Scottish Lowlands. It is quite unstratified and here and ther it contains beds of sand and gravel, I have called it a blue clay but its colour varies considerably with the nature of the underlying rocks. Its included boulders are essentially shaped by ice action and there is little doubt that this is an old ground moraine. In addition too, we often find it lying directly on a smoothed and striated pavement of rock.

In Lancashire and Cheshire up to a height of 150feet (about) this lower boulder-clay contains shells and shell fragments but they are undoubtedly derivative.

The relationship of these two boulder-clays and their intercalate beds is well shown in the cliffs of Colwyn Bay.

Here the succession is:-

Newer (
- 4. Brown boulder-clay with broken shells and some northern erratics,
- 3. Obliquely stratified sands resting on an eroded surface,

(2. Cream coloured till in discontinuous patches,
(
Older. (1. Hard bluish gray till packed full of stones derived
(
(from Carb and Silurian rocks of Wales.

Between the Upper and Lower or Newer and Older boulder-clays we have a series of aqueous deposits which vary greatly in thickness This series consists generally of sands and gravel with perhaps a few clays.

MrJ.D.Kendall found in North Lancashire (Furness district) that between the upper and lower boulder-clays there occurs a bed of vegatable matter which varies from a few feet up to 8 yards in thickness.

Many geologists have upheld the idea that these boulder-clays are of marine origin. This is of course chiefly due to the shells which they contain and the heights at which they occur.

The glacial origin of the boulder-clays however is now supported by the leading geologists.

It is doubtful too if even the middle sands, as the layer between the upper and lower boulder-clays, is called, is even partly of marine origin. In many places they have quite the appearence of Kames. It is probable that there was a slight submergence of the land after the retreat of the ice-sheet that laid down the lower boulder-clay but to what extent is apparently quite unknown.

Thus in Lancashire and District the series of changes was as follows:-

1. Great ice-sheet from the Irish Sea invaded this

district and laid down lower boulder-clays.

2. Ice-sheet vanishes and land becomes covered with vegetation and mammals (remains found in caves between layers of boulder-clay) occupy land. Thus probably climate fairly temperate.

As the ice-sheet retreated too some of the sands and gravels were probably deposited by the streams from the ice-sheet.

3. Submergence of land ?

4. A second ice-sheet invaded the land and laid down th e upper boulder-clay. It would perhaps be best at this point to Shortly run through what appears to have been the succession of events in this area and the areas affected by the glaciation in this district.

Mr J.Geikie points out that there is abundant evidence in the valleys of the Lake District and North Wales, to show that before the advent of the first great Mer-de-glace in the Irish-Sea, there were local glaciers in these valleys which streamed down and coalesced on the plains below. He says that some of the local moraines of this stage can still be recognised. However as we will show directly the directions of these glaciers were altered on account of the later great ice-sheet which came down from Scotland into the Irish-Sea.

It has been pointed out that North Lancashire, and parts of Yorkshire and Westmorland had been traversed by an ice-sheet

Impossible I think for moraines to survive a general re-advance of which moved to south or south-east. If this was so there must have been a barrier to the west preventing it flowing to the Sea by the most direct course. It is now generally accepted that this deflection was due to the great ice-sheet formed by the joining in the Irish-Sea of ice from Scotland and Ireland. This ice must have filled up the Irish-Sea to a great depth, for we know that it covered up completely the Isle of Man.

Thus then the ice of the Lake District was forced to flow southwards over the lowlands of Lancashire.

Let us return to our great Irish Sea ice-sheet what happened to it when it reached the mountains of North Wales?. Did it over--flow these as it did the Isle of Man?. It is generally realised now by the geologists that it did not, but that it was deflected part going west and south west, and some east and south east. Thus the former part overflowed Anglesea and then continued its course to the south. The latter part probably streamed accross Cheshire and into the Severn Valley. After invading Chester this lobe forced aside the Welsh Glaciers and continued down the Severn Valley into the Bristol Channel. Thus this ice probably extended as far south as the Cotteswolds and Mendips. The eastern ice-sheet reached the Thames Valley by London, but between here and the limit of ice on the west we have no certain evidence of the position reached by the ice, during the lower boulder-clay age. Thus Mr J. Geikie says, "practically the whole country as far south as the Cotteswolds and the Thames Valley was shrouded in ice. Above the surface of which the Yorkshire Moors and the Derbyshire Hills peered as Nunatakkr. The Welsh mountains must also have raised theirr summits above the general level of the ice-sheet.") Geikie is antiquated [illegible] England [illegible] Wales

This great ice-sheet finally retreated and was followed by a much milder climate and this is represented by the interglacial vegetable beds and the glacial gravels of the Midlands.
These sands and gravels of the Midlands are certainly not marine and they are now generally looked upon as having been deposited by the torrential waters coming from the melting ice or by the large lakes that must have beem formed by the damming back of the rivers by the ice-sheet. This, as already pointed out may have been followed by a submergence but certainly to not more than 400feet and it may not have been even as much .
Following this we get the second great invasion of the ice,but not to so large an extent as before. Small glaciers may have appeared in the hilly parts and flowed just as they liked for a time, but they were turned from the sea by a second great ice-sheet in the Irish-Sea. As before this ice-sheet was deflected round North Wales and we get one tongue stretching across Cheshire into Staffordshire where it may have met the glaciers coming from the Pennine Chain.
It wasthe second great ice-sheet that laid down the upper boulder-clay. Overlying this boulder-clay we often find deposits of sand, gravel and clay which were probably laid down by the waters flowing from this ice-sheet as it retreated. In this

retreat too it dropped down erratic boulders. Thus in the Midlands we commonly find erratics of rocks brought from the North Wales district, by that part or tongue of the ice-sheet which came across Cheshire into Staffordshire. Just as we found in Scotland there was evidently a return of glacial conditions after the disappearance of the second great ice-sheet. Ramsay pointed out many years ago that the upper and lower boulder-clays had been ploughed into in North Wales by a series of later glaciers, some of which he says must have been of considerable size.

"The ploughing of this drift he tells us is well seen in the Passes of Nant-Francon and Llanberis and that the large local glacier of Nant Francon, which descended the valley of the Ogwen, deposited the well marked moraines on which Penrhyn Castle stands."

As we thought took place in Scotland, probably took place in North Wales and the Lake District, namely that there was another glacial epoch after the second great ice-sheet.

This epoch was represented by large valley glaciers which left behind them the moraines already referred to in North Wales and the moraines and morainic gravels of the Lake district.

As these later valley glaciers retreated they dropped numerous perched blocks on the mountain sides as we find them in many of the passes of North Wales.

(4) The Cleveland Area.

In treating with the East coast of England generally we touched very shortly on parts of the Yorkshire coast.

I now however intend to briefly refer to certain glacial phenomena, of the Cleveland district, which have in recent years been described in detail by Professor P. F. Kendall in a paper to the Q.J.G.S. for 1902. I dont intend to put forward here any of the details which Kendall refers to in his paper but simply to give some of the wider results of his investigations. Before dealing with these it would probably be best to refer to the ice-sheets that invaded this country. First of all as pointed out before the ice in the lake district being unable to force its way into the Irish Sea, turned in the other direction passed over the Tyne water shed and invaded Northumberland and the Tees valley.

From here it would probably have passed right out to sea but was prevented from doing so by the Scandinavian ice sheet and so it was forced to turn south and passed into the Vale of York. This of course can be traced by its Lake District erratics.

Besides this there was in all probability an ice sheet from the Tweed Valley. This flowed seaward at first but like the former one it was forced to turn south round the end of the Cheviots and flow down by the coast. It may have left the land and entered the sea north of the Tyne mouth but if so it invaded the land again in all probability near Roker and then flowed south again at any rate as far as the Cleveland Hills.

Besides these two of course there was the Scandinavian Ice which has carried Scandinavian Rocks to our coast and even inland as well-marked beaches.

Deltas:- The material deposited by a stream entering a lake and stretching out in a fan-like shape, these deltas too are rarely seen in Cleveland.

Floor deposits, i.e. upon the lake bottom Professor Kendall agrees withCarvill Lewis that the Warp Clays of the Vale of Pickering and the Vale of York are of the lacustrine origin.

Overflow-channels. By this title we mean ~~that~~ the channels by which water blocked up by ice can escape.

It is to these old overflow channels that Professor Kendall turns for much of his evidence of former lakes in Cleveland. He divides these channels into four types

(a) Direct overflows. Those which cut across the main watershed of the country away from the ice.

(b) Severed Spurs. Those which cut across spurs of the main water shed.

(c) Marginal overflows.These are ~~shelves~~ trenches benches cut in the hill sides by the water escaping between the hill side and the ice.

(d) In-and-out channels. These are crescentic shelves or valleys cut in the hill side by water escaping round a labe of ice.

Turn for a moment to the drift itself. The usual three members of this have been recognised namely

3. Upper Boulder-Clay.
2. Middle sands and gravels.
1. Lower Boulder-Clay.

The drift, containing these three forms completely surrounds the Cleveland area and also extends ~~through~~ into the two valleys of Pickering and Eskdale, but otherwise the drift does not enter far into the hilly country. The most elevated drift according to Kendall is found at 867 feet in the Lockwood Hills. Erratics however have been found up to a height of 1000 feet. Leaving this let us turn directly to the Lakes. Of these undoubtedly the most im-portant was Lake Pickering, the lowest lake of the sequence and into which at one time the northern, eastern, southern and central parts of the area drained, leaving only the western part with an independent drainage.

For a description of the valley in which it lies I cannot do better than quote Kendall's own words. He says,

" It is a long faulted synclinal trough of Kimmeridge Clay lying between the dip-slope of the Corallian Series on the north and the chalk escarpment on the south. On the west, it is to a large extent shut in by a much faulted track of Jurassic rocks from the Corallian down to the Lias while on the east, along the strike of Kimmeridge Clay, it opens out into Filey Bay.

As Kendall goes on to point out the natural direction of drainage of this area is to the east but that the eastern end of the valley is occupied by a thick series.

At the western end there are two gaps in the barrier of rock.

Of these two one is the deep narrow gorge of the Derwent which cuts through a depth of from 200 to 225 feet and is undoubtedly a direct lake overflow. The whole drainage of the country south of the Esk enters the Vale of Pickering and passes out through the gorge into the Vale of York instead of passing out to the sea by Filey.

On the floor of the valley is alluvium. The glacial deposits only extend for a short way up the valley.

The phenomena exhibited in this valley is undoubtedly the result of glacial action when the end of the valley was blocked up by an ice-sheet, so that a lake was formed. As already pointed out there are no really well marked beaches although Fox Strangways has recognised one at Hutton Bushel at a level of about 2 00 feet above the sea. This is not a beach but an elongated delta
This is not a beach but an elongated delta.

Of the valleys entering Lake Pickering by far the most interesting is that of Newton Dale which is very deep and passes directly through the water shed. Kendall then points out that it undoubtedly was an overflow from a glacier-dammed lake in the Esk-Dale country, and this would be the natural course ofthings if t he outlet of the Esk were closed. This is borne out by the presence on the north side of the Vale of Pickering of a fan of gravel, that is the detritus brought down the Newton Dale from the valley and the glacial lake above. If the gravels are examined they are found to consist of rocks from Newton Dale. As pointed out above, there must have been a lake or series of lakes on the northern side of the water shed, and this was the case due to the ice damming up Esk Dale to a height of 525 feet, i.e. the height of the outflow.

Kendall points out that at the maximum extension of the ice there was a lake in Esk Dale, 11 miles long and not less than 400 feet deep and he has named this lake Eskdale.

Close to this was Lake Wheeldale into which Lake Eskdale drains. It was about three miles long and about 225 feet deep.

Lake Wheeldale drained into a small lakelet in Eller Beck valley

and which is known as Eller Beck Lake.
In Lake Eskdale there are no well marked beaches. At many places there are small notches but the only ones that seem at all continuous are at a level of about 560 to 575 feet.
Leaving these old lakes of the north of the Cleveland Hills and turning to the west the first valley of importance is that of Scugdale which is the only one to open to the northwards. It is surrounded by hills to a height of about 1000 feet with only one break a'narrow sharply cut notch' which crosses the 1000 foot contour and Kendal says is a lake overflow. Thus in all probability there was a lake here when the valley was quite blocked up by ice. Close by Lake Scugdale there was also a small lakelet which at first probably drained into the valley leading to Osmotherly but that later both lakes were drained by Scarth Nick, a typical overflow. When Scarth Nick was opened Kendall estimates that the level of Lake Scugdale was lowered 200 feet.
Just north of the valley of Scugdale we came to the deep reentrant angle of the escarpment at Ingleby Greenhow. This is marked at the eastern end by a fine overflow channel which probably drained the ice-margin. North of the Ingleby Greenhow angle we come to the Kildale valley facing west. Through this valley runs the river Leven which at the western end has to cut through a moraine. The upper end of the valley too is occupied by drift deposits of sand and gravel in the middle and boulder-clay along the edges. There was undoubtedly a lake in this valley which outflowe into Lake Eskdale but it seems very improbable that there was ever a

reversal of the flow. The flow into Lake Eskdale is substantiated by the presence of deltas where the overflow stream entered.
From Kildale passing north and then east round by Bold Venture there are a series of outflows cutting through the escarpment but none of great importance until we come to the Stonegate Overflow. Here round the invading margin of the ice-sheet a deep overflow channel was formed down the Stonegate Valley. This valley as the ice retreated took the whole of the drainage of this district.
Leaving this district and going to the extreme east of the area we come to Iburndale Valley. This valley opens northwards into Eskdale. The bottom and considerably up the sides of the valley are covered by drift deposits. In the eastern wall of the valley Kendall found a gap near the head and which he says is undoubtedly a lake overflow and so establishes the presence of a lake in this valley.
Coming now to the central tract along the east of the area we have a remarkable series of drainage. For about 3 miles inland the drainage of the country is quite normal, i.e. to the sea, but beyond this distance from the coast we get a series of gorges which carry all the drainage southward through the Vale of Pickering to the Ouse and Humber basins. In this district Kendall found that most of the overflows were marginal. He says that some of the cuttings were through high watersheds, but most of them followed the existing drainage lines I don't propose to go into this eastern area in detail but simply to point out that here as elsewhere there were extramorainic lakes of which perhaps the most important were Harwood Dale Lake and Hackness Lake. These two occur fairly close together and the former drains into

he latter through a deep gorge, and Hackness Lake in turn drains hrough Forge Valley into Lake Pickering near East Ayton.

ut in all probability the Vale of Pickering at this point was locked up by ice for some distance so that the water from Forge 'alley would have to flow along westwards by the side of the ice into .ake Pickering.

As the ice further retreated the waters of Lake Pickering flowed out into the extramorainic Humber Lake and since the Wash was closed the waters from here Kendall suggests flowed across Norfolk and so south to the sea, and he further suggests that the Straits of Dover were brought into existence by the discharge of the overflow waters of the British Extra-Morainic lakes together with a larger series on the Continent.

Chapter iii.

Glaciology of North America.

North America.

First let us get a general idea of the American drift deposits. It is estimated that nearly one half of the total area of North America is covered by drift-deposits. The great size of this area can be better understood perhaps if we express it in figures. It is estimated that the ice in what is known as the Ice Age covered about 4,000,000 square miles. In this estimation of course we are agreeing with those geologists who believe that the drift deposits were laid down by ice-action.

Just as in Britain, so in America, there are those geologists who dissent from this idea. Many of them argue that about one half of this area is covered by drift from glaciers or ice-sheets, and the other half by deposits from sea-borne ice.

However the former view is now the more popular one, and it is borne out by the presence below the deposits of the ice-grooved rock floor..

Most of the deposits are attributed to one huge ice-sheet which Dr Dawson has called the Laurentide Glacier. It is estimated that about 4/5 of the glaciated tracts of North America were occupied by this glacier. Chamberlain says that this great ice-sheet spread over the eastern five-sixths of the Great Dominion of Canada, and enveloped the larger part of sixteen of the Northern States of the Union, and smaller portions of seven others. This he estimates as covering more than 3,000,000 square miles.

In the extreme north the great glacier was bounded on the east by the great Greenland ice-sheet, and on the west by the

Cerdilleran Glaciers, but in all probability these three series were not joined but quite distinct from one another.

It is interesting to note that the North West corner of the Continent, i.e. Alaska, shows no signs of glaciation at the time of the Laurentide glaciers.

It will now probably be best for me to give some account of the limits of the Laurentide Glacier. To do this I think I cannot do better than to quote Chamberlain's own description.

" The great north eastern ice-sheet reached its southermost extention in the State of Illinois where a lobe stretched out on the plains between the Ohio and the Mississippi rivers to within forty miles of their junction, attaining the very low latitude of 37.35'. From this apex of glaciation - this supreme triumph of the ice - the limit of the invasion may be traced north-eastward in a sinuous course along the right-hand slope of the Ohio Valley, swaying northward and southward through a considerable altitude.

In Indiana the drift border, as we now find it, retires well towards the heart of the State but swings quickly back to the Ohio, and crossing it encroaches a little upon Kentucky near Cincinnati. It soon again strikes half way back to Lake Erie and then runs easterly to the Pennsylvania line, where its course is north eastward to western New York. Here at a point 33 miles due south from the foot of Lake Erie the border line trends away in a south - easterly course and runs with somewhat remarkable directness across the Appalachian range, reaching the Atlantic at New York Harbour.

coincided approximately with the present coast line and finally reached the Gulf of St Lawrence where in all probility there was a deep re-entrant angle and then this limit united with the other that we traced north from Long Island.

Let us turn now to ice movements and centres of dispersion. Many ideas have been put forward with regard to both these points but Chamberlain says " Perhaps the most plausible hypothesis at present is that glaciation on the American mainland set in independently in Labrador and in the region north west of Hudson Bay, perhaps in more than one locality, and that these nuclei grew until their borders coalesced, submerging the Hudson Bay region, and at length developing a great arcuate zone of accumulation along the Laurentian uplands from the coast of Labrador all the way round to the Arctic Ocean, embracing at the maximum of glaciation a great reservoir of ice, as Dr Bell has expressed it, in the Hudson basin. It is possible that the ice over this central basin grew to be a central embossment, but there is no evidence that it was ever so dominant as to cause the ice to push eastward over the Labrador plateau ".

Later he adds, " There seems no present ground for believing that the Laurentian uplands between Hudson Bay and Lake Superior were ever gathering grounds of such dominance as to produce a northerly movement of the ice ".

In south-western Wisconsin we find a tract of about 10,000 square miles in the valley of the Mississippi which appears to have never been covered by the ice. All around it we have glacial deposits but this tract seems to have been protected from the general sweep f the ice. This is probably due, not to its own elevation, but o the fact that it lay in the lee of the highlands that lie orth of the area. We find a similar area, formed probably in he same way, between the Illinois and Mississippi rivers, just .bove their junction.

.et us turn now to a study of the drift itself.

Ve find that the series forms sheets as it were which overlap each other in what Chamberlain calls imbricate fashion, that is to say the outermost disappears beneath the next inner, and this in turn beneath the succeeding , and so Chamberlain says of this structure,

" In a general view of the drift it is essential to grasp clearly this conception of the overlapping of the sheets and to distinguish this imbricate structure from the simple stratigraphical superposition of marine sediments on the one hand and of simple morainic corrugations following each other in concentric recessional lines on the other. Theoretically there are at least two of these imbricate series for every period of glaciation and the order of imbrication takes on opposite phases.

During the first part of the glaciation, when the ice on the whole was extending, though by alternate advances and retreats, the later were generally greater than the earlier advances.

During the succeeding stage, however, when the ice was, upon the whole, retiring (though by oscillations) the later advances generally fell short of the earlier. In the case of the older or lower series of glacial accumulations therefore, the later deposits generally reach further south than the earlier ones, whereas, during the recessional stages of glaciation, the earlier sheets extend farther south than the later. These two imbricate series of sheets of contrasted order represent the two great halves of a period of glaciation "

" If with every advance the ice pushed all loose débris in ~~frontxity~~ front of it, imbrication or overlapping would entirely disappear & a series of concentric moraines would be all that would be left "

THE TILL.

This is by far the most important, or I suppose I should say the largest part of the glacial deposits of America. In its general characteristics it is very similar to the European deposits. It forms most uniform and continuous sheets over the Ameriuan plains, and these sheets are estimated from 26-60 feet in average thickness, but this dimension varies very greatly, for it is known to reach a thickness of 500 and even 1000 feet . In the Mississippi basin the average thickness is about 100 feet and that of the north western plains of Canada are probably the same.

In Pennsylvania, New York, & New England the till varies greatly in thickness, but it is probably less than that of the Mississippi basin.

In the Laurentian tract of Canada the drift deposits are very thin and bears out the idea previously put forward that this area was a source of dispersion.

TERMINAL MORAINES.

Terminal Moraines are very uncommon in the area of the Laurentide glacier, but where they do occur they attain a very great size in many places. Sometimes of course they become very thin, in which case it is very difficult to trace by them the limits of the ice sheet.

The terminal moraines have been most carefully studied in the Mississippi basin, and here they are laid out in loops or festoons. Often between these loops we get re-entrant angles prolonged to a large distance.

Where there have been successive advances and retreats of the ice we find a series of terminal morraines more or less parallel to each other on account of the constant topography of the land. Sometimes despite the topographical conditions the terminal moraines cross one another instead of being parallel.

Chamberlain delineates this terminal moraine as extending in a series of lobes pointing to the south across the States of Ohio & Indiana, making one grand loop whose axis is nearly parallel with that of Lake Erie returning with its western arm into eastern Michigan between Saginaw Bay and the southern end of Lake Huron. He discovered also five minor loops in this moraine in the axes of some of the rivers. These moraines however have been very difficult to trace west of Hudson Valley, as we have already seen it is very difficult to trace a well defined and continuous moraine along the extreme glacial boundry.

In New Jersey and between the Delaware and Susquehana Rivers in

Pennsylvania however the terminal moraine is pretty definite. Through central New York we find well marked accumulations of débris near the water-partings between the St Lawrence and Mohawk Valleys and that of the Susquehanna west of Lake Michigan these moraines again become prominent and form the Kettle Range. These terminal moraines are well shown in the level country of southeastern Dakota.

So level is the country here that every special line of glacial accumulatiom is a prominent feature in the landscape and the various halting-places of the ice in its retreat are easily discerned.

Besides these terminal moraines already discussed there are those later and more local moraines which were formed when the ice withdrew itself from the country in general but yet lingered in the mountains.

Thus on the Pacific slope Mr J. C. Russell says

" If one proceeds up the Cannon of Leevining River, California, he will cross five or six small terminal moraines which traverse from side to side the broad trench left by the ancient glacier. These are seldom more than 15 to 20 feet high and are separated by grassy meadows. The creek was formerly dammed by the moraines and forced to expand so as to form small lakes; but these have long since been drained by the cutting of channels through the obstructions "

DRUMLINS.

The next form of glacial deposit to consider, I think, are what are known as Drumlins. They have been described thus:-
These hills vary in size from a few hundred feet to a mile in length, with usually half to two thirds as great width.
Their height, corresponding to their area, varies from twenty five to two hundred feet. But, whatever may be their size and height, they are similar alike in outline and form, usually having steep sides, with gentle sloping rounded tops, and presenting a very smooth and regular contour.
The trend or direction of the longer axes of the drumlins in any district is the same and agrees with the direction of the striae.
By some these deposits are spoken of as lenticular hills on account of their shape.
In the vicinity of Boston we find a large number of these drumlins.
They occur on the islands of Boston Harbour, in the adjacent parts of Massachusetts, in the central parts of Masachusetts, in south-eastern New Hampshire, and in north-eastern Connecticut. These drumlins, like those spoken of in chapter 1, consist of unassorted drift, but Mr Upham and other American Geologists have pointed out that they have stratified material at their bases.
Drumlins also occur in Maine and New Brunswick. In central New York we find Drumlins which are often several miles in length.
Chamberlain says, " The most extensive, and taken altogether, perhaps the most remarkable drumlin area is found in eastern Wisconsin " This area lies round Green Bay and Lake Michigan, and

the drumlins are due probably to the two lobes of ice which invaded the districts of these two. In the central portion of the tract the more elongated forms prevail while towards the edges we find the shorter forms. It has been estimated that there are 10,000 of these drumlins in this area. We really get two series here. One series to the west of Lake Michigan have an east-west direction, while those round Green Bay have a direction from north-west to the south-east, showing that the lobes of ice here were moving in opposite directions, and where these two lobes of ice met they formed a joint terminal, or interlobate moraine, known as "Kettle moraine".

In north-western Canada drumlins are supposed to occur on the islands of Lake Winnipeg and Lake Cree, and in isolated instances elsewhere.

It is worthy of note that these drumlins occur chiefly within the area of terminal moraines, and as a matter of fact we find few if any outside this morainic barrier.

Deposits due to Glacial Drainage.

Under this heading we include what we have spoken of before as Åsar or Eskers and Kames. There is no sharp line of distinction between these two.

The finest development of American Eskers, as they are there called, occurs in Maine. Their ~~length~~ heights range from fifteen to a hundred and even one hundred and forty feet. They occur also frequently in central and western New England, but since they aggregate in clustered hills it is doubtful if they should really not be considered as kames. On the plains of the interior they do not occur commonly but one or two good specimens have been found, some of which occupy valleys cut in the drift Typical kames on the other hand occur throughout the area along most of the great terminal moraines, but often they are found unassociated with moraines. They are made up of assorted material on account of the preponderance of fluvial over glacial action. We can now turn to those deposits which stretch out in plains or aprons as they are sometimes called. These have been laid down by water after it has escaped from the edge of the ice.

Thus the deposits are coarsest and thickest nearest to the old ridge or margin of the ice and they become thinner and finer at increasing distances from it. We often find these associated with terminal moraines.

As the waters issuing were usually soon drawn into the main drainage lines, the deposits are found to merge into valley-trains which follow the drainage lines.

It often occurs that Esker ridges terminate in delta-fans caused by the spreading out of the glacial streams when it left the ice, and the consequent deposition of its detritus.

Similarly too we get gravel and sand plains extending from kames on their side distant from the ice sheet.

Aprons, as we will call the deposits, of one kind or another are found associated with most of the great terminal moraines of America. Most of them are made up of sand and gravel.

We find a good example on the south side of the terminal moraine of Long Island and continued as this moraine extends westward. They occur also in the valleys of the Appalachians, but are not very continuous here.

On the plains of the interior the deposits are laid out more widely, and they occur almost universally.

Until a few years ago little had been done towards ~~the~~ dividing up and correlating the glacial deposits of North America . However during recent years much work has been done, and although American Geologists disagree in many points of division, most of them agree that the glacial formations are not of the same age. The following are the American stages of the glacial period now recognised in the interior of North America, numbered in the order of their age (From Chamberlain & Salisbury)

13. The Champlain sub-stage (Marine).
12. The glacio-lacustrive sub-stage.
11. The Later Wisconsin, the sixth advance.
10. The fifth interval of deglaciation as yet unnamed.
9. The Earlier Wisconsin, the fifth invasion.
8. The Peorian, the fourth interglacial interval.
7, The Iowan, the fourth invasion.
6. The Sangamon, the third interglacial interval.
5. The Illinoian, the third invasion.
4. The Yarmouth or Buchanan, the second interglacial period.
3. The Kansan or second invasion now recognised.
2. The Aftonian, the first known interglacial interval.
1. The Sub-Aftonian or Jerseyan, the earliest known invasion.

In Chamberlain's chapter on North America in J. Gakies Ice Age he does not include all these divisions.
Thus he says 1 & 2 are a concealed under-series which are extremely theoretical. He also omits 5 & 6 and joins 9,10 & 11 to form

one formation which he calls the Eastern Wisconsin formation. However we will deal shortly with each of these divisions.

1. The Sub-Aftonian or Jerseyan glacial stage.

Lying beneath the Kansan drift of Iowa there is a very old drift-sheet and it is separated from the drift above by sand with gravel, peat, old soil, and other deposits of an ancient surface.

It does not come to the surface but is exposed by erosion. It may be correlated with the oldest portions of the Labradorean drift, but this is doubtful. There is a very old drift-sheet exposed in Pennsylvania & New Jersey which may possibly be of the same period as the Sub-Aftonian.

It is a typical piece of till, this Sub-Aftonian, and contains a large number of greenstone erratics. It gets its name from an exposure at Afton in Iowa.

2. Aftonian Interglacial Stage.

This is represented by the sand with gravel, peat, old soil etc which we said overlaid the till sheet of 1. The Organic remains in these beds imply a cool temperate climate. The old drift in Pennsylvania referred to in 1 is in a similar manner overlaid by gravel deposits. It has not yet been decided whether or not these gravels are the glacio-fluvial deposits of the closing stages of the Sub-Aftonian Ice-sheet.

3. Kansan Glacial Stage.

This is represented by a typical sheet of drift occupying a large area in Kansas, Missouri, Iowa, & Nebraska. From here too it probably stretches under the later glacial formations northwards, probably

to the centre of dispersion.
This formation consists of a sheet of till essentially. With it is associated silt,sand and gravel in small quantities. It consists chiefly of a clayey till. It is not bordered by terminal moraines, but generally thins away to a vanishing edge, which distinguishes it from some of the later formations which are limited by terminal moraines.
Deposits of this age form the margin of the series across Missouri and in part at least through southern Illinois & Indiana. A narrow irregular band outside the terminal moraine in Ohio is referred to this stage. Also some of the thin patchy drift in eastern Pennsylvania & New Jersey are parts of this formation.
In the west the Kansan formation extends 200 miles beyond the next layer about but as you go eastward it becomes more and more buried until between Ohio & New Jersey it is almost completely buried.
Much of the drift on the north-western plains of Canada may belong to this stage of glaciation, but this cannot yet be stated with certainty.
The underlying rock surfaces have only been slightly modified by ice-abrasion, scored surfaces only occuring occasionally.
The surface of the till itself bears evidence of strong erosion before the next drift sheet was laid down, which indicates that the following interglacial period was a rather long one.

.The Yarmouth or Post Kansan Interglacial Stage.

The strong erosion just mentioned as taking place on the surface of Kansan till is the best evidence of a prolonged interval between

Kansan Ice invasion and the next succeeding one. Between them too there is a well developed soil-horizon where weathering has taken place to a large extent. Here too we find vegetable accumulations preserved. We get a good example of these organic remains at Yarmouth in Iowa, and hence the name of the interval.

In Eastern Iowa well sections have been taken in which this intermediate vegetal debris is found to continue, but the farther you go back from the margin the more disturbed are the vegetal beds. Mr McGee says that coniferous wood is by far the most important constituent of the vegetal zone in North-Eastern Iowa, but pine, oak, ash, elm, walnut, and tamarac have also been recognised. These, together with the remains of animal life, point to conditions not more severe than those of the present day.

Judging by the quantity per cent of vegetal remains it is inferred that this period was a very long one. The peat beds are traceable in every well over an area of 5000 sq. miles.

5. The Illinoian Glacial Stage.

The typical formation of this stage was a sheet of till occupying the surface in southern and western portions of Illinois and running back under the later formations to the northeast towards the Labradorean centre of radiation.

It can be traced northerly into Wisconsin and easterly into Indiana and Ohio. It has a similar constitution to the Kansan formation, i.e. clayey till. There are tracts of kames in some sections but terminal moraines are rarely if ever found.

6. The Sangamon Interglacial Stage.

Like the previous interglacial stages it is marked by peat, old soil and subsoil, weathering and surface erosion. This was probably not a very long period.

7. The Iowan Glacial Stage.

This stage is represented by a thin sheet of till marked by an exceptional profusion of large granatoid boulders which lie on the surface. It is typically developed, as its name suggests, in Iowa by a lobe of the Keewatin ice sheet which did not stretch as far as the Kansan one.

As with the Kansan and Illinoian there are no terminal moraines. In addition there are few fluvio-glacial deposits from it round its borders.

8. The Peorian Interglacial Stage.

This is represented much in the same way as the former interglacial stages but less strongly and obviously represents a less important epoch.

9. The Earlier Wisconsin Glacial Age.

The formations of the two Wisconsin stages occupy more surface area than either of the other formations, probably on account of their not being overlapped by later drift deposits. The till sheets are marked not only at their edges but at intervals by terminal moraines. The surfaces too are marked by Kames, Eskers, & Drumlins due to outwash from the ice sheet, and this distinguishes them from the earlier drift surfaces.

At least three terminal morainic tracts are found on the Early Wisconsin formation of Illinois that is not covered by Later Wisconsin. The outermost lies on the border of the drift and the others more or less concentric to and within it, marking stages of halt in the advance or retreat of the ice-sheet.

10.The fifth interval of Recession.

We cannot call this a stage as we have done the others, it simply represents a retreat of the earlier Wisconsin ice-sheet which was followed at a short time later by the later Wisconsin sheet but the lobes of the ice-sheet had changed their relative size and relation to one another for the moraines of the later stage cross those of the earlier at large angles at some points.

1.The Later Wisconsin Glacial Stage.

In this stage the ice assumed a distinct lobate form due probably to the large open valleys of the region. Nearly all the well known mountain glaciation of the west is referred to this epoch. The drift sheet is characterized by enormous terminal moraines, boulder belts, kames, eskers, drumlins, and other fluvio-glacial deposits. In some places we find nearly a score of concentric moraines which represent readvances or halts of the ice-sheet. In this stage too the ice action on the lower drift deposits appear to have been very powerful as is shown by the cutting away and scoring of the rocks below.

2.Locustrine Formations.

As the ice-sheet drew back into the basims of the great lakes, water became pounded back by it and between it and the water-shed behind. These marginal lakes made deposits of greater or less extent according to the extent and time of existence of the lakes. The deposits consist of stratified clays, sands, and gravels. Among these deposits clays and glaciated erratics are found quite commonly and these may be due to a readvance of the ice-sheet, or more probably they have been dropped on the last retreat of the ice. All the existing great lakes between U.S.A. and Canada, and probably all the great lakes of north-western Canada are bordered by these deposits which bear witness of their previous extension. Of these lakes perhaps the most important was formed in the Red River Valley and is known as Lake Agassiz. Lake Winnipeg and Winnipegosis may be regarded as its diminutive successors, except that they are rock bound whilst Lake Agassiz was bound on the North by ice.

13. Champlain Deposits.

After the retreat of the ice from the St Lawrence valley the sea extended up to its lower portion but to exactly what distance has not yet been definitely ascertained. However it is known that it deeply submerged Montreal to a height of 560 feet above the present sea level, and to have occupied the Champain basin, ~~basin~~ for abundant fossils (marine) are found there. In the great lake region no marine fossils have yet been found, and so we may conclude that it did not reach this far. Besides these deposits formed here, there are a similar series on the coast of the south eastern Provinces, and on the south coast of Maine, which are probably of the same epoch of submergence or if not strictly contemporaneous they may have been closely successive.

Toronto Fossiliferons Beds.

Besides the deposits we have already considered there are a series of deposits on the northern shore of Lake Ontario near Toronto. They are stratified beds overlain by till and contain fossils that indicate an important interglacial epoch. These are well exposed at Scarborough. The lowest exposed member of the Scarborough series consists of 140 feet of fossiliferous, clays and sands, well stratified and containing plant remains from base to summit together with some animal remains. Upon these fossiliferous beds lie 10-70 feet of till, overlain in turn by 90 feet of laminated clay and sand in which no fossils are found.

The facies of the fauna and flora of these beds points to milder climates than that of the present.

The Great Lakes.

We will turn now to shortly review the relationship that existed between the Ice Age and the Great Lakes.

First of all it must be pointed out that Lake Ontario, Lake Erie, Lake Huron, and Lake Michigan, being surrounded by sedimentary rocks whose strata at the present time lie nearly horizontal, evidently occupy valleys of erosion. On the other han the western end of Lake Superior occupies a synclinal trough which was due probably to the early warping of the earth's crust.

Again, with the exception of Lake Erie, the bottoms of these lakes are lower than the present sea level. If, then, these lakes occupy valleys of erosion we want to know what agency has acted at such distances below sea-level.

To do this I don't think I can do better than quote Professor Newbury's statement of this phenomena (From Wright's Ice Age of North America)

"Previous to the glacial period the elevation of this portion of the continent was considerably greater than now, and it was drained by a river system which flowed at a much lower level than at present. At that time our chain of lakes - Ontario, Erie and Huron - apparently formed portions of the valley of a river which subsequently became the St Lawrence, but which then flowed between the Adirondacks and the Appelachians in the line of the deeply buried channel of the Mohawk, passing through the trough of the Hudson and emptying into the Ocean eighty miles southeast of New York.

Lake Michigan was apparently then a part of a river-course which drained Lake Superior and emptied into the Mississippi, the straits of Mackinaw being not yet opened.

With the approach of the cold period local glaciers formed on the Laurentian Mountains, and, as they increased in size, gradually crept down on to and began to excavate the plateau which bordered them on the West and South. The excavation of our lake-basins was begun, and perhaps in large part effected, in this epoch.

As the cold increased a great ice sheetwas formed by the enormously increased and partially coalescing local glaciers of the former epoch. This many lobed ice-sheet, or compound glacier, moved radiatingly from the south, southwest and western slopes of the Canadian highlands, its Ohio lobe reaching as far south as Cincinnati. The effect of this glacier upon Lake Erie and Lake Ontario would be to broaden their basins by impinging against and grinding away with inconceivable power their southern margins. To the action of this agent we must ascribe the peculiar outline sections drawn from the Laurentian Hills across the basin of Lake Ontario to the Alleghanies and across that of Lake Erie to the highlands of Ohio, namely, a long gradual slope from the north to the bottom of the depression and then an abrupt ascent over the massive and immovable obstacle against which the ice was banked, until it overtopped the barrier.

With the amelioration of the climate the wide-spread ice-sheets of the period of intensest cold became again local glaciers which completed the already begun work of cutting out the lake basins. At first the glacier which had ~~at fir~~ before flowed over the water-shed in Ohio was so far reduced as to be unable to overtop the summit, but deflected by it, it flowed along its base, spending its energies in cutting the shallow basin in which Lake Erie now lies.

A further elevation of temperature curtailed the glacier still more, and Lake Erie became a water-basin, while local glaciers left ~~here~~ from the ice sheet excavated the basins of Lake

Michigan, Lake Huron, and Lake Ontario. The latter lake was apparently formed by the same glacier that made the Erie basin, but when much abbreviated. It flowed from the Laurentian Hills and the north slope of the Adirondacks and was deflected by the highlands south of the lake-basin, so that its motion was nearly westwards. This chapter in the history of our lakes was apparently a long one, for Lake Superior, Lake Michigan, Lake Huron and Lake Ontario are all of great depth "

As the great ice-sheet retreated north, as already pointed out, the waters became ponded back between the highlands of Ohio and the ice-sheet, so as to form large lakes which constantly changed their positions with the retreat of the ice-sheet. As the ice continued to retreat into the basin the sizes of these lakes naturally increased but at the same time the ponded waters tended to unite along the edge of the withdrawing ice. This continued until the obstructing ice withdrew from the axis of the St Lawrence basin. The last of the shifting series of ice-ponded lakes of this basin then disappeared, leaving the present rock bound lakes as their successors.

The influence of warping should be dealt with here

The influence of warping should be dealt with here.

Rocky Mountain Glaciation.

We must now turn to study the glaciation of North America west of the Rocky Mountains. We can divide this into two parts

1. That south of the 48th parallel of north latitude,i.e. just south of the Canadian border.

2. That to the north of this latitude, and extending as far north as Alaska.

1.To the westward of, and in the Rocky Mountain region, there were formerly extensive glaciers in Montana, Wyoming, Colorado, Utah, Nevada and California where now they are almost entirely absent. The glaciation of this region however was never general but only local. Thus in Western Nevada for instance there is no sign of ancient glaciation at all, whilst in the east glaciers once existed in all the higher portions. In some of the valleys they extended for seven or eight miles.

In Utah the Wahsatch Mountains were the chief centre of local glaciers. The glaciers from this centre however did not reach a very low level.

In Colorado such valleys as those occupied by the head-waters of the Platte & Arkansas Rivers were once filled with glaciers which laid down terminal moraines in some cases forming dams which led to the formation of temporary glacial lakes.

Near the summits of the San Juan Range in south-western Colorado we find evidence of the former presence of moving ice, but this is the most southerly point at which such evidence is found.

Northwards of Utah & Colorado we find just the same evidence of local glaciation - that is where glaciers have been formed on the highest peaks and have extended ~~dn~~ for a short distance down the valleys.

The glaciers of the Sierra Nevada and Cascade Range in California Oregon & Washington were on a much larger scale than those in the Rocky Mountains.

Mr Clarence King says,

" In the field of the United States Cordilleras we have so far failed to find any evidence whatever of a southward moving continental ice-mass.

As far north as the upper Columbia River and southward to the Mexican boundary there is neither any boulder clay nor scorings indicative of a general southward moving ice sheet, Therocks outside the limit of local glaciation show no traces either of the rounding, scoring or polishing which are so conspicuously preserved in the regions overridden by the Northern Glacier "

. If we go north between the Cascade Range and the Coast Range of Washington we come to Puget Sound. The shores and islands of Puget Sòund are everywhere covered by a vast terminal moraine. This deposit presents a mixture of that stratified and unstratified material characteristic of the terminal accumulations of a great glacier.

The channels of the sound, and of the adjacent fresh-water lakes have a general north and south direction parallel with the axis of the valley, and they are separated by a series of ridges showing every mark of glacial origin.

From here to the north we find extending a sheet of coarse unstratified material abounding in large striated stones and undoubtedly deposited by a great ice-sheet.

Everywhere round this district and on Vancouver Island we find evidences of this great-ice-sheet in the form of erratics, groovings, deposits etc.

The evidence points to the direction of this ice-flow as north to south, or north north west to south south east.

According to Dr G. M. Dawson the central névé of this great ice-sheet lay between the 55th and 59th parallels of north latitude, and occupied the plateau between the coast-ranges and the Rocky Mountains.

From this central tract it has been estimated that there was a general ice-movement south eastward for 600 miles and north westward for about 350 miles.

The north westerly movement invaded the valley of the Yukon and reached to about 62° or 63° north latitude. We have already seen that the south-eastward movement reached just south of the Canadian border. On the west side of the Rockies many lobes or tongues reached down to the Pacific Ocean and these may have been joined by those from local centres in the coast ranges.

On the east side of the Rockies there may have been small centres of local accumulation from which tongues of ice were thrust down on to the plains by way of the valleys. There was however no great outflow from the Rocky Mountains to the east on to the plains. Thus from this centre there was no general outflow in all directions as took place in the Laurentian

Uplands or in Scandinavia but only a flow to the north & south and partly to the west.

Alaska.

Alaska presents to us an unlimited tract of land for glacial study, but despite the wideness of the glaciology of Alaska I intend here only to give a very brief outline of general disposition of the glaciers.

The mountains of Alaska occur mostly along its southern border. The entire Pacific coast is in fact rugged and mountainous and presents magnificent scenery to the tourist.

Here we have the mighty peaks of Mount Logan and Mount St Elias and a crowd of sister peaks forming an immense névé region with a general elevation of 8000 to 9000 feet.

Going northward along the coast from the Canadian border we soon come to the mouth of the large Stickeen River. Here we have evidence of two great glaciers which at one time probably met while the river passed underneath the ice to the sea. Round the mouth of the river we find series of terminal moraines, crescentic shaped, and covered by forests.

Mr W. P. Blake says that from the mouth of this river there can be seen four large glaciers and several smaller ones.

Going northwards of the Stickeen River, glaciers of great size are of increasing frequency and can be well seen from the ship. These glaciers come down to the sea-level in most cases, and Mr I. Russell has named them Tide-water Glaciers.

Thus at the head of Taku inlet and filling the gorge from side to side so as hold the waters of the Ocean in check, is a wall of ice formed by the extremity of a typical tide-water glacier. This glacier is known as the Taku Glacier, and rises in the mountains many miles back from the sea. It is estimated that at the sea the wall of ice is 200 feet thick and nearly a mile in length. Many icebergs are broken off from its front, which undoubtedly at one time extended much farther south than it does now.

In going from Juneau to Chilkat, i.e.from one end to the other of Lynn Canal, a distance of about eighty miles, nineteen glaciers of large size can be seen from the ship, but none of them come near enough to the waters edge to form ice-bergs. It is worthy of note here as an example to the steep slope inland from the waters edge that it is only 35 miles from the head of Lynn Canal to the sources of the Yukon River (at Lake Lindeman) which then flows to the north and west for nearly 3000 miles before entering the sea.

In the short distance from Lynn Canal to Lake Lindeman, Schwatka says, there are four glaciers of considerable size. Proceeding just to the west of Lynn Canal we enter Glacier Bay. Several glaciers here pour their ice into the sea. 32 years ago these magnificent glaciers were undiscovered, but in 1878 John Muir discovered this bay and the magnificent glaciers on its shores. Of these glaciers the largest and best known has been named after the discoverer.

At the head of Muir inlet a mass of ice two miles ~~long~~ broad and from

130 - 210 feet high can be seen rising from the water. From this mass of ice large icebergs are broken off and floated away. Like Taku Glacier this Muir Glacier is slowly receding and in fact Vancouver in 1794 says that the whole of Glacier Bay was blocked up with ice.

From Cross Sound westwards to the Alaskan Peninsula the coast is bordered by a most magnificent semicircle of mountains opening to the south and extending far more than a thousand miles. Throughout this whole extent, glaciers of large size are everywhere to be seen, and it is estimated that there are altogether nearly 5000. However little detail is known of the glaciers of this region, but those in the neighbourhood of St Elias are probably the largest to be found in the northern hemisphere outside of Greenland.

St Elias is 19.500 feet above the sea, and Schwatka said there were eleven glaciers on its southern side. One of these which he named Agassiz Glacier he estimated to be 20 miles in width and fifty miles in length, and to cover an area of about 1000 square miles. Another he called Guyot Glacier and was probably of the same size. Both of these extended down to the sea level. Where these large Glaciers extend on to a low plain between the mountains and the sea and there expand often joining one another, we give them the name Piedmont Glaciers. Perhaps the most famous of this type is the Malaspina Glacier. It covers an area of 1500 square miles and forms a nearly horizontal plateau of ice. Its surface is broadly undulating very much like the prairie land of the central United States west of the Mississippi. It is formed chiefly of three lobes each of which is supplied by glaciers

(a) By the Seward Glacier mainly and flows towards Yakutat Bay.

(b) By Agassiz Glacier.

(c) By Tyndall & Guyot Glaciers.

The central parts are free from moraines or dirt of any kinds, but its edges are surrounded and covered by morainic material. Beyond Mount St Elias in the neighbourhood of the Copper River and Prince William Sound, Elliott says there are numerous glaciers many of them of great size.

Mount Wrangel in the fork of the Copper River he estimates as being 20,000 feet high, and that from its sides huge glaciers flow down to Prince William Sound. In addition too glaciers abound both in the Kenai and the Alaskan Peninsulas and even in the island of Unalaska.

North of Mount St Elias and the Clugatch Alps we come to what is known as the interior. Here it is generally agreed that there are no glaciers, and in fact there is no evidence that any ever existed in this part of the country.

Much of the land is now Tundra, that is to say it consists of a level tract so deeply frozen that it never thaws below a few feet from the surface. The surface is covered by a dense growth of mosses.

Russell says " Along the Yukon, from its mouth to near its source, one may frequently see strata of clear ice or more frequently of black, dirt-stained ice and frozen gravel several feet thick in the freshly cut bands of the stream " The exact depth of this frozen strata has never been exactly found.

In 1818 Kotzebue discovered at Eschscholtz Bay on Kotzebue Sound a cliff of frozen mud and ice capped by a few feet of soil bearing moss and grass.

From more recent investigation it is now pretty certain that the conditions in northern Alaska are the same, or at least similar, to those of Siberia, for in both these countries we find similar remains of extinct and other animals frozen in the soil.

Chapter lV.

Glaciology of the Alpine Region.

Much work has been done on the action of past and present day glaciers in the Alpine districts. Now most glaciologists are unanimous in considering that all the marks of old ice-action are the work of glaciers alone and are nowhere due to ice-bergs or rafts as is so often suggested in the case of other countries. Here we find striae on some of the highest hills, with erratics carried for long distances across broad valleys and deposited high up on the hill sides, and also thick deposits of till, terminal moraines, and fluvio-glacial gravels.

The ground moraine which occurs throughout the Alpine lands is similar to the boulder-clays we have already previously considered Its colour varies according to the principal rock masses in the districts where it occurs.

Shells occasionally occur in this ground moraine of boulder-clay but on examination they are found to be simply derivative and are generally Pliocene and Miocene species.

As a general rule we find the boulder-clay occuring in layers of considerable thickness in the main valleys, forming interrupted terraces that thin out up the mountain slopes. In the narrower and steeper transverse valleys it occurs only in smaller patches, which however may be met with at very considerable heights.

The ground-moraine is best developed of course on the lower grounds that surround the foot of the Alps. Thus stretching out from the Alps into southern Germany we get a plain covered by this ground-moraine. Also to the west of the Alps reaching as far as the Jura we get a ground-moraine-covered plain.

From the evidence afforded us by the distribution of drift also many high levels, by the great elevation of some of the roches montonnées, and by the positions of some of the perched blocks and lateral moraines it seems certain that the ice flows in the valley swept over the mountain peaks, in many cases joining the ice fields of the next valley, and in fact forming almost one continuous 'mer-de-glace' above the level of which only some of the highest peaks stood out like the nunatakkr of Greenland.

The limits reached by these old glaciers are generally well marked out on the surrounding plains by well developed terminal moraines. Unlike the terminal moraines of the present day however they are made up chiefly of ground morainic material whilst the present day ones consist of rock-rubbish from the surface of the glaciers.

Thus on the plains of south Germany the terminal moraines are made up from the material of the ground moraine of the old glaciers. On the other hand on the southern side of the Alps where probably more rock-surfaces were exposed to supply superficial material to the glaciers we find that the terminal moraines of Lombardy are made up of loose angular superficial débris to a much greater extent. But even here ground-moranic material figures to a large extent. In North Italy we find some of these terminal moraines rising up from the plain to a height of from 1000 to 2000 feet.

At this point it might be well to trace the limits attained by some of these glaciers. First, for example, let us consider what was probably the greatest of the old Alpine glaciers, namely, that of the Rhone Valley.

The present glacier is quite insignificant compared with the former one, being now about six miles in length.

At the close of the Ice-Age the Rhone glacier had its origin on the flanks of the Schneéstock at a level probably of 1400 feet above the present level of the ice. From here we can trace it down the valley by the glaciated rocks, and we find it had a gradual slope all the way down the mountain valley. After leaving the mountain valley it spread out over the lowlying plains at the foot of the Alps and extended outward as a great 'mer-de-glace' as far as the Jura Mountains, of which only the highest points stood out above the ice-sheet.

However the Jura Mountains acted as a barrier to the direct outward flow of the ice, and so we find that the ice was deflected to the right and left along these mountains. The left, or south branch, continued for a short distance westerly and then being forced to go south continued as far as the lowlands of Dauphine, a distance of about 100 miles. All along its route we find the hills rounded and ice-worn, and the land covered with a thin layer of ground-moraine. The total distance covered by this glacier from the Schneéstock has been estimated at about 245 miles.

The right branch flowed north-east by Lake Neuchatel along the Jura Mountains. As it continued in this direction it was joined by smaller glaciers, and finally by the great glacier of the Rhine Valley.

The extent of the Rhine Glacier has not been definitely determined on account of the valley being so deeply covered by fluvio-glacial and alluvial deposits. Undoubtedly it received tributary glaciers from the Black Forest, and probably extended much farther than this. We do know however that it filled up Lake Constance and extended to the Danube Valley. In fact it was probably joined by other great glaciers and formed a sheet of ice extending over the plain north of Lake Constance for many miles into southern Germany.

Just as was the case in the north and west of the Alpine region, so in the South, we get large valley glaciers extending for distances up to 30 miles from the valley on to the plains of North Italy. In all probability however most of these ice-flows did not become confluent on the plains but remained as separate lobes.

In the eastern Alps we do not get evidence of the same thing taking place. In all probability the glaciers here did not extend beyond their valleys, and were on a much smaller scale than those of the north, south, and west.

To return shortly to our terminal moraines, Sir John Lubbock having described the terminal moraimes of the north and west goes on to say

Quote Falsan for the Western flows

" The moraines on the south of the Alps are even more astonishing. Probably from the steeper slope, and more rapid melting under a southern sun, the ends of the glaciers do not appear to have moved so frequently. Hence the terminal moraines are more concentrated, grander and higher. They form immense amphitheatres terminating in ridges several hundred feet high, and no one seeing them for the first time would for a moment guess their true nature. The blueness of the sky, moreover, the brilliancy of colouring, the variety and richness of the vegetation, give the morainic scenery of Italy an exquisite beauty with which the north can scarcely vie.

Each great valley opening on the plain of Lombardy has its own moraine. At the lower end of the Lago Maggiore at Sesto-Calende are three enormous concentric moraines. Those of Lake Garda are perhaps the largest. They form a series of concentric hills and attain a height of 300 metres, but those of Ivrea at the opening of the Val d'Aosta, due to the great glacier proceeding from the south flanks of the Mont Blanc range are the highest and most imposing. They form an amphitheatre round Ivrea ".

Besides the evidence afforded us by the terminal moraines as to the extension of the ice we have the evidence of the erratic blocks which occur in the lands surrounding the Alps.

These erratics often attain a huge size, are unrounded, and may have come from great distances. Thus we have what is known as the 'Pierre à Bot' near Neuchâtel. It occurs at a height of 2,200 feet. It is 62 feet in length, 48 feet in breadth, and 40 feet high. This huge block has probably come from St Bernard, and, if so, it would probably have taken 1000 years to move to its present position.

Such erratic blocks appear in large numbers high up on the slopes of the Jura. Since the Jura Mountains consist of Limestone and the blocks are of various crystalline rocks belonging to the higher parts of the Alps, it cannot be doubted that they have been transported by some very powerful agent.

Thousands of them form a great belt of boulders extending for miles at an average height of 800 feet above Lake Neuchâtel. These must have travelled about 60 or 70 miles. It was at first thought by geologists, before they realised the immense power of glaciers, that these erratic boulders had been transported on floating ice when central Europe was submerged beneath an ice sea.

Besides the erratics of the Jura we have a famous series disposed in a belt which extends for miles along the mountain slopes of the left bank of the Rhone near its union with Lake Geneva. These are known as the 'Blocks of Monthey' and consist of huge masses of granite.

Again on the southern slopes of the Alps we get a similar phenomenon.

On the flanks of the limestone heights on the farther side of the Lake of Como blocks of granite, gneiss and other crystalline rock lie scattered about in hundreds.

We will now turn to another series of deposits of the Ice Age namely, the "Fluvio Glacial Gravels" as they are called.

The large terminal moraines of the plains surrounding the Alps are everywhere dovetailed with, and usually rest upon, thick deposits of gravel. There has been much discussion as to the orogin of these gravels, but they are now considered by most geologists to be fluvio-glacial, that is to say they have been laid down by water escaping from the glaciers.

If these gravels are closely studied it is found that they xxxxxt consist of the same kinds of rock as the blocks and boulders of the moraines against which they lie. That is to say the gravels have in all probability been derived from moranic material of the glaciers.

The gravels are usually well stratified, and the pebbles water-worn and rounded. Now and again quite close to the moraines we find striated stones in the gravels, but farther away striated stones are practically absent. This is due to the fact that striated stones lose their glaciation marks or surfaces in running water. As the gravels approach the moraines too more angular blocks appear, and the bedding becomes much less definite, and in fact there is a gradual transition from the gravels to the moraine.

Thus the evidence points to the fact that these gravels have undoubtedly been deposited by the waters escaping from the glaciers. Then if the glacier advances after a period of rest it will move over and drop its moraines on the gravel laid down during its last period of rest.

The geologists in northern Switzerland and southern Germany have made a careful study of these gravels. Thus Dr Du Pasquier has made a careful study of the fluvio-glacial deposits of Switzerland and has come to the conclusion that there is strong evidence for believing that there were at least three periods of great extension of the glaciers with intervals of a milder climate. This view has been borne out by work done in Bavaria & Swabia. Probably the best work done on this subject, and certainly the most recent, is that of Penck & Brückner, and I will give a short account of their work.

For the last twenty years these two men have been working on a series of gravels which they found in Bavaria. These gravels lie in sheets which are known as "Deckenschotter".

The sheets lie in terraces one above the other. Round the country there are series of moraines whose relative age can be found by their amount of weathering . These moraines interdigitate with the gravels and so moraines and gravels correspond one with the other.

Thus the formations of gravel coincide with advances of the ice-sheet and the denudation periods coincide with the interglacial periods, and we are living in the last interglacial period.

The lowest gravel layer corresponds to the latest moraines.

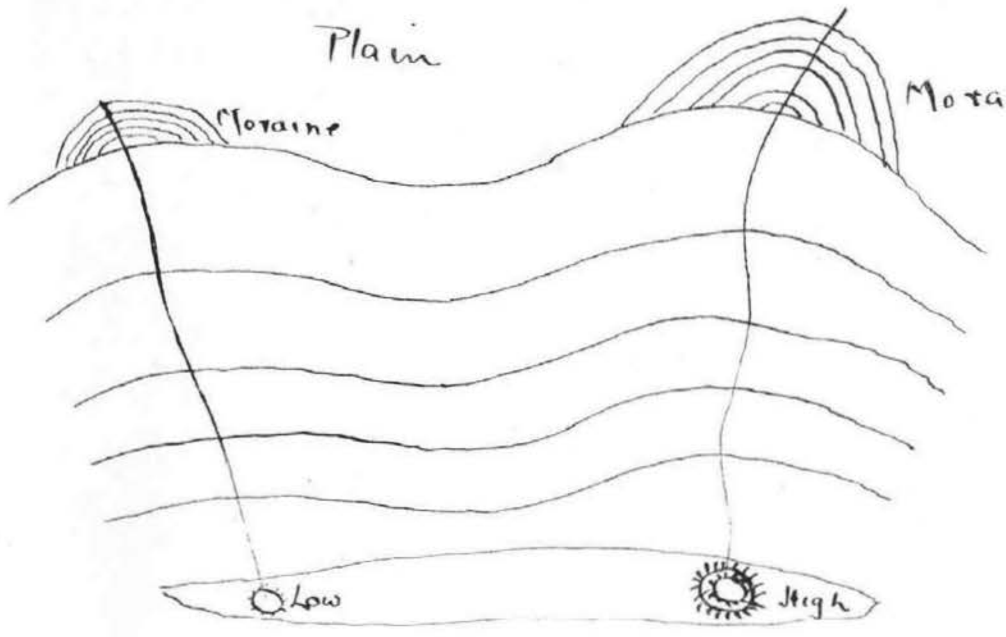
The layers in between the gravels, representing interglacial periods, are often covered with löess and so Penck says it is an interglacial formation. On the inner or newer moraines there is no löess; it is only formed on the outer and older moraines.

Penck named the four gravel terraces as follows:-

1st (newest) Würm Period or Würmian.
2nd. Riss Period or Rissian.
3rd. Mindel Period or Mindelian.
4th.(oldest) Gunz Period or Gunzian.

These names Penck took from the names of four rivers in Bavaria.

He found that the higher the mountains the greater the distance did the glaciers extend, and so the moraines lie further out. Thus in a diagram

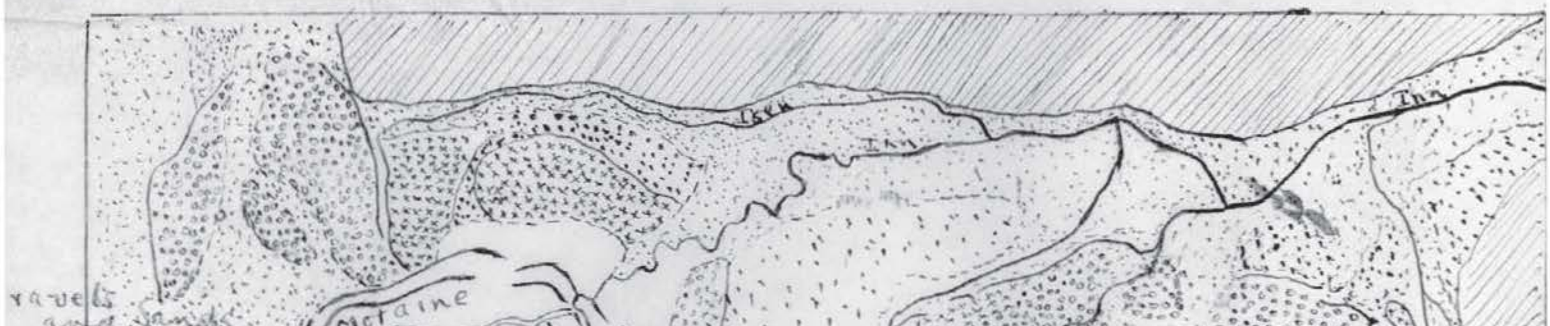


The moraines also depend on the area of drainage of the river. The greater the area of drainage the larger is the extent of the moraine.

Having proceeded thus far with Penck's work on the gravels and moraines of Bavaria I think it will not be out of place if I here shortly add some of the other glacial phenomena of Bavaria pointed out by Penck & Brückner.

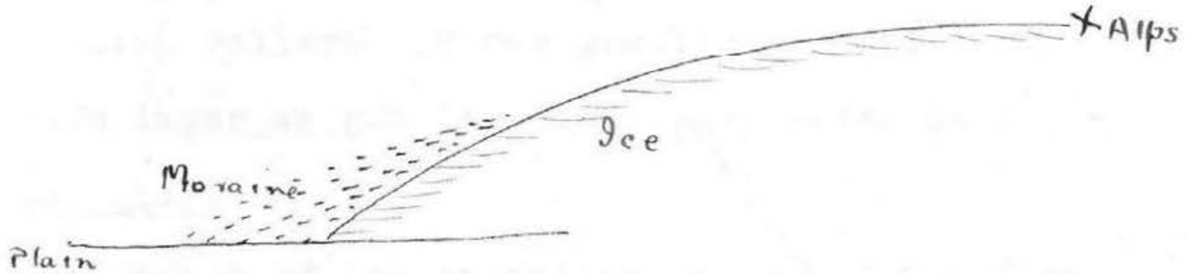
There are two chief rivers running from the Alps into the Bavarian Plain as can be seen from the map opposite. They are the Inn and Salzach.

Let us first deal with the Inn. Along this valley, over the Bavarian Plain moraines, extend from 60 - 100 kilometres and about the same distance on either side as seen in the map.



Penck & Brückners Area

All the moraines are convex to the outside and behave in the same way to the smaller valleys as they do to the large one. (i.e. are always concave to the direction of flow)
The heights of the moraines vary all over the country.
Penck has suggested that the ice was in all probability steep in front and gently sloping back towards the Alps, thus



The whole area enclosed by the moraine has been called a 'Glacial Amphitheatre'. All the valleys in the amphitheatre are radial from the point where the river leaves the Alps, and this point Penck called the "Eye". Between these radial valleys are mounds of morainic material, and are in fact what I have earlier referred to as 'Drumlins' These too like the valleys are radial from the eye.
Apparently the Drumlins are made up of material from the older moraines, and they may be simply what is left of the old moraines.
The radial valleys are now usually peat bogs, and under the surface there are layers of clay known as Bänder Clay or Bänderthon.
In the centre of the amphitheatre we get the finest bog of all, the 'Rosenstein' as it is called.
The rivers when they reach the morainic mounds at the edge of the amphitheatre are unable to get out. They then become periphera

and leaves the Alps and is known as the Eye.
Between these radial valleys are mounds of morainic material. These mounds are known as Drumlins, and like the valleys they too are radial from the eye.
The Drumlins are made up of material of older moraines, and are probably remnants of these old remains.
The radial valleys are now usually peak bogs, and under the surface layer we get layers of clay known as Bänderthorn, or Bänder Clay.
In the centre of the amphitheatre we get the finest bog of all, known as the Rosenheim.
Under its surface too we find Bänder Clay.
Disposition of the Rivers is peculiar in this district. The rivers run round the edges of the amphitheatre (i.e. they are peripheral) This is due to the moraines stopping them leaving the amphitheatre, and so we find they run back down the radial valleys towards the eye. Thus the drainage of the country is due to the ice-age.
Penck points out that the big valley, Rosenheim, and also the smaller valleys, now peat bogs, were undoubtedly cut out by the ice as it came from the Alps on to the plain. Thus the ice coming down the slope at a relatively great rate encounters a great resistance due to the pxx plain and it is forced to dip down into the pxx plain digging out the land as it were.
Leaving Penck's work in Bavaria let us now turn to the lakes of the Alpine districts and briefly discuss their general position

and mode of formation.

The larger lakes lie roughly round the margins of the mountain regions, but besides these we find smaller ones occuring at the heads of some of the mountain valleys.

Thus we see as a general rule that the larger lakes appear at or near the lower ends of the great valleys, and generally too in areas occupied by glacial deposits.

Mr J. Geikie speaks of these larger lakes as "Low-Level" lakes, and says that their dimensions are proportionate to the size of the great ice-flows which formerly occupied them.

In north Switzerland and Bavaria the lakes occur well beyond the mouths of the valleys for here the glaciers flowed well out on to the plain, while in northern Italy we find the lakes partly in the mountain valleys and partly on the plain, but the presence of the terminal moraine round their lower ends points clearly to the fact that the ice front did not extend beyond. Undoubtedly then these lakes have been formed at least partly by the glaciers.

Dr Böhm has done much work on the conditions of formation of these lakes and he points out that as the glacier escaped from the mountain slope the erosive action would be increased, and, as we pointed out in the case of Penck's Bavarian area, would dig out troughs in the plain.

Further he points out that the depths of the lakes are proportionate to their proximity to the mountains. Thus the lakes of Lombardy which occur just where the glaciers reached the plain are very deep compared with those such as Lake Geneva, which lie some distance away from the mountain base and are really only shallow troughs.

Besides the present existing lakes there are basins which have been dug out by the ice and which once probably contained water but which are now filled up with alluvium. Thus in Penck's area we have the Rosenheim in the valley of the Inn, and we get a similar one in the valley of the Salzach.

Sir John Lubbock in his book on the 'Scenery of Switzerland' grants that to a small extent perhaps these lakes basins are due to glaciers, but is more of opinion that the valleys were excavated by running water which was followed by the upheaval of parts of the valleys with the formation of lakes. That is to say the great Swiss lakes are "drowned river valleys". Thus he suggests that the lakes of northern Italy are remains of an ancient sea which once occupied the whole of the plain of Lombardy.

To me however the glacial hypothesis seems the more likely one, and although the alterations in the level of the land surface may have had something to do with the formation of some of the lakes I think that the majority have been formed by the glacial erosion of the ice-age. The smaller lakes which occur high up in the mountain tracts are also probably due to glacial action. They have probably been dug out by smaller local glaciers many of which probably only disappeared at relatively recent times. Although there are still many of these smaller lakes left, a good number have undoubtedly been drained or silted up.

They seldom reach a mile across, and are usually only a few feet deep. Many do not fill up rock basins but are simply formed in the hollows left in glacial accumulations or have been dammed back by rock-falls.

Chapter V.

SCANDINAVIA

and Northern Europe.

In chapter 11 we referred on several occasions to the great ice-sheet that extended from Scandinavia and joimed that of Great Britain in the North Sea.

In Scandinavia itself we find ample evidence of the tremendous action of ice. We get deep depressions in many valleys formed by the ice and where the valley is continued to the coast we get the magnificent fiords of Norway which are practically all the results of ice action.

Besides these we have the smoothed and straited mountain slopes, the rounded islands which stand up from the water like the rounded backs of Whales, the great perched blocks which stand up on the ledges of rock, andlastly the huge quantities of morainic material left in the valleys.

It is now almost universally accepted that the whole of the country has been covered, moulded and polished by one huge ice-sheet which was probably from 5000 - 6000 feet in thickness. The whole of the Gulf of Bothnia was undoubtedly filled with ice which spread out westward across the peninsular into the North Sea. This we know by the erratics which have been carried from the east of Sweden across to the fiords of the west of Norway. Many of these blocks too are remarkably found at a height much above the height at which the rock occurs from which they have been derived. Not only did this ice-sheet cover the Baltic Sea & Scandinavia, but it covered Denmark, Finland, North Russia, the Baltic coast-lands of Germany, and in fact the greater portion of the Central Plain of Europe.

If we trace the direction of glaciation we find that in all probability this ice sheet radiated outwards from the high-lands of Norway and Sweden in all directions. Throughout Germany we find glaciated surfaces and roches montonnées which show that the country has been traversed by inland ice which has come from Scandinavia. In Saxony the Striae appear to be all due to the same ice-sheet, but in the Berlin district there are two sets which have different directions.

Besides the evidence thus afforded we have that of the Boulder-clay, and also to a smaller extent that of the "Giants" Kettles which are found in different parts of the area.

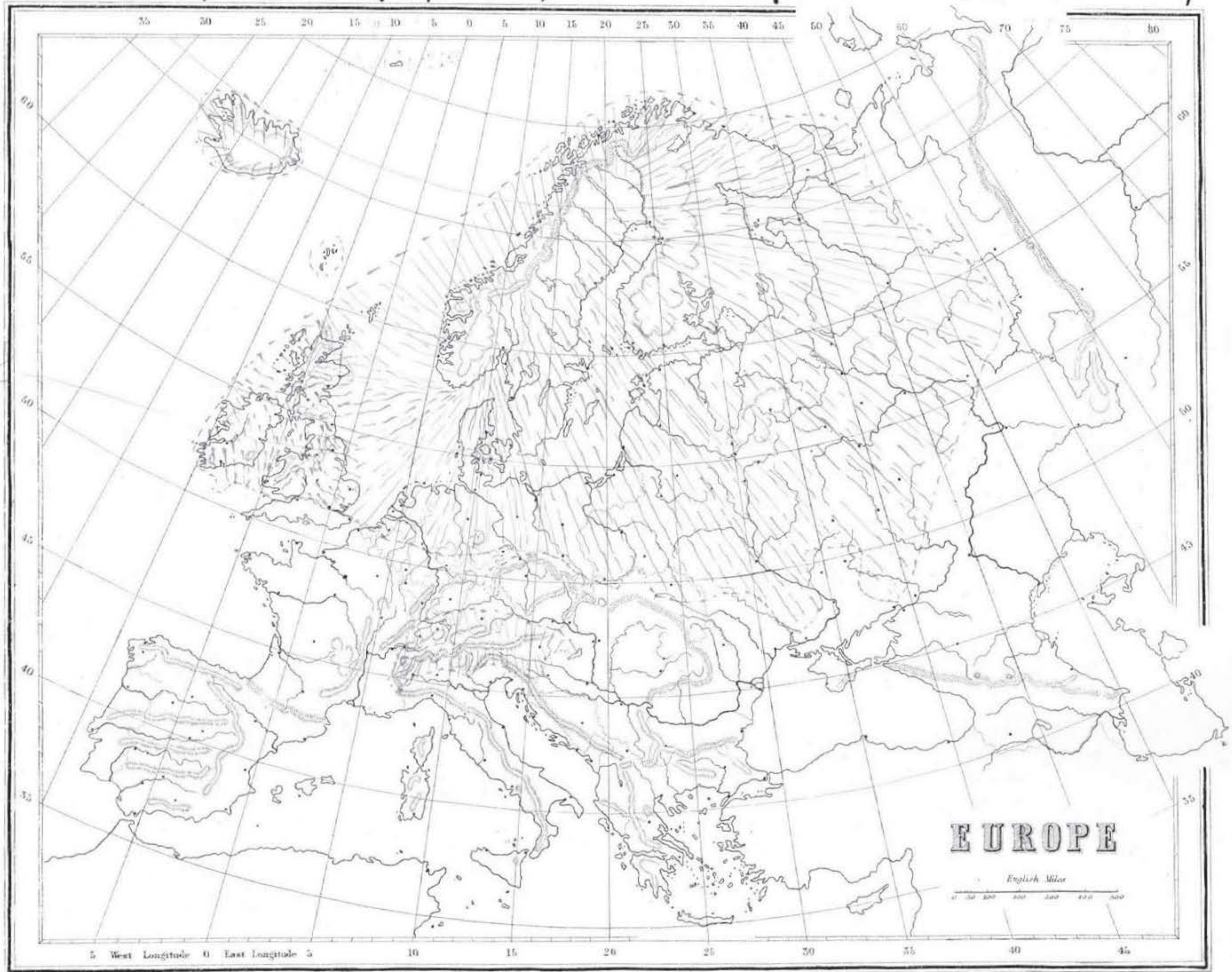
The former, the boulder-clay, has been traced over a large area in Northern Europe. These deposits are the same in almost all particulars to those of Great Britain. Seldom do we find drumlins however as we do in this country. [Important to define distribution in Britain. Not in area invaded by [illegible] Scandinavian [illegible] Scandinavian ice sheet] There are some to be seen according to Professor Credner in the Island of Rügen in the Baltic .

Often associated with the deposits we get layers or better masses of sand and gravel.

As in many other places these deposits were first said to be due to ice-bergs, but now this has entirely given way to the glacial theory.

Generally the stony clays thicken out as they are followed from the highlands to the valleys. The aqueous beds, which so largely accompany the drift deposits, are developed in just the same way being thin in the districts where the boulder clay is thin, and vice-versa.

Europe during Epoch of Maximum Glaciation (2nd Glacial Epoch)



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Red - Glaciated Areas

t countries the boulder-clay can be divided into

(a) Upper

(b) Lower or 'diluvium'

se the lower one is by far the more extensive, and is supposed e been laid down when the ice attained its greatest development. mits of this ice-sheet are gradually becoming better known the extreme south, i.e. in Saxony and near the Harz Mountains t no terminal moraines as we found on the plains round the The extreme limits of this extension are determined roughly presence of erratics, striations, boulder-clay, and gravel and.

m the map opposite it will be seen that the ice radiated rds from Scandinavia across the great plains of Europe into ern Belgium and to the foot-slopes of the hills of Middle ny - the Harz, the Erizgebirge, the Sudetes etc, and extending -east and east over a vast region in Russia. The limit reached e ice-sheet in Belgium are indicated by the presence of inavian Erratics "   (From Geikies Ice Age)

arly in Russia the limits are marked by the erratics. Here the ce-sheet terminated at the Timan Mountains, but from the east ese mountains there are local glaciers which spread out into alley of the Petschora.

a few years ago the ground moraine of this great ice-sheet, lower diluvium, as it was called, was considered to be the st glacial formation; but a few years ago Dr A.G.Nathorst that before this great ice-sheet there was a great Baltic glacier which deposited an earlier boulder-clay than the lower diluvium.

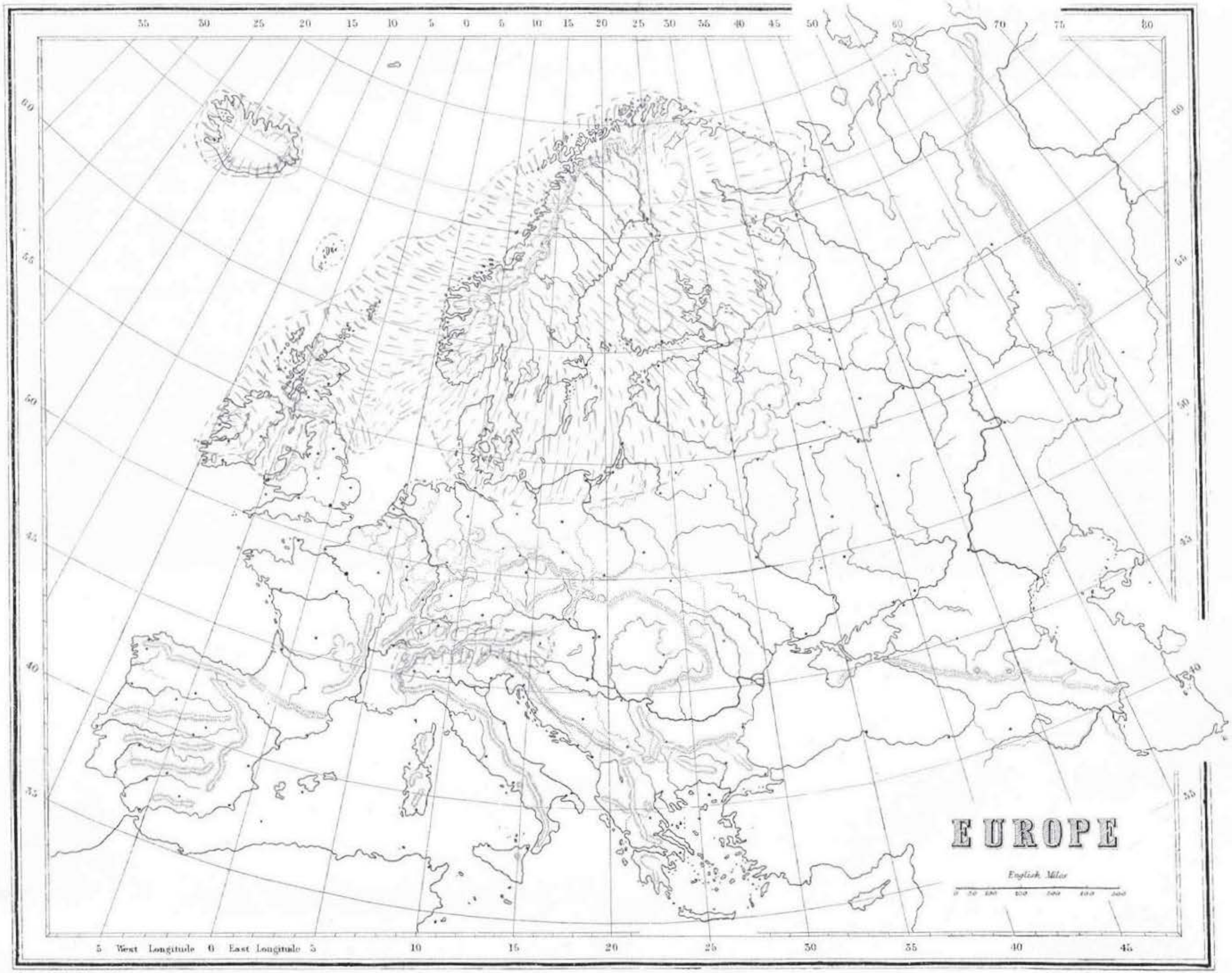
The chief difficulty that has arisen in connection with the classification of these clays is the absence of an interglacial deposit.

Between the upper (b) and the lower (a) glacial deposits or diluvium, as it is called, we get an interglacial series. This series is represented by terrestrial, fresh-water and marine deposits which are met with from the North Sea as far as Moscow. These interglacial deposits do not occur as one sheet, but only in broken patches or layers, just as we found them in Britain. Where these interglacial deposits are absent we can often separate the upper and lower diluvium, for the upper often appears on the denuded surface of the lower which points to a considerable interglacial period.

Interglacial accumulations occur to a large extent in Sweden and indicate the former existence of large lakes. Interglacial accumulations occur in many of the islands of the Baltic, but in the Baltic area the best development is found in east and west Prussia. Here they are fairly thick and continuous, and are made up of sand and sheets of clay chiefly, although beds of gravel occur now and again. From a close study of the fossil forms of these interglacial deposit it has been inferred that during interglacial times the Baltic communicated directly with the North Sea across Holstein, whilst parts of Schleswig and the Danish Islands were probably submerged. Without going into a description of the interglacial deposits of the different countries I shall pass right on now to discuss

2.

Europe during the Third Glacial Epoch.



Red = Glaciated Areas.

shortly the 'upper diluvium'. It consists, like the lower one, of boulder-clay, chiefly, with underlying and overlying erratic gravel and sand.

These deposits are undoubtedly the ground moraines and fluvio-glacial accumulations of another great ice-sheet which however did not extend nearly so far as the former one.

The lower and upper boulder-clays can usually be easily distinguished for the lower is usually tougher, more crowded with stones, and has a bluish-grey colour. Also the erratics in the two clays have apparently travelled in different directions. The colour of the upper boulder-clay is usually yellowish to red.

The limit of this second great ice-sheet in western Germany seems rather doubtful. Roughly it extended to the Elbe Basin. From here it can be traced across Poland and northward across Russia by the Valdai Hills to the White Sea, as shown on the map opposite.

Thus we can see by examining the map that the extent of this later ice-sheet was much less than that of the former.

Round the Baltic coast there are a series of remarkable terminal moraines which has been very closely studied by the leading geologists of Scandinavia and Germany. These end moraines lie round the southern coast of Norway across Gottland (Sweden) passing through the lower ends of Lakes Wener and Wetter. These reappear in Finland passing north of Lake Ladoga and then north to the White Sea. They also appear along the Baltic coast of Germany and Denmark. These terminal moraines, or Baltic Ridge, as it is called, forms a belt of land in which lakes are plentifully formed. It consists of

Europe during Epoch of Great Baltic Glacier (4th Glacial Epoch)

Black line = Coast Line in this Epoch

a series of hummocky ridges of gravel, sand, and boulder-clay. Associated with the ridges we find plenty of fluvioglacial accumulations and in all probability the end of the glacier was lobate in form so that the fluvio-glacial material has been laid down between the lobes.

It is the general belief now that this ridge was accumulated during the retreat of the Baltic glacier, but by certain geologists the idea has been advanced that it was formed during a halt in the advance of an ice-sheet, probably the one that laid down the upper diluvium. If this later was the case it seems most probable that the mounds would have been destroyed and the material redistributed so that it seems more likely that they were formed at the margin of a great Baltic glacier which halted for a time and then retreated.

It is the general idea that these moraines are of the same age as the upper diluvium of Germany which extends as far south and west as the Elbe. That is to say it is taken for granted that the upper boulder-clay of Germany is of the same age as the upper boulder-clay which extends north from the terminal moraines of the Baltic ridge. Undoubtedly both are ground moraines of a great Baltic glacier.

James Geikie however is strongly of the belief that these two boulder clays are of different ages and that the terminal moraines of the Baltic Ridge in Sweden, Finland etc, mark the southern limits of a last great ice-sheet whose limits are shown in the map opposite. Further he says that the boulder-clays which lie to the north of the Baltic Ridge were the old ground moraines of this ice-sheet, so that in the lowlands of north Germany we have boulder-clays of three great ice-sheets. Thus too in all the Baltic coast lands we have at least two boulder-clays, and in some places even three and four have been recognised which are supposed to be distinctly marked off from each other.

In all probability then there have been four ice-ages recognised b-y their boulder-clays. We have

1. Earliest great Baltic glacier whose deposits have been recognised by Nathost.

2. The maximum glaciation with formations of lower diluvium as far south as Saxony.

3. The lesser glaciation with formations of the 'Upper diluvium' as far as the Elbe.

4. The Baltic Glacier, whose limit was the Baltic Ridge.

2 & 3 undoubtedly correspond to those periods when the lower and upper boulder-clays of Britain were laid down, and 4 probably corresponds to that age in which the district ground moraines and valley moraines of Britain were laid down.

To return to Scandinavia for a few moments we find accumulations of aqueons material overlying the youngest glacial deposits.

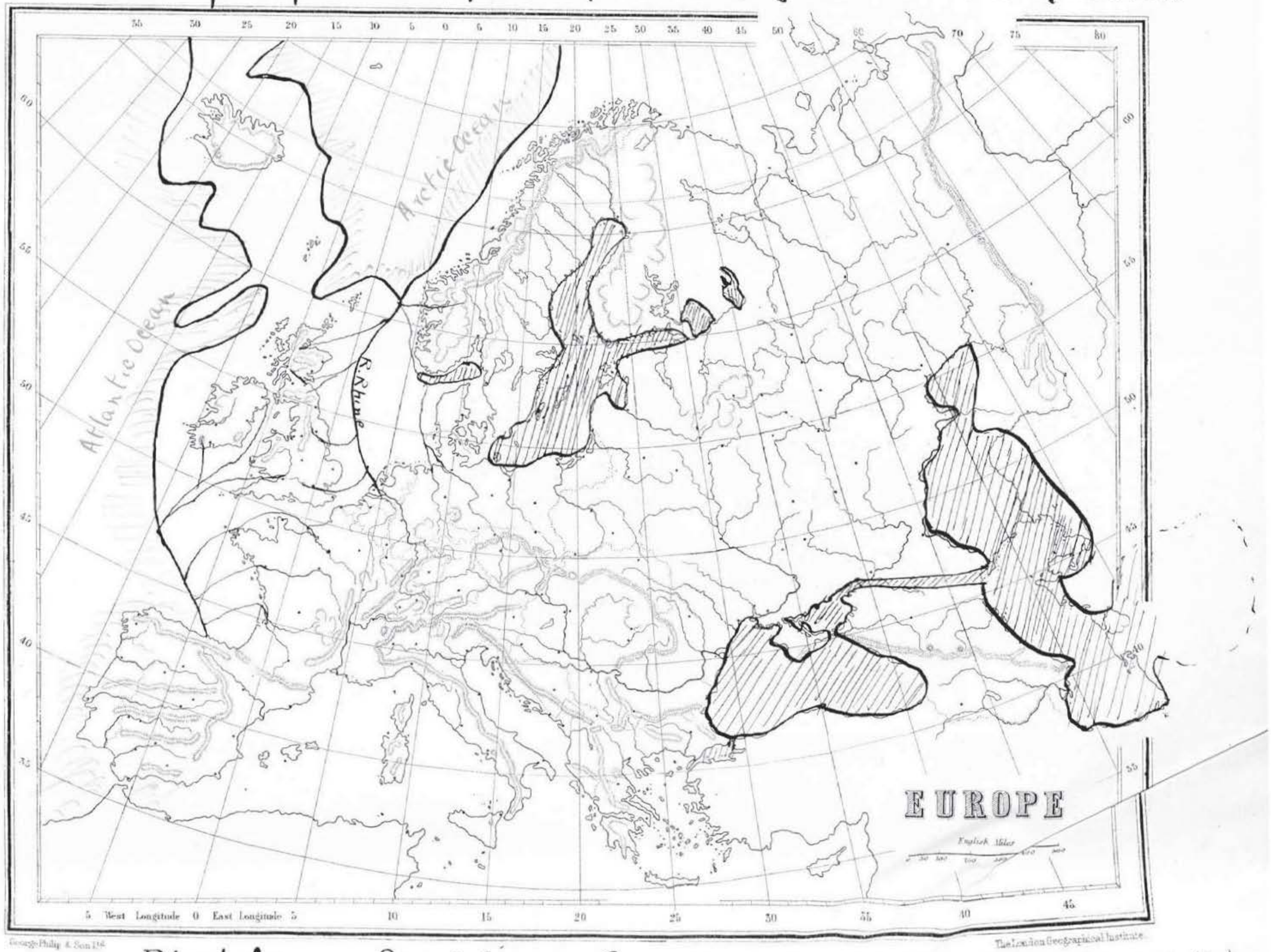
Of these aqueons deposits probably the most interesting are the remarkable series of Åsar. They rest upon both boulder-clay and solid rock and rise to heights from 50 to 100 feet. We generally find these Asar following as ridges right down the valleys from the interior of the country. These ridges often reach a length of 100 miles. They consist chiefly of coarse shingle, gravel and sand. These Åsar are not only found in Scandinavia, but all round the Baltic coast.

There has been much x discussion as to the origin of these ridges, but in all probability, as pointed out earlier in this essay, they mark the sites of sub-glacial tunnels in the last great Baltic ice-sheet.

Besides the Åsar we have series of high level plains and terraces which are made up of aqueous deposits. These deposits are in all probability those of lakes which were formed between the water-shed of the country and the ice as it retreated.

After the retreat of the last great ice-sheet there was probably a submergence of parts of Scandinavia, so that communication was opened between the Baltic and the North Sea across central Sweden. At the same time too the Baltic was probably joined to the White Sea through Lakes Ladoga and Onega. On the other hand south Sweden was probably joined with Denmark by way of the Danish Islands. During this time there was an Artic flora in northern Germany. With the reelevation of the land the Artic flora moved northwards until the sea disappeared from central Sweden when the whole climate became less severe. From the evidence of well marked beaches, round the Baltic coast, which are purely fresh-water beaches, it is now generally admitted that the Baltic became a fresh water lake. If this was the case there must have been a land connection between South Sweden and Denmark. That this was true is borne out by the evidence of peat and beach deposits off the south xxxx coast of Sweden at depths of 100 feet. Also in the great

Europe after the Epoch of the Last Great Baltic Glacier.



Black Line = Coast Line. Cross Marked = Inland Lakes. (Fresh Water)

Great and Little Belts and in the Sound river-like channels occur on the bed of the sea.

At this time the coast line of Europe probablt took the form indicated by the map opposite, so that the British Isles were Continental.

Finally there was another depression until the regions assumed their present conditions.

After the present conditions had been xaxx reached there was probably a return of glacial conditions which however was only represented by glaciers in the higher valleys. Geikie thinks that at this epoch were formed the valley-moraines of Scotland, and also corresponding ones in Norway.

Chapter Vl.

The General Glaciology in other parts of the World.

Having considered the glaciology of Europe and North America in such detail we will turn now to briefly consider what traces we have of glaciers in other parts of the World.

First of all let us consider the mighty continent of Asia. Here we shall find and in fact in most of the other parts of the world to be considered in this chapter, that very little has been done, and in consequence, is known about the glacial phenomena. It will be remembered that when dealing with the greatest extension of the Scandinavian Ice we traced it as far as the Urals or rather I should say the Timan Mountains. On the other side of the Urals as we should expect large glaciers have decended into Asia.

In the Caucasus we find evidence of more extensive snow-fields and glaciers than now exist. The glaciers that now exist are confined to the upper parts of the valleys and are better developed on the northern than on the southern slope.

In glacial times too the same was probably the case for we find that the old glaciers on the north side extended on to the plain for a distance of about 5 miles whilst those on the south side were relatively unimportant.

In Asia Minor old glaciers have left their traces in the mountains of Trebizond and Erzeroum, Ararat and Lebanon, but in the Taurus Mountains no such evidence has yet been found.

We have very little detailed knowledge of the glacial phenomena of the central plateau of Asia with its bordering mountain ranges.

In the Himalayas however we have evidence of a great extension of glaciers, moraines being found in valleys up to 7000 and 8000 feet and distinct traces of glacial action occur in the valleys. Erratics have been found in the Western Himalayas perched as low as 3,000 feet and in the Upper Punjab at much lower levels.

We find generally that compared with the modern glaciers the old ones were very great.

In the Deccan there is no evidence of previous glaciation but showing that its climate was affected by the glacial conditions that existed in what is known as the ice-age, we find a series of plants and animals of Himalayan character.

No evidence has yet been furnished to prove a great extension of ice in the Thibetan Plateau but this may be due to the relatively little work that has been done on the subject.

In the mountain ranges that border the plateau on the north-west we find fairly distinct traces of former glaciation. Thus in the Thian Shan Mountains terminal moraines have been discovered at a height of about 2,600 feet. The mountains that border the great plateau in Eastern Siberia all show evidence of glaciation and Kropotkin has concluded that the whole of the upper plateau of Asia and its border-ridges were once under a mighty cap of ice. At one or two places in eastern China too there are evidences of former glaciation.

It is practically impossible to find a succession of events in glacial times in Asia on account of the complete absence of interglacial deposits.

We will now turn very briefly to consider Africa.
Evidence has been given of former glaciation in the Great Atlas district where terminal moraines have been found at a level of 800 to 900 feet by Sir J. Hooker. Here too have been found striated stones and scratched and polished rock surfaces giving clear proof of the presence of glaciers at one time. Nowhere else in North Africa has evidence of former glaciation been found but from the species found in alluvial deposits of Pleistocene Age we have evidence that the climate of this country was considerably affected.
Although there is no evidence of glaciation in Abyssinia, Dr Gregory describes the occurence in British East Africa of moraines, striae, glacial lake basins, perched blocks and roches mountonées below the present limits of glaciers in Mt Kenia which is just south of the Equator. There is evidence he says of an ice-cap extending 5000 feet farther down the mountain than the present glaciers do. This Dr Gregory thinks is due to a former greater elevation of Mt Kenia and not for any theory of a universal glaciation.
We find glaciers also in Kilimanjaro and also striations far below the present level of the ice.
In South Africa too Mr G. W. Stow has detected traces of glaciation in the mountains of Kahlamba between 1000 and 1500 feet. These traces consist of erratics, roches mountonées, clays with erratic blocks, and in one place striations on the rock surface.

In Australia for some time there was a doubt as to the presence at any time of glaciers but later Dr Ledenfeld found in the Alps, roches moutonnées, striated surfaces, perched blocks and moraines thus proving conclusively the presence of glaciers which came down to about 3,280 feet above sea level.

In South Australia at Hallets Cove, in St Vincent Gulf glaciated surfaces have been recognised with highly polished or striated surfaces. Morainic material too occurs in fairly large quantities with here and there perched blocks. Some of the erratics can be traced for a distance of forty six miles to the south. Permo-Carb

The direction of ice movement has been proved to be from south to north, and Mr R. L. Jack believes that a sheet of ice has at one time moved up St Vincent Gulf.

In Western Tasmania striated surfaces, moraines and larger erratics have been found in the valleys, giving evidence of former glaciation.

In New Zealand there is no doubt that the present glaciers are the descendants of the far greater ones which reached the plains on the east side of the island and in the west probably as far as the sea, for along the coast there are erratics and old moraines. This greater extension on the west is borne out by the present condition of things for now the glaciers descend about 1600 feet lower on the west than on the east side of the Alps.

Judging by the size of the moraines (600 feet) and by their distances from the mountain tops (50-60 miles) the glaciers on the south east side must have been pretty large.

These moraines are often found at the lower end of the lakes.

On the west side instead of series of lakes there is a series of fiords, of which Milford Sound is one. All these are apparently rock basins ground out by glaciers. It appears too that the depths of these sounds or fiords are proportional to size and character of the glaciers which filled them.

There appears to be a great diversity of opinion as to the date of these glaciers, but judging from their striae, which are relatively faint, they were anterior to the glaciers of Europe.

Turning lastly to South America it is believed by Darwin & Agassiz that Patagonia has been covered by a sheet of ice. Over a large area there are Roches montonnées, striated rock surfaces, erratics and boulder-clay.

In the Chilian Andes ice streams appear to have occupied the valleys but never reached to the sea. We also find evidence of these valley glaciers in Bolivian Andes and in the mountains of Columbia.

Before leaving this general distribution of glacial deposits I should like to refer to a series which has in recent years been supposed to be of glacial origin. Of course I refer to the conglomerates and breccia of the ~~peruvian~~ Permian system. This likeness to glacial drift is found not only in the presence of large boulders but in their character and in the matrix in which they are set.

In 1855 Ramsay pointed out that in the Midland breccia the shapes of the stones recall those of ice-worn boulders and pebbles and that in many cases they are distinctly striated. Ramsay thought the boulders had been brought from the Silurian high ground of North Wales but later investigation has led to the belief that they have come from the Pre-Cambrian and Palaeozoic rocks of the Charnwood Forest district.

Since Ramsays observations work in India, Australia and South Africa has considerably strengthened his inferences.

We will briefly consider the formations in these countries,

India.

In the central part of the peninsula of India there is a system of rocks known as the Gondwana system. The lowest division of this is the Talchir formation consisting of what is believed to be glacial conglomerate. The boulders are sometimes as large as five yards in diameter and very often striated. The surface underlying the conglomerate too is polished and striated Similar glacial deposits of the same age have been found in the Salt Range, in the central Himalayas, in Cashmire, and Afghanistan.

Australia.

Here are found similar conglomerates to those of India mentioned above, filled with striated blocks and resting on rounded and striated bosses of rock. These conglomerates extend over a wide area, from Tasmania to Queensland and from Sydney to Adelaide. Geikie states that in Victoria these conglomerates cover several thousand miles, and with their included sandstones attain a thickness of 3500 feet. The ice appears to have moved from the south but the source of the erratics is quite unknown. The recurrence of the boulder beds points to the repeated recurrence of glacial conditions.

South Africa.

Here we get a series of conglomerates known as the Dwyka Conglomerate which is practically the same as those already described in India and Australia. It is composed of stones varying in size from the smallest pebbles up to blocks weighing a ton or more dispersed in a dark grey or blue cement. The blocks are covered with fine paralled striae. The older rocks on which the conglomerate rests unconformably have rounded, smoothed, striated and grooved surfaces exactly similar to roches montonnées. The markings have a general direction from south-east to north-west.

It is believed that this formation has once covered the surface of the Transvaal at least as far north as Pretoria.

The evidence thus obtained from these countries so resembles the phenomena of the Glacial Period that undoubtedly it proves the occurence of a former ice-age in late Palaeozoic times which can rival the later glaciation of the Northern Hemisphere. While, by the intercalated marine beds we can be sure that the ice reached sea-level, we are quite unable to detect the high grounds from which the ice-sheets descended.

Chapter Vll.

Conclusion.

In conclusion there are one or two things which I must briefly sum up.

We have seen that in many parts of the Northern Hemisphere we find series of deposits containing chiefly boulder-clays and gravels. These deposits are spread out in sheets often covering very great areas. Thus in North America much of Canada and for many hundreds of miles south of the Canadian border we have sheets of boulder-clay. In Europe too we find layers extending from the extreme north and with very little break as far south as Northern Italy. Also as we saw in the last chapter we have deposits in different parts of Asia and also in Australia, South Africa and South America.

We have come to the general result that these deposits which are practically the most recent ones have been laid down undoubtedly by huge sheets of land ice, and that in all probability in recent geological times most of the Northern Hemisphere and parts of the Southern Hemisphere that have been studied, have been subjected to extremely Arctic conditions. During this period these lands have been overcome by the ice-sheets which have laid down the boulder-clays from their huge ground moraines and the gravels from the torrential streams excaping from their ends or had we better say sides.

These materials laid down by the glaciers have been first eroded by the glacier from their original position and carried to their present one, often traversing hundreds of miles.

Besides laying down these gravels the ice-sheets in many cases quite altered the drainage of a country, blocking up the old one in one place and opening up or forcing the water to open up a new one in another place.

Thus in America we found that the drainage of the area ~~of the area~~ of the great lakes has been completely altered by the great ice-sheet. Or take again the drainage of the Cleveland area. We saw that in many cases the natural drainage was to the east but on account of the ice-sheet streams had been forced to cut out for themselves new channels to the west and to flow in that direction. Again too the ice-sheets have in many cases carved out deep rock basins which are now filled with water and form some of our most beautiful lakes, for example Lake Geneoa. So we could go on pointing out the effects we have noted of the ice on the land surface. If it has had an effect on the surface of the land it has also had an effect on the fauna and flora of the land. With its approach we get the appearance of more Arctic forms of life and in the warmer interglacial periods more southerly forms appear. This continued until the final disappearance of the ice-sheets from the general tracts of the land and then we get the fauna and flora introduced as it exists at the present day.

Causes of the Ice Age.

Many hypotheses have been advanced at different times to give reasons for the glacial period. I do not propose to deal with these in detail but simply to mention some of them.

These hypotheses fall roughly into three classes,

(a) Hypsomeric.
(b) Astronomic.
(c) Atmospheric.

Hypsomeric or the elevation hypothesis advances the idea of the lifting of the glaciated regions to the snow line by a wide reaching deformative movement. Auxiliary geographical changes would be attendant on such a movement and the elevation and these geographical changes have been united in the forming of this hypothesis.

The chief evidence brought forward in support of this hypothesis, are the buried valleys of the sea coasts, especially in northern latitudes and it is held that the 4000 feet of elevation, thought to be indicated by the fiords, together with the geographical changes were powerful enough to produce the glaciation.

There are naturally many difficulties in the way of this hypothesis and probably the greatest is the explanation of the milder interglacial periods.

Some years ago James Croll advanced an astronomical hypothesis founded on variations in the eccentricity of the earth's orbit, combined with the precession of the equinoxes. To this he also added the effects of meteorological and geographical influences. The hypothesis is built up to a certain extent on the idea that snow accumulation would be favoured by long winters and snow melting reduced by the short summers, notwithstanding the great heat of the sun for the shorter time.

In this hypothesis glacial conditions are pointed out as being due to the developement of certain general atmospheric conditions through certain agencies.

In this hypothesis it is brought out that with a deformation of the land as in Pliocene times there must be an upsetting of the Ocean currents so that they would not equalise one another and so in some parts we should get the atmosphere due to the sea so low as to allow glacial conditions.

Chamberlain says that

1. The Ocean circulation was interrupted by the extension of land.
2. That vertical circulation of the atmosphere was accelerated by continental and other influences.
3. That the thermal blanketing of the earth was reduced by a depletion of the moisture and carbon dioxide in the atmosphere, and that hence the average temperature of the surface of the earth and of the body of the ocean was reduced and diversity in the distribution of heat and moisture introduced.

He then goes on to say

" The general conditions for glaciation are thus supposed to have been supplied conditions without which all more special and local causes would be inoperative "

I am afraid I am unable to appreciate this atmospheric hypothesis as pointed out by Chamberlain and I must say that at first sight Crolls idea appears much more feasible.

Man and the Ice-Age.

A question that is continually arising is that demanding the relationship of man to the ice-age.

Before this can be answered we must come to a definite idea of what we mean by the ice-age. Whilst some great geologists say man was present during the ice-age and others say he was not, I think that really their observations would lead to the same result if they were agreed in their idea of the ice-age.

The presence of man of course is judged by the implements and not by the human remains that he has left behind. These implements at any rate of the earliest man, i.e. of the Palaeothic age, consists of flints.

Sir A. Geikie says

" There can be no doubt that he inhabited Europe after the greatest extension of the ice. He not improbably migrated with the animals that came from warmer climates into this continent during interglacial conditions. But that he remained when the climate again became cold enough to freeze the rivers and permit an Arctic fauna to roam far south into Europe is proved by the abundance of his flint instruments in the thick rivergravels, into which they no doubt often fell through holes in the ice as he was fishing "

Professor G. F. Wright in his ' Ice Age in North America ' expresses most decidedly that man was present in the Ice Age. He bases this on flint instruments found in the Delaware gravels of New Jersey. Undoubtedly the instruments he has found are palaeolithic but I really doubt that despite Professor Wright's emphatic statement, that these gravels are of the ice-age but are more probably ordinary river terrace gravels of the same age as those of the River Somme and those of the South of England where similar implements have been found.

Professor Chamberlain points out in his joint book with Salisbury, that it is exceeding difficult to judge of the age of these implements unless we can be sure that there has been no secondary burials which as he explains in great detail can so easily take place. He then points out that the only places where implements will point to the existance of man in the glacial period is when they occur in

1. Undisturbed till sheets below horizons affected by surface intrusion and
2. In interglacial beds where overlain by till and protected from subsequent intermixture.

In Europe we have examples of palaeolithic remains associated with animal remains but even by means of these it is very difficult to find the exact period with regard to the ice-age, in which man appeared.

Suggestions as to the further work in Glaciology.

Lastly I suppose I ought to make a few suggestions as to further work in glaciology. This is a rather hard task when dealing with so large a subject but there are just one or two points that I think might with advantage be more fully developed.
Since Penck and Brückners work in Bavaria on the glacial gravels has been so successful and led to such a classification indicating the different glacial and interglacial periods it seems to me that their method of studying the gravels might with advantage be followed in other parts of the world. In the Midlands we have large areas of glacial gravels which might afford opportunities nearly as good as those of Penck and Brückner for working out the glacial periods

At any rate they are worth more study than has already been bestowed upon them. Similarly in other parts of the world there are gravels which remain practically unstudied. In this last chapter I have already remarked upon the lack of certain information which would lead to a definite relationship between man and the ice-age. As I pointed out then if man was present in the ice-age as is so often stated we ought to find traces of his implements in the undisturbed till-sheets which are quite unaffected by intrusion or in the untouched interglacial beds. Thus then in suitable areas this question might be carefully ixxx investigated.

Again too there is the cause ofthe ice age always to be settled but it seems to me that it is more the work of the physicist than the geologist. In many areas not only in the British Isles but elsewhere it seems to me that much might be done in investigating old glacial lakes as Professor Kendal has done in Cleveland. Wherever an ice-sheet crossed the ends of the valleys, shutting them xpx up, glacial lakes would certainly be formed and of these glacial lakes many undoubtedly were of very considerable size, and worthy of further investigation.