extent represented is clear, from the presence here of *Pecten Valoniensis* and the small bivalve Crustacean *Estheria minuta*, and of *Pullastra arenicola* at Copt Heath.

As most of the available stone in this outlier has been worked out, it is very difficult to get a section exposed, or to trace out the succession of the strata with any accuracy. Northwards, towards Moreton Bagot, the Estheria-bed is seen, and a limestone which belongs either to the Firestone or the White Lias, containing a species of small Coral not uncommon in this latter stratum.

The outlier at Brown's Wood is traversed by a line of fault running from north-west to south-east. This is entirely separated from the larger mass of Lias at Stooper's Wood, south of Warren Manor. The Lias in each case forms a long ridge or terrace, at a considerable height above the New Red Sandstone.

These two remnants of the Lias are the extreme limit of that formation in Warwickshire in a northerly direction; and no trace of it appears again nearer than the outlier in North Staffordshire before mentioned, and the other remarkable outlier on the borders of Cheshire and Shropshire, long since described by Sir R. I. Murchison *.

When the limit of the Lias has been fully determined, the strata below the Saurian beds, referred to in this paper, will probably come within the Rhætic series of the Trias.

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2. *On the* History *of the* Last Geological Changes *in* Scotland. By Thomas F. Jamieson, Esq., F.G.S., Fordyce Lecturer in the University of Aberdeen.

Contents.

* Geol. Proc. vol. ii. no. 38, p. 115.

§ 1. Introduction.

At the end of a paper forwarded to the Society in December 1859, and printed in the 16th volume of the Quarterly Journal, I gave a concise outline of what seemed to me to have been the geological history of Scotland since the commencement of the glacial period. The following pages are devoted to a further illustration of this subject. The facts on which I rest my conclusions are derived from the midland region of Scotland, chiefly from the part lying between the Moray Firth and the Firth of Forth. This district seems to me to contain remarkably good evidence of the changes that have taken place, and these changes, I believe, have been general over the greater part of Britain.

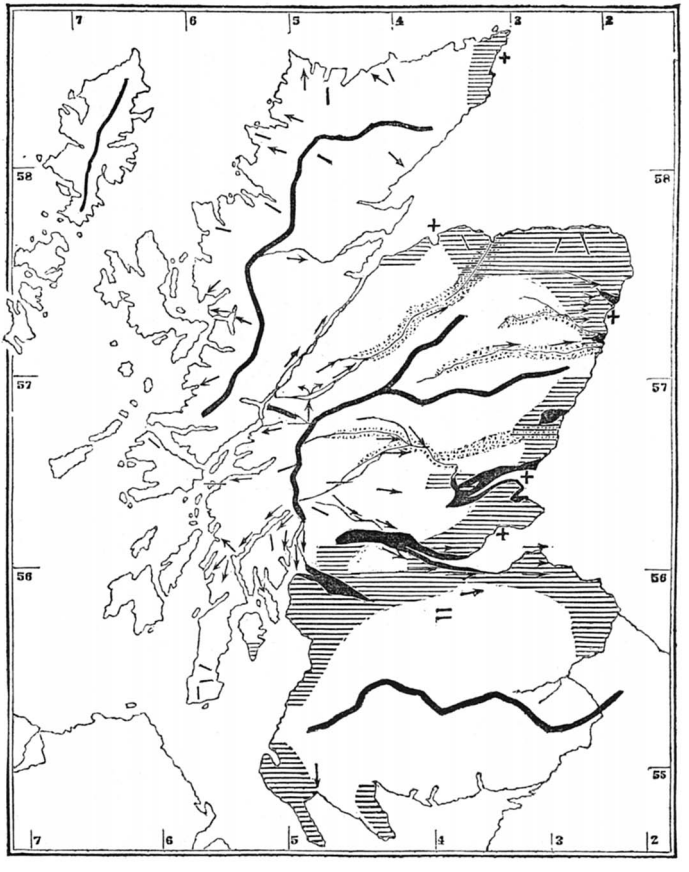
§ 2. Preglacial Traces.

The absence of the later Tertiary strata in Scotland leaves us in the dark as to the state of things that ushered in the glacial period in that country. There are, however, on the eastern coast of Aberdeenshire, in the parishes of Slains and Cruden, some thick masses of sand and gravel which appear to be of Tertiary age, and are probably equivalent to the Red Crag of England. These beds, in some places, contain remains of shells evidently belonging to a considerable number of species, but so broken and worn that in the great majority of cases it is impossible to arrive at a satisfactory determination of their specific character. Nevertheless I have got enough now collected to enable me to see that they form a group very distinct from those met with in our glacial beds, and more resembling what are found in the Crag strata of England. Some of them are of species that seem to be extinct. There are fragments of *Voluta Lamberti*, *Cyprina rustica*, *Nucula Cobboldiæ*, *Fusus contrarius*, *Purpura incrassata*, *Nassa elegans*, *Nassa reticosa*, *Turritella incrassata*, and probably *Trophon costiferum*,—forms unknown either in our glacial beds or in our present sea. Besides these there are the broken remains of many others, of the genera *Cardium*, *Pecten*, *Venus*, and *Astarte*, which differ from those found in any of our glacial beds; and one of the most common shells is the *Pectunculus glycimeris*, which attained a large size.

The position of the sand and gravel containing these shells also leads me to think them preglacial. So far as I have seen, no Boulder-clay occurs below them, neither does the rock on which they rest exhibit any appearance of glaciation, nor do the pebbles show any glacial scratches. This Crag-gravel ranges up to about 200 feet above the present sea-level, and is covered in many places by red clay of the glacial period, containing large boulders and ice-scratched stones. Along its landward margin the gravel is frequently thrown into abrupt and irregular mounds, more especially at its south-western border, near the Loch of Slains*; and this I am disposed to attribute to the pressure of the land-ice during the

* See Quart. Journ. Geol. Soc. vol. xiv. p. 522.

Fig. 1.—*Sketch-map illustrating the Glacial Phenomena of Scotland.*



Explanation.—The arrows show the directions of the glacial markings; the thick black lines the chief ice-sheds, or lines whence the land-ice flowed during the period of the Boulder-earth. The ruled parallel lines show the districts where the Brick-clays and fossiliferous glacial-marine beds seem chiefly to occur. The dotted lines illustrate the distribution of the valley-gravel; the black patches mark the beds of old estuarine mud, or Carse-lands; and the sites of submerged forests are indicated by a cross (+).

glacial period. In other places, however, it lies in undisturbed strata, as in the base of the sea-cliff at Collieston Preventive Station (where it consists of a great thickness of fine soft sand), and along the coast from that to the old castle of Slains *.

There are also some other spots in this low north-eastern part of Aberdeenshire that seem to have escaped the erosive action of the ice, to which I ascribe the denudation of the older superficial deposits of North Britain. The extensive bed of chalk-flints covering the top of a low moory ridge for six or seven miles near Peterhead†, with its associated patch of Greensand at Moreseat, is the most notable of these. The remarkable bank of quartz-shingle, on the top of the Windyhills‡, near Fyvie, is perhaps another; large flints abound in it, in some of which I have detected chalk-fossils. On the top of a ridge near Delgaty Castle, and about two miles north-east of the town of Turriff, there is a bed of similar pebbles, all finely water-worn, and resting on the slaty rocks of the district. Here again are flints; but I also observed another circumstance which seemed to me of importance. This bed of shingle containing the flints is covered in some places by a mass of glacier-mud full of ice-scratched stones; and as this is on the top of a hill about 400 feet above the sea, with no height in the neighbourhood whence there could have been a slip, it seemed to me to establish a very old date for the formation of the shingle. The flint-pebbles at Windyhills and near Peterhead also lie on the top of a set of low hills of similar elevation.

In addition to the above there are indications of the Mammoth, or large fossil Elephant, having inhabited Scotland before the glacial period. These consist of a few instances of its tusks having been found imbedded in the Boulder-clay. Now the condition of Scotland during the glacial period, as I shall presently endeavour to show, seems to have been such as would be incompatible with the existence of the Elephant in that country; I therefore consider that the animals whose remains we find imbedded in our old Boulder-clay must have lived at an earlier time, when the climate and state of the surface were more favourable.

§ 3. Period of Land-ice.

a. *Glaciation of the Rocky Surface.*—The next condition of which we have any clear evidence is that indicated by the mark of the ice upon the rocky framework of the country. This we find here and there over the length and breadth of the land, from Aberdeen to the Hebrides, from the south of Scotland even to Orkney, Shetland, and the Faroe Islands, and from the tops of high hills in the centre of the country to the sea-shore down to low-water mark and further, as far as the eye can penetrate. The frequency, however, of these

* See Quart. Journ. Geol. Soc. vol. xiv. p. 515, where a sketch of the section is given, showing a deep mass of Crag-sand covered by glacial clay. In this sand I got *Nucula Cobboldiæ*.

† *Ibid.* p. 528. ‡ *Ibid.* p. 530.

markings, and the perfection in which they are to be seen, depend greatly upon the quality of the rock, and the circumstance of its having been well covered with clay so as to preserve the traces from obliteration. In the north and west Highlands the markings are more frequent and striking than elsewhere. Along the rocky shores of the west coast they may be studied with great advantage—as at the Gareloch, Loch Fyne, Ballachulish, and many other places. On the other hand, there are wide districts, as in Fife and the low north-east part of Aberdeenshire, where it is rare to find them; and it is only by keeping a look-out where quarries are opened, or railway-cuttings and such like works are in progress, and a fresh surface is thus exposed to view, that they are to be seen.

In the open country, and on the tops of ridges, the direction of the furrows is generally very uniform over wide districts; but in the deep mountain-valleys it conforms, as a rule, to the direction of the glen. Taking the country as a whole, we find, on coming to map the markings, that they radiate from the chief mountain-masses of the interior, and that the rubbed faces of the rocks look towards the great watersheds.

The group of hills stretching from Ben Lomond towards Ben Nevis, and from that mountain eastward to the sources of the River Dee, forms one line from which the erosive agent seems to have descended. Another lies along the watershed that extends from the head of Loch Arkaig northward to Loch Shin, and from that eastward to the Ord of Caithness, as shown in the little map accompanying this paper.

In a former contribution to the Journal of the Society (vol. xviii. p. 164), I have given my reasons for thinking that this remarkable action upon the surface of the country has, in the great majority of instances, been caused by land-ice moving downward and outward from the chief mountain-masses of the interior. Along these lines, when the ice was at its greatest development, there seems to have been an immense accumulation, not merely in the hollows and valleys, but even along the whole crest and centre of each ridge; and from each of these lines the ice seems to have flowed off, not in a multitude of separate glaciers, but in one wide and connected stream. At the same time I do not mean to deny that there has been some scratching by means of floating ice.

All the facts are in harmony with the notion that the ice was of enormous thickness. Thus the detached mountain of Schihallion in Perthshire, 3500 feet high, is marked near the top as well as on its flanks—and this not by ice flowing down the sides of the hill itself, but by ice pressing over it from the north. On the top of another isolated hill, called Morven, about 3000 feet high, and situated a few miles to the north of the village of Ballater, in the county of Aberdeen, I found granite-boulders unlike the rock of the hill, and apparently derived from the mountains to the west. Again, on the highest watersheds of the Ochils (a range of trap-hills stretching from Stirling towards Perth), at altitudes of about 2000 feet, I found this summer (1864) pieces of mica-schist full of

garnets, which seem to have come from the Grampian Hills to the north-west showing that the transporting agent had overflowed even the highest parts of the Ochil ridge. And on the West Lomonds in Fifeshire, at the Clattering-well Quarry, 1450 feet high, I found ice-worn pebbles of red sandstone and porphyry in the débris covering the Carboniferous Limestone of the top of the Bishop Hill. Facts like these meet us everywhere: thus on the Perthshire Hills, between Blair Athol and Dunkeld, I found ice-worn surfaces of rock on the tops of hills at elevations of 2200 feet, as if caused by ice pressing over them from the north-west, and transported boulders at even greater heights.

It was therefore not in the form of narrow glaciers like those of the Alps that the ice existed at this time, but as a thick cake, like that of North Greenland, enveloping both hill and dale, and flowing off, not so much on account of the inclination of the bed on which it rested, as owing to the internal pressure exerted by the immense accumulation of snow over the whole interior of the island, somewhat in the way that a heap of grain flows off when poured down on the floor of a granary. The floor is flat, and therefore does not conduct the grain in any direction; the outward motion is due to the pressure of the particles of grain on one another; and given a floor of infinite extension, and a pile of grain of sufficient amount, the mass would move outward to any distance; and with a very slight pitch or slope it would slide forward along the incline.

The want of much inclination in the surface of a country, and the absence of great Alpine heights, are therefore objections of no moment to the movement of land-ice, *provided we have snow enough.*

Now let us look the matter fairly in the face. It will be found that if instead of land-ice we are to use floating ice, or diluvial action of any kind, for the explanation of the facts, we must do so on a very large scale. These two cases of Schihallion and Morven neatly set before us the extent of the phenomenon, whichever way we are to take it. If we are to adopt the theory of floating ice, we require a submergence of 3000 or 3500 feet to suit these facts; in short, we require to have the whole of Scotland down below water to the top of all but the highest hills, and so with a diluvial action. We cannot take refuge in small local depressions to account for these cases; we cannot confine the submergence merely to the district of Schihallion or to that of Morven; for we find on the high ground over all the island (not to speak of Scandinavia) facts that necessitate the application of like conditions.

Again, if we are to use land-ice as the agency, these two cases are excellently adapted for showing us to what a prodigious extent the snow and ice must have accumulated.

b. *The Boulder-earth or Glacier-mud.*—Resting on the surface of the ice-worn rocks we find a widespread accumulation of boulder-earth, an unstratified mass of coarse gritty mud, in which are imbedded pebbles, boulders, and stony particles, often of many different kinds, and of all shapes and sizes, from a grain of sand to blocks of considerable weight. These are scattered promiscuously

through it, without any regular arrangement. The surfaces of the stones are often scratched and worn like the subjacent rock; and this is the case alike with the large boulders and smaller pebbles, pieces of the size of the finger-nail being frequently well marked if of a fine-grained quality; and it is on stones of this kind, such as clay-slate, serpentine, and limestone, that these appearances are best displayed. When the stone is of an elliptical form, the scratches run lengthways along it; they are not confined to one side, but often cover the whole surface; and it is worthy of notice that the scores on the boulders, as they lie imbedded in the clay, often coincide in their direction with the furrows on the solid rock beneath*. The stones themselves are of such kinds as occur in the direction towards which the ice-worn faces of the rock look; the scores on the subjacent rock point towards the mineral masses whence the boulders have come. Now all this shows that the boulder-earth, with its imbedded fragments, was pushed along by the same agent that scored the rocky bed on which it lies. Thus on the top of the sandstone-hills that form the south end of the island of Bute, we find the ice-worn débris of the mountains of Argyleshire; in the boulders of Inverness we find samples of the rocks that occur along the line of the Caledonian Canal; and at Aberdeen we get specimens of all those that are to be met with in the Valley of the Dee. The materials of this boulder-earth have therefore set out from the same regions as the striæ on the rocks, namely, from the lines laid down on the map (fig. 1), and as they moved along they have mingled with the débris of each successive formation they passed over.

Underneath the present glaciers of Switzerland there is found a bed of mud mixed with stones, which Agassiz describes as *la couche de boue*, or *la boue glaciaire* (see 'Système Glaciaire,' p. 574), being the stuff that arises from the triturating action of the ice on its rocky bed; and Dr. Hooker, in his Himalayan Journals, remarks that "the action of broad glaciers on gentle slopes is to raise their own beds by the accumulation of gravel, which their lower surface carries and pushes forward." The boulder-mud of Scotland (or *Till* as Sir Charles Lyell calls it), I therefore take to be the stuff resulting from the triturating action of the great fields of ice which overspread the country during the Glacial period. It lay beneath the ice-crust, and was compressed and pushed along by it, and accordingly its features correspond with this notion. It is generally hard and compact, as if it had been subjected to great compression. It is an azoic mass, destitute of all trace of contemporary animal or vegetable life. The beds that contain remains of sea-shells and other marine organisms belong, so far as my own observation goes,

* That is to say, supposing the scores on the subjacent rock point north-west, then the longer axes of the pebbles in the clay generally point in the same direction. In the bed of the Lothrie burn, near the village of Leslie in Fife, immediately above Ballingall Mill, I observed a fine example of parallelism of the scratches on a number of large boulders—the direction being about W. 10° N.

to a later period, and are superimposed upon the irregular undulating surface of this old boulder-earth.

It is evident, however, that preexisting organisms, whose remains lay on the surface before the advance of the glacier, might be mixed up with the other superficial débris and carried along by it, and thus broken shells of the Crag-period, and remains of the Mammoth, may have come to be imbedded in the Boulder-clay. In the Boulder-clay of Norfolk broken bits of Crag shells are common, and in that of Yorkshire and of Scotland the tusks of the Elephant have occasionally been got.

If the whole country was buried under a thick covering of snow, it is clear that no proper moraines would be formed. Moraines are deposited along the outer edge of the ice, and consist for the most part of the débris hurled down upon its surface from the rocky slopes and precipices overhanging the glacier. This mass of stony rubbish lying on the top is not scratched and worn like that which lies beneath the ice; for it floats, as it were, on the surface, and is deposited quietly at the end (and sometimes along the sides) of the glacier. It is the stuff caught between the ice and its rocky bed that is rubbed and worn; the débris on the surface is not scratched. Now if the ice covered the whole land, so that no rocky cliffs protruded through it to send down their débris upon its surface, it is clear that there would be an absence of all this superficial stony rubbish which goes to form the moraine of a Swiss glacier of the present day.

In Aberdeenshire this old boulder-mud is of a dull greyish tint, such as might be derived from the trituration of the metamorphic schists and crystalline rocks. It may be traced from the shore at the Bay of Nigg all up the valley of the Dee for sixty miles inland, and from the sea to the height of 1500 feet, everywhere of very much the same general hue and character; the stones in it are often well rounded, some of the granite ones being nearly as round as cannon-balls. From Stonehaven to the banks of the Leven in Fife the Boulder-clay is reddish, owing to the broad zone of red sandstone which the ice had to pass over. In the basin of the Forth it is dull grey in the upper part of the valley (near the Loch of Monteith, for example), where the débris consists of stuff from the old crystalline rocks; near Stirling it is reddish brown, from the influence of the red sandstone; at Falkirk it is a deep brown, becoming blackish towards Edinburgh, owing to the gradually increasing effect of the débris from the coal-strata.

The ice that overspread Perthshire, as it moved south-east, carried along the boulders of Grampian mica-schist, and mixed them up with the red sandstone of the Lowlands, next with the trap of the Ochil Hills, and finally with the fragments of the coal-beds, until on the shores of the Firth of Forth it has left a medley of all the different kinds.

The granite-boulders from the Ben Muick Dhui mountains have been thrown in profusion north-westward into the valley of the Spey—even crossing that valley, and lying in thick beds high up on the slopes of the hills to the north of Aviemore; they have also

gone eastward down the valley of the Dee, but not southward, being repelled apparently by the ice descending from the high ridge of quartz-mountains that forms the boundary between the counties of Aberdeen and Perth.

As regards the midland region of Scotland, the Boulder-clay lies thickest on the eastern slope of the island; in the West Highlands there is comparatively little of it, the rocks being very much bared. This is what might be expected from the more gradual and longer slope of the east side. Over much of the low ground of the Scottish coal-field also there seem to be heavy masses of it. It is frequently disposed in banks of very irregular thickness, often thinning out abruptly, and having occasionally an irregularly undulating or hummocky surface.

The physical quality of this boulder-earth shows it to be due to some peculiar action. It may be said to consist of rough stony débris intimately mixed with a very fine mud, which seems to have been derived from the tear and wear of the stones. This implies powerful friction, combined with the presence of water, and yet an absence of any current to carry off the fine sediment. Earthy stuff dropped in the sea from melting ice I should think would form a different deposit; for the water would hold the fine muddy particles in suspension for a time, while the sand and stones would fall at once to the bottom. I consider that its true nature and origin was first indicated by Agassiz, in his communication to the Geological Society of London, on the 4th Nov. 1840, and more clearly developed by him in a subsequent paper in the Edinburgh New Philosophical Journal for 1842*.

§ 4. Period of Depression.

a. *Glacial-marine beds.*—Reposing on the irregular surface of the boulder-earth, we find, in some of the lower grounds adjoining the coast, beds of finely laminated clay and sand containing sea-shells, remains of starfishes and *Echini*, bones of seals, stones encrusted with *Balani*, *Foraminifera*, and other relics of marine life, showing that the sea had occupied a considerable part of what is now dry land.

Thick beds of this laminated marine clay frequently occupy basin-shaped hollows of very limited extent in the Boulder-clay, thinning out abruptly where the ground rises, as, for example, at Portobello near Edinburgh; this mode of distribution seems to occur chiefly where there is hilly ground in the neighbourhood. In the low north-eastern part of Aberdeenshire the marine clay is often spread in wide sheets, ranging up to a height of 300 feet above the sea: at this altitude there is a bed of it 13 feet thick on the brow of an eminence near the town of Turriff, eight miles inland, where it is dug for making bricks and tiles. It is rare, however, to find it of pure quality at this height. In most districts this fine laminated clay

* My confidence in the opinions I have formed regarding the glacial phenomena of Scotland is greatly strengthened by finding the same views ably advocated by Mr. Geikie in his admirable memoir on this subject, "On the Phenomena of the Glacial Drift of Scotland," Trans. Geol. Soc. Glasgow, vol. i. part 2.

is met with only at very low altitudes near the coast. It frequently alternates with beds of fine sand, and sometimes with gravel, and generally becomes more stony and of coarser quality on the higher ground. This may be seen along the line of the Forth and Clyde Junction Railway between Drymen and Bucklyvie, where I have found remains of marine shells. The greatest height at which I have met with these fossils is, in Aberdeenshire, 300 feet, in this instance in a deep mass of stratified gravel forming the crest of a low hill about five miles from the sea. The top of this gravel-bed reaches about 360 feet higher. At Gamrie, in Banffshire, the beds of sand and clay containing Arctic shells (first noticed by Mr. Prestwich) reach to very nearly the same height, but the position of the shells there is only about 150 feet. These are the highest positions known to me of marine fossils in the glacial beds of the north of Scotland. In the Clyde district, near Airdrie, they have been found up to 350, and in one case 512 feet, which is the greatest elevation yet reported from any part of Scotland. These facts indicate a considerable depression of the land, which seems to have extended over all North Britain, even to the furthest extremity of the island; and these fossiliferous beds of clay, sand, and gravel are proved to be of later date than the scratching of many of the rocks, and the deposition of much boulder-earth, from the fact of their being in many instances seen to rest upon the irregular and hummocky surface of the latter. This I have myself seen in the vicinity of Edinburgh, in Fifeshire, Aberdeenshire, and also on the west coast. Dr. Fleming has likewise given some good illustrations of the same in his 'Lithology of Edinburgh.'

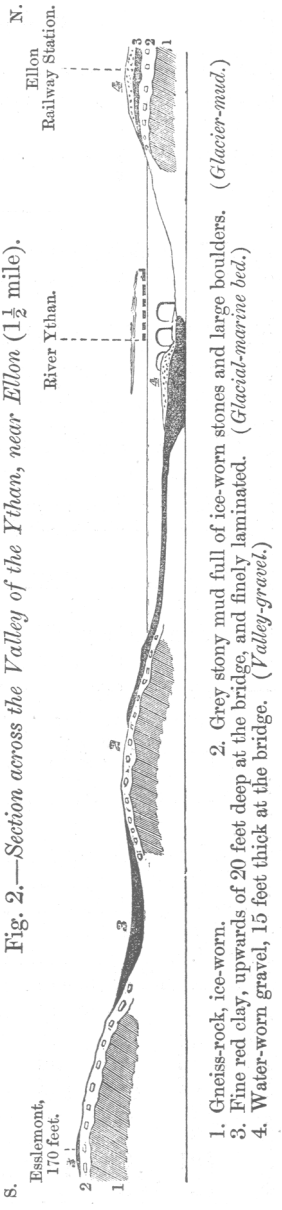


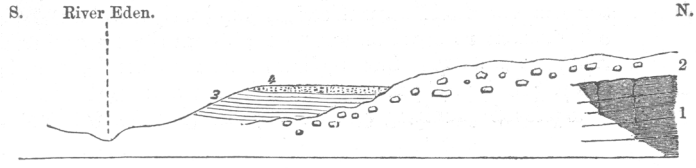
Fig. 2.—*Section across the Valley of the Ythan, near Ellon* (1½ mile).

1. Gneiss-rock, ice-worn.
2. Grey stony mud full of ice-worn stones and large boulders. (*Glacier-mud.*)
3. Fine red clay, upwards of 20 feet deep at the bridge, and finely laminated. (*Glacial-marine bed.*)
4. Water-worn gravel, 15 feet thick at the bridge. (*Valley-gravel.*)

This submergence seems to have followed very close upon the great glaciation of the country, if, indeed, it was not to some extent contemporaneous with it. It may have been that after the land-ice had reached its greatest development, a depression of the coast took

place while the ice still kept possession of the unsubmerged land*. This, however, is one of the points regarding which more evidence is greatly wanted. If such was the case, it is probable that where the ice was thin it melted completely away; but in other parts, where it was in greater force, it protruded into the sea, its outer edge being floated by the water. In some cases it may have been so thick that the depth of water was not sufficient to float it off the bottom, and consequently in such places no marine beds would be formed†.

Fig. 3.—*Section at Springfield Brickwork, in Fife.*



1. Sandstone-rock. 2. Coarse stony earth with ice-worn boulders.
3. Fine laminated clay or Glacial-marine bed; has yielded skeletons of Seal (Page). 4. Sand and gravel.

It is a remarkable fact, that although these marine fossiliferous beds may be traced in many places to a height of 200 or 300 feet above the sea, they are nevertheless totally absent, to all appearance, along many of the valleys in the interior of the country at much lower levels. Thus no marine fossils have been met with along the valley of the Caledonian Canal between Fort William and Inverness, although the summit-level of that valley is only about 90 feet above the sea; neither have any been found, so far as I can learn, along the whole line of the Highland Railway from Dunkeld to Inverness. In the valley of the Dee we have some patches of this marine clay and sand, of great thickness in the neighbourhood of the town of Aberdeen, close to the mouth of the river; but they vanish before we get a couple of miles up the valley, nothing being found beyond that except gravel and boulder-earth. And along all the mountainous seabord of the West Highlands marine fossils are unknown, except in spots close to the shore and only a few feet above the reach of the tide. On the other hand, in the comparatively low outlying districts of Caithness, North-east Aberdeenshire, and Fife these marine clays

* This was the theory proposed by Dr. C. Martins, in a clever notice of the glacial phenomena of Scotland. See Edin. New Phil. Journ. for April 1851.

† The streams of water that escape from beneath glaciers are always loaded with fine muddy sediment, arising from the friction of the earthy matter produced by the pressure of the moving ice. M. Collomb long ago pointed out that the Loess-beds of certain valleys are accounted for by the deposition of this sediment. But we may suppose that where glaciers terminate in or near the sea the stuff will then go to form submarine mudbanks, like our laminated beds of brick-clay; and such has probably been the origin of many of these deposits. The formation of loess-beds on land, and brick-clays in the sea, during the Glacial period, therefore harmonizes well with the notion of an ice-covered country.

form wide sheets, and range up to 200 and even 300 feet above the sea.

Now these clay-beds have either never been deposited in the places I refer to, or something has removed them since their deposition. Two or three ways of accounting for this may be suggested: we may suppose that after the marine beds had been laid down in these places they were carried off by the sea itself when the land was emerging from the water, aided perhaps by the action of the rivers; or we may suppose that, after the land had emerged, the glaciers again took possession of the ground and swept these marine beds out of all the Highland valleys and mountainous tracts; or, thirdly, it may have been, as I have already hinted, that the sea obtained only a partial possession of the land, owing to the glacier-ice lying in too heavy masses to be floated off the bottom, and thus preventing the deposition of any marine sediment.

As a contribution towards the solution of this problem, I shall describe a case I observed last summer in that part of Perthshire which lies to the south-east of Ben Lomond.

From the south extremity of Loch Lomond there is a tract of low undulating ground stretching north-eastward along the line of the Forth and Clyde Junction Railway into the valley of the Forth near Bucklyvie, and forming a sort of low watershed between that river and the basin of the Clyde. The summit-level of this watershed is only about 220 feet above the sea. Now this tract of land is overspread with marine clay and sand of the Glacial period. We find in some places (near Balfron, for example) thick beds of red clay, very pure and finely laminated, and used for making bricks and tiles; in other places this clay alternates with, and passes gradually into, masses of fine soft sand, with occasional beds of gravel. In one of these gravelly seams, at a cutting near Gartness Railway-station, I found remains of sea-shells, generally much broken and water-worn, but some of the smaller ones entire. Of these I collected fourteen species (see Appendix, No. 4) of the same kinds and of the same northern character as those met with in the Clyde beds at Paisley and elsewhere. The position of this shelly gravel, as I learn from the levels of the railway, is about 120 feet above the sea. Stones and boulders are not uncommon in some of these marine beds, and much of the clay is of rather coarse quality.

Now when we descend into the valley of the Forth and go to the Loch of Monteith, which is only a few miles from Bucklyvie, and at a considerably lower level than the shelly gravel at Gartness, this red clay and sand is no longer to be seen, and we find ourselves among large abrupt mounds of gravel and rough stony débris, full of heavy boulders, and piled together in a confused manner without any regular stratification—in short, having all the appearance of glacier-moraines. This picturesque little lake, in fact, seems to be formed by a great heap of moraine-débris, which stretches across the valley of the Forth as if it had been formed by a glacier coming down from the flanks of Ben Lomond and Ben Venue; a transverse barrier has thus been produced which obstructs the drainage. The

surface of the Loch of Monteith, as I learn from the Ordnance Survey, is only 55 feet above the present mean level of the sea. A submergence, therefore, that would account for the marine strata of Gartness, would, in the present configuration of the country, cover the site of this little lake, as well as the greater part of these mounds.

Does it not, therefore, look as if the glacier had occupied the valley of the Forth, at least as far down as this little lake, after the marine beds were deposited on the higher grounds?

Part of the lake is said to be very deep; the bottom, therefore, is probably in some places lower than the present sea-level, seeing that the surface is only 55 feet above it.

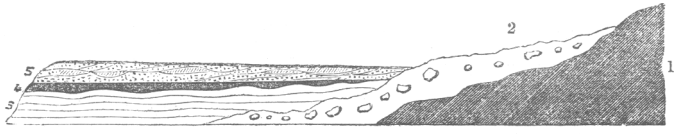
The eastern base of the mounds meets the upper extremity of the "*Carse*" of Stirling, which is a flat expanse of fine alluvial soil, covered here and there with peat. The surface of this *Carse* is only 30 feet or so above the sea; it encircles these moraine-like heaps, and seems to overlap their base, as if it had been gently deposited around them long after their formation.

b. *Character of the Fossils.*—The Mollusca, whose remains are found in the glacial beds of Scotland, are of a much more northern character than the group which inhabits the seas of Britain at the present day. This result was clearly brought out by Mr. Smith of Jordan Hill many years ago; and all subsequent investigation has tended to confirm the accuracy of his induction. In the clays and sands of the east of Scotland the shells are much rarer, and in worse preservation, than they are in the Clyde beds.

Some of the shelly clays of the Clyde district and of the west coast seem to belong to the close of the submergence, when the land had risen well out of the sea, almost to its present height. This is well exemplified at the Kilchattan brickwork in the island of Bute, where we have at the bottom a thick mass of laminated clay destitute of shells, and lying upon an irregular surface of the boulder-earth, which, again, is found at the distance of 70 yards to repose upon the Devonian rocks, or Old Red Sandstone (see section, fig. 4). The surface of this fine laminated brick-clay is undulated; and resting upon the top of it, so as to fill up the undulations and bring the surface to a nearly horizontal plane, we find a looser, sandier clay full of shells. Of these I collected sixteen species (see Appendix, No. 3). The most common is the *Tellina calcarea* (*T. proxima* of Brown). It is very abundant, and of all sizes, from 1 inch in length down to very young individuals; and they are often quite entire, as if there had been a bed of them *in situ*. This loose sandy stratum varies in thickness from a few inches, or almost nothing on the top of the undulating rolls of the lower clay, to 3 feet or more in the hollows. Where there is much depth of it, the shells are chiefly in the lower part. Above this shelly stratum we find a heavy mass of stratified gravel and shingle from 4 to 10 feet thick, looking as if it had been formed on a beach. Here, then, we have, subsequent to the Boulder-clay, three changes of conditions in the marine beds: first and lowest, we have the

laminated clay, which probably has been a deep-water deposit, and seems to have been heaved up and its surface water-worn before the deposition of the next bed, or that containing the shells; and thirdly, above all, we have the beach-like gravel. The top of the section is not more than 25 feet above the present reach of the tide.

Fig. 4.—*Section at Kilchattan Brick-work, in Bute.*



1. Sandstone-rock.
2. Boulder-earth.
3. Fine laminated clay.
4. Shell-bed.
5. Stratified gravel and shingle.

In 1860 I examined several of these clays of the west coast; they occur in a great number of places along the shores of Argyleshire, and, coming from the comparatively barren district of the east coast, I was delighted with the abundance and fine preservation of the fossils; for in Aberdeenshire and on the east coast generally the shells are usually much broken, or, if found entire, they are so decayed as to be with difficulty obtained in a state fit for examination.

Many of the localities on the west coast have been explored and described by Mr. Smith of Jordan Hill, Hugh Miller, Mr. Geikie of the Geological Survey, the Rev. Mr. M'Bride, Mr. Crosskey of Glasgow, and probably others. The localities, however, where shells occur are so numerous that doubtless much remains to be done*. One of the most remarkable circumstances connected with them is that they are, as I have already mentioned, for the most part confined to very low levels, and to the immediate vicinity of the coast. I have observed them on the shores of Upper Loch Fyne, and in my paper "On the Parallel Roads of Glen Roy"† have described an instance near Fort William, which was also explored about the same time by Mr. Gwyn Jeffreys, who gave an excellent account of the fossil contents in the British Association Reports for 1862. This shell-bed near Fort William I believe to represent one of the last stages of the submergence. In the south of Arran, however, the Rev. R. B. Watson has discovered these shell-beds at much higher levels.

It will be seen from the list given in the Appendix, No. 1, that of fifty-four species enumerated from the east side of Scotland, all, according to Mr. Jeffreys, are now found living in the Arctic seas, none are extinct, thirty-two are still living on the coasts of Britain,

* The Rev. Mr. Crosskey, who has made large collections of the fossils, and has an intimate knowledge of the glacial beds, will, I hope, soon favour us with a paper on the subject.

† Quart. Journ. Geol. Soc. vol. xix. p. 235.

while only twenty are known to occur to the south of this country. This shows very clearly how northern is the character of the group. Another circumstance of interest is the large proportion of them, namely forty-nine, that occur on the east coast of North America, considerably more than what now live on our own shores*.

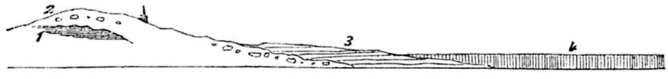
The proportions in 100 would be as follows:—

Living in the seas of Britain	59
Living to the south of Britain	37
Living within the Arctic Circle	100
Living on the east coast of North America	91

This might lead us to speculate on some connexion between the coasts of northern Europe and America during the glacial period. A column is added, headed North Pacific, to show the proportion occurring on the west coast of North America. I am afraid, however, that our knowledge of the Mollusca of that region is as yet too imperfect to warrant us in placing much confidence in the figures. It would seem, from the elaborate report drawn up by Mr. P. P. Carpenter, that several forms occur there which may be said to be representative of those found in the North Atlantic, being extremely like, although not altogether identical. If these had been included, the proportion would have been much larger.

c. *Boulders of the Brick-clay—Floating ice.*—Many of the beds of finely laminated marine clay of this period contain few or no boulders; but this is not always the case. Thus in the clay at Errol in Perthshire, which contains remains of Arctic shells, I observed that small stones are by no means uncommon, and many of them are glacially scratched. Occasionally one may be found with barnacles (*Balani*) on it.

S. Fig. 5.—*Section at Errol.* N.



1. Sandstone-rock.
2. Boulder-earth.
3. Fine clay with Arctic shells.
4. Carse, or old estuarine mud of the Tay.

In the Paisley brick-clay, which abounds in shells (see Appendix, No. 2), boulders of from 1 to 3 feet in length are not uncommon, and in the bottom of one pit I saw a block 6 feet in length. They are chiefly fragments of the older crystalline rocks, and many of them show the glacial striæ. These boulders occur imbedded here and

* This group probably belongs to an earlier stage of the submergence than those got from most of the clay-beds of the west of Scotland, and is of a more decidedly Arctic character. This is indicated by the prevalence of *Leda Arctica* and *Astarte borealis*, the rather larger average size of the *Tellina calcarea*, and the presence of some very Arctic forms, not yet reported from the western beds, such as *Cardium Grœnlandicum*, *Pecten Grœnlandicus*, *Leda lucida*, *Leda limatula*, *Thracia myopsis*, *Mesalia erosa*, *M. reticulata*, *Modiolaria lævigata*, *Axinus Sarsii*, and *Crenella faba*.

there at various depths in the fine clay—sometimes singly, but frequently one or two together. Now it is quite common in some of the pits to find a crust of *Balani* attached to one of these boulders, and I think it has generally been supposed that the *Balani* are confined to the upper surface and sides of the stone, as if they had grown upon it after it had been dropped into its present position. I satisfied myself, however, that this is not always the case; for I found that *Balani* do occasionally occur all over the lowermost side. For example, I observed one heavy stone, measuring 32 inches in length ($32 \times 14 \times 18$ inches), imbedded in the clay about 15 feet from the surface. This boulder had not been moved out of its original position, and there were remains of *Balani* on various parts of the surface. With the assistance of the foreman of the work, I dug round it, and heaved it out of its bed, and found that the whole under side of it was covered with a close thick crust of entire *Balani*, the points of which were sticking downwards into the soft clay beneath, showing clearly that they must have grown upon the stone before it was dropped into its muddy bed. Other instances of the same kind were observed by me in this brickwork. I conclude, therefore, with regard to some of these boulders at least, that *Balani* grew on them before they came to be lodged in the clay (probably when they lay on some shore), and that afterwards they had got encrusted with ice, and being floated off had dropped to the bottom when the ice about them melted *.

I noticed that these boulders, with the *Balani* on them, sometimes exhibit glacial scratches. Here, then, we have evidence of three distinct events: first, the boulder was scratched; secondly, barnacles grew on it; thirdly, it was carried off and dropped to the bottom of the sea. If this transportation was due to floating ice (and I do not see to what else we can ascribe it), it would therefore appear that the floating ice had nothing to do with the scratching of the stone.

I by no means deny that barnacles likewise grew on the stones after they had fallen to the bottom; I have no doubt they did. They also occur on some of the larger shells, such as the *Buccinum undatum*, and I picked up a specimen of the *Trophon scalariformis* with three attached to it.

In this Paisley clay I sometimes found, on heaving up a boulder, a number of young crushed mussel-shells beneath it, as if they had been squashed by the fall of the stone. The clay around also occa-

* I believe the species of *Balanus* on the under side of the boulder above mentioned was *B. balanoides* of Darwin's monograph, for I feel pretty sure it had no calcareous base; but not having brought away specimens, I am unable to be quite certain of this. Those I have, adhering to shells, are not this species, but *B. porcatus* or *B. crenatus*. Now *B. balanoides*, according to Darwin, is a species that lives only between tide-marks; if this is correct, then it could scarcely have grown on stones lying in water so deep as is indicated by the shells in this clay; and its presence could be explained only by some such theory as I have suggested. It would be an interesting fact should the *Balani* on the upper surface prove to be of a deep-water species, and those on the lower of a tidal one.

sionally exhibits black stains, as if from the decay of sea-weed that had been attached to the stone. I likewise noticed the *Littorina litorea* close beside a large boulder, as if it had been sticking to the stone like the *Balani*, and had gone down with it.

These heavy boulders in the middle of this deep mass of fine marine clay, far from any high ground whence they could have rolled down, afford the best evidence I have seen of the action of floating ice during the glacial period; for by what other means can we suppose that stones of such weight could have been lodged here and there in the midst of a bed of the finest sediment, having all the appearance of a tranquil deposit. The large shells of the *Cyprina Islandica* are very numerous and perfectly entire, and lie gaping half open and filled with fine mud. Even the most delicate bivalves, such as the *Nucula tenuis* and *Leda pygmæa*, occur entire, with the epidermis quite unruffled; and it is just alongside of such as these that we see now and then a boulder of some 2 or 3 feet in diameter. It was under the friendly guidance of Mr. Smith, of Jordan Hill, that in 1860 I made my first acquaintance with these Paisley beds, and he particularly drew my attention to the evidence of tranquillity, and of the long-continued presence of the sea, afforded by the growth of *Balani* on the upper surface of the stones.

d. *Stratified Beds at high levels.*—Beds of stratified clay and earthy matter may sometimes be observed at high levels. I have myself described a remarkable instance of such near Pitlochrie in Perthshire, where a thick bed of stratified débris stretches up to a height of 1200 feet above the sea. Although some of these may be marine, yet in the total absence of fossils I think it unsafe to rely upon any of those hitherto adduced as evidences of submergence, owing to the fact that similar stratified beds are frequently found in alpine districts that have been occupied by glaciers, as we know from the accounts of the Upper Himalayan valleys by Dr. Thomson and Dr. Hooker. Charpentier also mentions their occurrence in Switzerland, and describes how they may have been formed. Moraine-matter is occasionally deposited in singular situations in this way when it falls into a lake or pool confined by the ice.

Although, therefore, we have evidence from marine shells of submergence in Scotland up to 500 feet above the present sea-level, we are still in the dark as to the exact upper limit of this submergence. The marine beds are so very barren of fossils, at least on the eastern side of Scotland, that their occurrence is the rare exception, and their absence the rule; we are therefore not entitled to say that the submergence reached no higher than 500 feet, merely because marine fossils have not been discovered at greater heights. There are many places, even in the lower grounds, where the character of the superficial débris is such that it is doubtful whether it should be referred to submarine or supra-marine action, the true marine clay of this period being occasionally so charged with stones as to resemble some of the softer varieties of glacier-mud; and at high levels this is more generally the case. If it be also the fact, as I have already hinted, that the marine beds have been deranged, and sometimes

remanié by glacier-action, the confusion becomes still more confounded. Such obscure portions must be deciphered by the aid of the clear evidence afforded by more favourable localities. It seems indeed to be the character of glacial deposits in general, whether formed on land or in water, to have a confused arrangement, so that the character of a section changes at almost every step; and this may help to distinguish them from ordinary marine beds, whose sections have regular features over wide areas.

e. *Cause of the submergence.*—It is worthy of remark that in Scandinavia and North America, as well as in Scotland, we have evidence of a depression of the land following close upon the presence of the great ice-covering; and, singular to say, the height to which marine fossils have been found in all these countries is very nearly the same. It has occurred to me that the enormous weight of ice thrown upon the land may have had something to do with this depression. Agassiz considers the ice to have been a mile thick in some parts of America; and everything points to a great thickness in Scandinavia and North Britain. We don't know what is the state of the matter on which the solid crust of the earth reposes. If it is in a state of fusion, a depression might take place from a cause of this kind, and then the melting of the ice would account for the rising of the land, which seems to have followed upon the decrease of the glaciers.

§ 5. Emergence of Land and final retreat of the Glaciers.

a. *Valley-Gravel.*—Along the course of all our larger river-valleys, as in those of the Spey, the Dee and Don, the Tay, and others, we find extensive beds and terraces of rolled gravel, which seem to be of later date than the laminated clay with Arctic shells, seeing that in the lower parts of the valleys the gravel overlies this clay. The more recent origin of the gravel is further proved by its sometimes containing rolled lumps or nodules of the laminated clay, showing that the latter must have suffered some denudation.

In the absence of all fossils it is often impossible to distinguish freshwater gravel from that which is marine; for water arranges sand and pebbles in the same way whether it be salt or fresh. False bedding, as Mr. Sorby has pointed out, will sometimes help us to trace the effect of tidal action; although it is well to bear in mind that back eddies often occur along the sides of a river, so that oblique laminæ pointing in reverse directions may occur even in freshwater beds. I am therefore of opinion that it is only when this feature is well developed that we can rely upon it as a test.

Beds of gravel are by no means uncommon in the marine glacial deposits, and in some of the lower districts I have occasionally observed this "oscillating current structure," as Mr. Sorby terms it, very well developed. At Ladybank railway-station in Fife, I have noticed some good examples of it in a large side-cutting, also in some sand-pits at Old Aberdeen. In the great shoals of gravel, however, which overspread the bottom of the valleys in the more hilly districts, I have never observed any decided instance of this

structure; and along some of our Highland rivers, the Dee for example, we may trace this gravel for more than fifty miles inland, namely, from the sea-coast to their very source in the midst of the Grampians. In some places it is spread out in wide sheets; in others it lies in large irregular mounds. The sections displaying its internal structure vary greatly in their character. Beds of fine laminated sand occur oddly intermixed with heaps of large pebbles, and often exhibiting very curious undulations. All the materials are usually much water-worn and well washed, so as to be free from muddy sediment. No fossils occur, neither do the stones exhibit the glacial striæ. In following up the course of a valley we sometimes find a great aggregation of this rolled gravel at certain points, with intermediate spaces along which comparatively little of it occurs.

There can be no doubt that much of this *valley-gravel*, as we may call it, has been the result of the long-continued action of the rivers since they came into play after the glaciers commenced their final retreat. Its distribution and mode of arrangement show that it has been deposited by water flowing down the valleys, and as we know that glaciers previously occupied these valleys, there is good reason for supposing that, as they gradually melted and withdrew to the mountains, they would give rise to much watery action. Those who have studied glaciers with most attention tell us that they produce, by friction on their rocky bed, much sand and gravel, which is strewed in front of them by the water issuing from beneath the ice. If, therefore, we conceive a sheet of such gravel to lie in front of a glacier, and a succession of snowy seasons to cause a temporary advance of the ice, the result would probably be that the end of the glacier would push into the gravel and raise it into a steep curving mound all along its border, and thus form an elongated narrow ridge, such as we see in certain parts of Scotland, where they are sometimes called *kaims*. I do not mean to say that all the kaims have been formed in this way, but many of them probably were. The descriptions of the Himalayan valleys by Dr. Thomson, Dr. Hooker, and Captain Godwin-Austen show that these great glens (which were formerly occupied by glaciers) now exhibit mounds and terraces of gravel which, on a great scale, seem to be an exact counterpart of those in the valleys of our Scottish Highlands; and it is impossible to read their descriptions without being struck with the close resemblance of the superficial features, not only as regards the gravel-terraces, but also the moraine-heaps, the large transported boulders, and the occasional traces of what seem to have been glacier-lakes.

In the valley of the Spey there seems to have been a large lake extending from Kinrara towards Laggan. The bottom of the valley near Kingussie is filled with deep masses of pure sand, which was well exposed in the cuttings for the Highland railway. In one of these I saw a thickness of 30 feet of the finest sand, without a pebble, passing at the bottom into a sort of silt, but no fossils could be perceived here or anywhere else along the valley. I think this

lake has been caused by the glaciers of the Cairngorm mountains barricading the valley near Aviemore; for I found the fine sandy beds terminate towards Rothiemurcus, while great quantities of granite-boulders and well-marked moraines occur on the flanks of the hills on the west side of the Spey to the north of Aviemore. The mineral quality of the débris composing these moraines is such as to lead one to believe that they are due to glaciers that proceeded from the high mountains on the opposite side of the valley, while their position further accords with this notion. We may easily suppose that many lakes and large pools would arise from causes of this nature, and from the irregular masses of débris left by the glaciers acting as dams here and there, so as to obstruct the drainage of the valleys.

In Arctic countries the periodical thawing of the ice occasions great floods in the rivers, which at such times rise to great heights, and overflow their banks to an extent that we in this country can scarcely believe; and there seems every reason to think that towards the close of the Glacial period a similar state of things prevailed here. I am therefore disposed to credit the rivers with a large share in the formation of our valley-gravels, as I did in a former paper some years ago*. Nevertheless I still maintain, as I did then, that there are some of these gravel-beds which mere river-action will not explain. Thus at the northern extremity of the valley of the Caledonian Canal, near Inverness, there are masses of coarse water-worn gravel, rudely piled together in heaps, 200 feet thick, and which I traced up the flank of the hill near the Lunatic Asylum to a height of 400 feet. Some of the pebbles are so large that one might with more propriety call them boulders, instances being seen of a diameter of from 2 to 4 feet. The stones, however, are all water-rolled, and show no glacial striæ. The stratification of this gravel is often very far from horizontal, great undulations appearing without any good development of false bedding. There is no very great difference in the nature of the stuff from top to bottom, so far as I saw; there is no clay, nor even silt; all is of washed gravel, with here and there some seams of fine sand, and there seems to be a complete absence of all fossils.

Now this valley of the Caledonian Canal forms a great gash across Scotland from sea to sea, and its summit-level at Loch Oich is only about 90 feet high. How, then, can any river-action account for this immense pile of gravel near Inverness, reaching, as it does, to so much greater a height? The materials composing it look as if they had been derived from the rocks along the valley to the south-west; and if they have come from that direction, how did they get past Loch Ness, which is of great depth, in some places 780 feet. I remarked that the pebbles are of various kinds of metamorphic and crystalline schists, red sandstone and conglomerate, granites and porphyries. This accumulation of gravel extends for a mile or two south-west of Inverness, beyond which it is not remarkable. Its greatest development is near Dun Ian, where there is a good exposure

* Quart. Journ. Geol. Soc. vol. xvi. p. 353.

of it in the flank of the little hill called Torvane, or Tor Bhain, which seems to be entirely composed of gravel.

Believing that glaciers occupied the valley of the Caledonian Canal both before and after the period represented by the marine beds with Arctic shells, I cannot help thinking they had something to do with the formation of this remarkable heap of gravel; and if we might believe that the débris brought down by the glaciers was acted upon by the sea beating upon the terminal moraines, it might help to explain the water-worn character of the stuff, as well as the terraced appearance which it frequently presents.

A somewhat similar accumulation of gravel and pebbles, although not so extensive, is seen at the entrance to Loch Treig, and there is also a prodigious quantity of it on the west side of the Spey, near Fochabers.

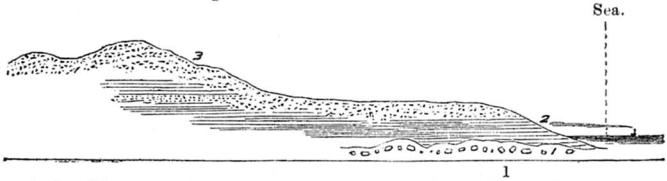
In the low grounds away from the mountains the superficial masses of rolled gravel are often of dubious origin, owing to the difficulty, where no fossils occur, of distinguishing that which is marine from what has been due to subsequent freshwater and glacial action. It seems likely that a good deal of gravel would be formed by the sea while the land was recovering from the depression that took place during the time that the marine clay was forming. If any sudden movements of elevation occurred, there must of necessity have arisen strong currents off the land, with several oscillations, which would effect a considerable denudation of the soft recently formed marine beds, and probably produce a large amount of rolled gravel. The tails of gravel on the seaward side of the rocky eminences near Edinburgh, long ago noticed by Sir James Hall, can hardly be referred to any river-action, and the marks of denudation around the Castle-rock and the base of Arthur's Seat show that some agency must have been in operation, subsequent to the deposition of the fine laminated clay near Lochend and Portobello, to carry off the small loose débris and sweep the surface bare.

At Aberdeen, and to the north of that city, there are mounds of loose gravel which are of later origin than the laminated clay containing Arctic shells; and Dr. Fleming tells us that Agassiz in 1840, on looking at some of these, pronounced them to be moraines. This would imply that the glaciers here extended to the present sea-coast after the deposition of the clay. At Belhelvie, four miles north of Aberdeen, there are remarkable piles of gravel, close to the sea, forming large irregular mounds. This gravel is certainly of more recent deposition than the clay close beside it, which contains Arctic shells (see Appendix). Its boundary to the north, at Millden, is sharply defined, and it seems to be a continuation of the gravel of the valley of the River Don, for I have traced it across the low intervening ground into that valley at a place called Dyce, four miles distant, where there is another large accumulation of it.

The River Don makes a sudden bend to the south at Dyce, and enters the sea two miles to the north of Aberdeen; but the valley-gravel does not follow it along that part of its course, but goes straight out to sea at Belhelvie, forming a series of mounds all the

way. Some of these mounds (especially those near the Corbie Loch) are certainly of a moraine-like character; but in general they consist of pebbly shingle and small gravel, like what mere watery action would produce; and this is the character of those large mounds near the coast, which I have already mentioned.

Fig. 6.—*Section at Belhelvie.*



1. Boulder-earth (inserted on the authority of Dr. Fleming).
2. Fine laminated clay and sand, containing remains of Arctic shells.
3. Gravel.

The moraine-character is much more strikingly displayed in the heaps of boulders and rough stony débris which cover the hills of Nigg—a set of low eminences running out to the coast immediately to the south of Aberdeen, and reaching an elevation of from 200 to 300 feet above the sea. These mounds of rough stony rubbish may be well seen beside a small lake called the Loch of Loirston, a little westward of the first railway-station to the south of Aberdeen, called the Cove. A good section of them is exposed at the mud-cliff facing the Bay of Nigg, where they are seen to rest directly upon the hard grey boulder-earth. The position and general character of these piles of stony rubbish at Nigg and Loirston would be explained by supposing them to be the moraine of a glacier filling the valley of the Dee; and I do not see how else they can be accounted for.

The foregoing observations will serve to show that these gravel-beds form a subject of much interest and difficulty, and one that will require a great deal of careful study before we can understand it thoroughly. Cases may have occurred of glacier-lakes bursting among the mountains, and sending a sudden deluge down the valleys, as sometimes occurs in the Alps and Himalaya at the present day. The letting off of the Glen Roy lakes, for example (if they were of this nature, as I believe them to have been), might have produced a considerable effect. The lowering of the water from the highest to the middle line, and from that to the lowest, would set free a large body of water into the valley of the Spey, while the final exit of the contents both of Loch Roy and Loch Gluoy would have been by the Caledonian Canal valley. Query, had this anything to do with the gravel-beds near Inverness, or with those in Strathspey?

In whatever way we are to account for the valley-gravel, it can be shown to be posterior to the laminated marine clay containing Arctic shells, both by the tests of superposition and of included fragments. It therefore represents a decided change of conditions fol-

lowing after those represented by the clay; and this is the point I am chiefly contending for in the present paper.

I am not aware that any evidence has as yet been got entitling us to say that the Mammoth or *Rhinoceros tichorinus* lived in Scotland after the Glacial period. No Mammalian remains have as yet been reported from our valley-gravel, which is singularly destitute of fossils of every kind.

b. *Moraines.*—Moraines occur in most, if not all, of the chief mountain-glens; and in tracing the valley-gravel up to the mountains, we frequently find it emerge into moraines.

In regard to the mounds in Glen Derry and other ravines of the Ben Muick Dhui mountains, I was formerly inclined to doubt their glacial origin, being at that time disposed to refer a larger amount of influence to marine agency in accounting for the superficial accumulations of our Highland glens. Our geological maps make the Ben Muick Dhui and Cairngorm mountains to be wholly of granite; and I remarked that these mounds in Glen Derry contained fragments of gneiss and laminated quartz, which was a circumstance opposed to the theory of their being glacier-moraines, if the maps were correct. I have, however, since satisfied myself that masses of metamorphic schist do occur in the midst of this mountain-group where our maps show nothing but granite, and therefore I no longer consider the above circumstance any difficulty. The absence of glacial striæ on the fragments, which I also mentioned, is likewise quite intelligible where the débris consists of stuff that lay on the surface of the glacier, for it is only that which lies between the ice and its rocky bed that is scratched.

There are some fine moraines in the glens that pierce the north flank of the Cairngorm mountains, as, for example, in Glen Innich and near Loch na Eilan and Loch Morlich. Those in Glen Spean, to the east of the entrance to Loch Treig, shown in my map of the Parallel Roads of Glen Roy, are also remarkably fine. To look at them is for ever to cease to doubt the former existence of glaciers in this country. The student of such phænomena will do well to betake himself to this region, or to the Cuchullin mountains of Skye, where Principal Forbes many years ago showed that there exists a fine exhibition of glacial action—or to the valleys of Caernarvonshire, which have been so well described by Buckland, Darwin, and Ramsay.

c. *Submarine Forest-beds.*—After the low grounds had emerged from the glacial sea, and the ice had retreated to the mountains, we have evidence that the land-area was more extensive in some districts than it is at present, owing to its higher elevation out of the sea. The evidence of this is, I think, sufficiently clear, and consists of the so-called submarine forests and beds of peat passing underneath the present sea-waters. In some of these cases the stumps of the trees may be traced, rooted manifestly in the spot where they grew, and surrounded by leaves, nuts, and seeds of land-plants. In regard to this point I shall content myself with referring to Dr. Fleming's account of the submarine forest in the Firth of Tay*,

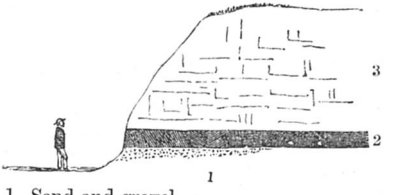
* Trans. Royal Soc. of Edinburgh, vol. ix. p. 419 (1823).

and to the same author's notice of the one in Largo Bay in the Firth of Forth*. Although Fleming's theory regarding these forest-beds was, I consider, erroneous, yet his facts are always valuable, and he entertained no doubt whatever as to the tree-roots in both of these cases being in the place where they grew, and he enumerates Birch, Hazel, and Alder as the prevailing species.

In the valley of the Tay this bed of peat is known to occur along a stretch of many miles, from the mouth of the Earn to Balmerino in Fife. It forms the bed of the present estuary in many places, and the tree-roots in it are frequently a source of annoyance to the salmon-fishers in hauling their nets. Now this bed of peat, full of remains of trees, passes right underneath the *Carse*, or old estuarine mud of the Tay. It does not intermingle with this clay, but lies clearly below it in a continuous stratum; and those engaged in sinking deep pits and wells near Abernethy are familiar with the fact that, after passing through some twenty feet of this fine silty clay, they get a bed of peat two or three feet thick, and beneath that no Carse-clay is found. Mr. George Buist deserves the credit of having clearly pointed out this in his memoir on the Geology of the south-east of Perthshire, in the 13th vol. of the Transactions of the Highland Society. I examined this peat-bed along the banks of some small streams that join the Earn, near Abernethy, and found it to be about 3 feet thick, in some places quite full of remains of trees, and lying clearly below the whole mass of Carse-clay. Dr. Dickie, who has examined for me some of the specimens I brought home, reports the trees to be Birch and Alder. Below the peat there is often a stratum of gravelly sand. The peat does not lie in disjointed masses as if it had been drifted, but, so far as I saw, forms a regular continuous bed of pretty uniform thickness and much compressed.

Near the farm of Invernethy I traced its outer edge, where it runs out apparently on the surface of some laminated clay, the boulder-earth emerging at a short distance. Dr. Fleming also states that at Largo Bay the tree-stumps are rooted in laminated brown clay.

Fig. 7.—*Section near Abernethy.*



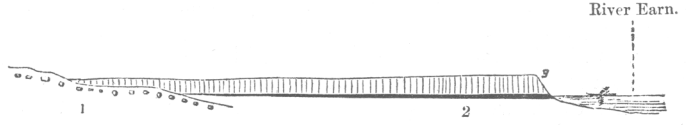
1. Sand and gravel.
2. Peat, full of remains of Birch and Alder.
3. Carse-clay, or old estuarine mud of the Tay.

A bed of peat, occupying the same geological position, is found in some places beneath the Carse-clay or old estuarine mud of the Forth, as we learn from Mr. Blackadder† and Mr. Home Drummond‡. This peat stratum was said to contain remains of Birch and Alder, together with seeds of a plant supposed to belong to the genus *Pedicularis*. In the Carse-clay immediately above it, part of

* Quart. Journ. of Science, Lit., and Art. vol. xxix. p. 21 (1830).
† Memoirs of the Wernerian Society, vol. v. p. 424.
‡ *Ibid.* vol. v. p. 440.

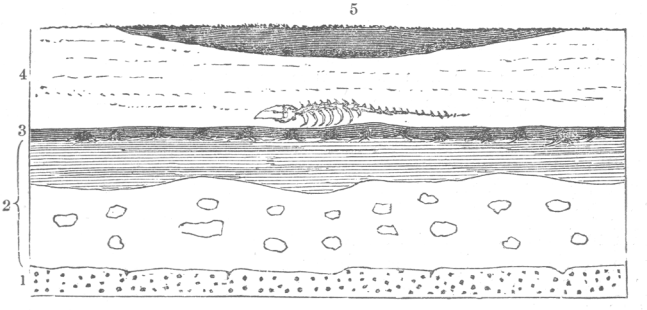
the skeleton of a whale was got at Blair Drummond. I have also seen a stratum of peat, containing remains of trees below the raised estuarine mud of the Ythan in Aberdeenshire, the clay above it containing remains of *Scrobicularia piperata* and other estuarine shells. This was exposed in cutting a deep drain near the village of Newburgh; there was a thickness of 8 feet of clay and silt above the peat in some places (see fig. 10).

Fig. 8.—*Section near Abernethy.*



1. Boulder-earth.
2. Bed of peat, with remains of trees.
3. Carse, or old estuarine mud of the Tay.

Fig. 9.—*Diagram showing the relations of the superficial Deposits at Blair Drummond, in the Valley of the Forth.*



1. Sandstone-rock.
2. Glacial beds.
3. Peat with remains of trees.
4. Carse-clay with bones of the Whale.
5. Peat, with roots of oak-trees at the bottom, and remains of an old wooden road.

I by no means deny the existence of *drift-peat*, for I am well aware that rivers flowing through mosses often float away great lumps of peat, as I have myself seen, but this need not blind us to the fact that there are also tracts of submerged peat, with remains of forest-trees, that have not been drifted, but lie where they grew. I believe, therefore, that this extensive bed beneath the Carse of Tay, together with the others I have mentioned, represents a land-surface of the period preceding the deposition of the old estuarine mud, and that it is not a mere local phænomenon, but will be found in the same geological position along many other parts of the coast. The submarine forest on the coast of Lincolnshire, explored by Sir Joseph Banks and Dr. Correa de Serra, appears to belong to the same period, for in some places there is said to be sixteen feet of

soil above it *. Hugh Miller tells us that in making a gas-tank at Rothesay, in the Isle of Bute, a bed of peat-moss, abounding in remains of trees and hazel-nuts, was found covered by seven feet of gravel. Miller classes this peat-bed with the submarine forests, and the overlying gravel he considers to be a raised beach (Sketch-book of Geology, p. 321). The peat here was 18 inches deep, and rested upon stratified sand and clay with marine Arctic shells.

De la Beche, in his Report on the Geology of Cornwall, Devon, and West Somerset, informs us that in the South of England these submarine forests are generally covered by estuarine deposits and gravel beaches containing shells of the species now living on our shores, and in the twenty-fourth chapter of his 'Geological Observer,' he gives a most instructive account of the subject in general. It seems to me that we entirely misapprehend the significance of these phænomena, if we suppose them to be due to mere local accidents that have affected a small bit of ground here and there along the coast. In truth they may be traced round the whole of Britain and Ireland, from Orkney to Cornwall, from Mayo to the shores of Fife, and even, it would seem, along a great part of the western sea-board of Europe, as if they bore witness to a period of widespread elevation, when Ireland and Britain with all its numerous islands formed one mass of dry land, united to the Continent, and stretching out into the Atlantic. Indeed, without something of this sort, how can we account for the immigration of all the land animals and plants that have overspread these islands since the close of the Glacial period. They have all come from Europe, and how were they to get into Ireland, the Isle of Man, the Hebrides, and all the numerous islands of our west coast, without a land-route being open to them? Ice might have formed a bridge to some, but not to the greater part; and I maintain that the introduction of the present land flora and fauna of Scotland is almost wholly Postglacial, that is to say, posterior to the marine glacial beds, or the period of great submergence.

This bed of peat lying beneath the raised estuarine beds is the first appearance of that substance we meet with in Scotland; indeed the period during which peat was formed so extensively from the gradual accumulation of mosses, sedges, and various other plants, is perhaps even a stage later; for at the bottom of many of our peat-mosses we find remains of trees, and in some cases beds of shell-marl. These trees are all of existing species, now indigenous to Scotland. The Birch, Hazel, and Oak are amongst the most common, and hazel-nuts are frequently found. Now these trees testify, I think, to a condition more favourable to the growth of wood than what we have at present. They evidently preceded the commencement of the peat in a multitude of instances, for their roots are spread on the hard earthy subsoil beneath it, and it is since the death of these trees that many of our peat-mosses date. I am quite aware, however, that many extensive swampy mosses contain no remains of trees. The present or historical period is the true peat-period for Scotland; for this substance is growing rapidly just now,

* Trans. Roy. Soc. for 1799, p. 145.

and in the Western Isles Captain Thomas* has described how it has accumulated round the ancient stone circles in the Lewis, so as in some cases to envelope the stones completely, and even to cover the tops of a few of them; and he believes that these so-called Druidical monuments were erected before the peat began to grow there. It would seem that remains of trees are found at heights beyond where wood can now be got to grow. Thus in the Transactions of the Highland Society for March 1860, Mr. J. B. Webster, in a report on planting-operations at Balmoral, states that he had found the remains of old trees averaging from 6 to 12 inches in diameter at an elevation of 2500 feet above the sea, on the mountain called Lochnagar†; and Dr. Dickie, who has paid much attention to the zones of altitude of British plants, remarks, in his 'Botanist's Guide to the Counties of Aberdeen, Banff and Kincardine,' regarding the Scotch Fir (*Pinus sylvestris*), "The stems are to be seen in peat-mosses at high altitudes, where such trees cannot grow at the present day;" and in reference to the Birch (*Betula alba*) he says, "On the summit of the ridge north of Mount Keen, and at an elevation of 2200 feet, I have seen the dead remains of Birches far larger than any growing at lower altitudes on other mountains of the district." It may be said that the more generally wooded character of the surface before mankind began to multiply may have contributed to render the climate more favourable to forest vegetation. It is, however, clear that on the first disappearance of the ice, the trees must have had to make their way over a surface destitute of wood.

Although coniferous trees are not now indigenous to Orkney, yet a submarine forest, consisting of remains of small Fir trees rooted in their natural position, occurs in the Bay of Skaill, on the west side of Mainland Island, and is sometimes to be seen during ebb tide in situations where the sea during flood rises at least 15 feet above it. (See Edinburgh Phil. Journ. vol. iii. p. 101, 1820).

It is to the time of this old land-surface with its forest vegetation that the remains of the Irish Elk and the Great Wild Bull (*Bos primigenius*) seem mostly to belong, although the latter survived to a later period; for it is in the marl-beds below the peat that the skeletons of the *Megaceros* are generally found. Although its remains are very rare in Scotland, yet they have been got. Thus in a marl-bed underlying peat in the parish of Maybole, in Ayrshire, the skull and horns of one were found, measuring 10 feet 4 inches between the tips of the antlers, while the breadth of the palm of the antler was 2 feet 7 inches. Horns of the stag, and remains of a large ox with concave forehead (apparently *Bos primigenius*), were got along with it. (See Statistical Account of Parish of Maybole.)

* Edinb. New Phil. Journ., new series, vol. xv. p. 235, 1862.

† H. C. Watson, in his 'Cybele Britannica,' vol. ii. p. 410, says that the present upper limit of the fir-woods on Lochnagar is at 1950 feet, and he cites Mr. Winch for the fact of trunks of large Pines occurring in peat in the north of England at an elevation of nearly 3000 feet. Mr. Watson further states that roots of fir occur in peat at an elevation of 2400 feet and upwards on the elevated tablelands of Forfar and Aberdeen.

§ 6. Second Period of Depression.

a. *Old Estuarine Beds and Beaches.*—After the period represented by the forest-bed just described we have evidence of a depression of the coast, which seems to have been very general along the shores of this country. In the Firths of Tay and Forth this depression caused the sea to reach about 25 or 30 feet above the present coast-line, so as to cover the rich flat country of the *Carses*, as they are locally termed. These Carse-lands are plains of fine silty clay, quite free from stones, and identical in character with the sediment now forming along the shallows of the present estuaries. It forms a smooth level sheet of rich mud occupying the whole width of each valley, and encircling the little rocky eminences and mounds of old glacial débris that project through it, much in the same way as the waters of a lake do the islands on its surface. In the district of the Tay it forms the Carse of Gowrie, the garden of Scotland, together with the flat lands at the mouth of the Earn. A narrow strip of it extends even a little above Perth, towards Scone, forming the rich ground of the Muirtown farms.

The Carse of the Forth, however, is the most extensive tract of this nature in Scotland. It stretches for many miles inland, overlapping the eastern base of the moraine-hillocks of the Loch of Monteith, and extending through a narrow opening up to Gartmore; while below Stirling it forms a broad margin on the south side of the valley down to Grangemouth, and on the north side to Alloa. Mr. Blackadder gave a good account of it many years ago in the fifth volume of the Wernerian Society's Memoirs, with a map showing its boundaries. A fine view of this beautiful plain is got from Stirling Castle. Marine shells of the kinds generally found in estuaries occur in some places abundantly.

For example, on the banks of the Forth, near Micklewood, some five miles to the west of Stirling, there are seams of shells imbedded in the old estuarine mud up to a height of 6 feet above the surface of the river; and as the tide is not now felt so far up the Forth, the elevation above the sea must be a little more. The species I found here were:—

Cardium edule. Abundant; generally of small size.
Mytilus edulis. Common.
Ostrea edulis. Frequent; many of the shells are very thick.
Tellina solidula. Occasional.
Scrobicularia piperata. Not very numerous.
Rissoa ulvæ. Frequent.
Littorina litorea. Rare.
Fusus antiquus. One broken specimen.

The most abundant of these by far was the Cockle (*Cardium*), the clay being in some places quite crowded with their remains. The size is small, as if they were young shells; many of them are quite entire, but the generality are decayed and broken. These shells occur in an undulating seam, which sometimes passes underneath the surface of the water, and at others rises a few feet above it. Occasionally there are two seams.

I also observed shells (*Scrobicularia piperata*) in the same clay at Stirling; and at Polgavie on the Tay a bed of similar shells occurs in the raised estuarine mud overlying the peat-bed with trees.

Three or four instances have occurred of remains of the Whale in this Carse-clay of the Forth, namely at Dunmore, Airthrey, Blair-Drummond, and Micklewood. Those at Airthrey and Dunmore* were entire skeletons about 70 feet long, and were imbedded in the clay at a height of fully 20 feet above the present reach of the tide†. The depth of this old estuarine mud is in some places very great, more especially below Stirling, where Mr. Blackadder says a depth of 70 feet has been reached; and Mr. Bald informs us that near Alloa there is 90 feet of it. A mass of such extent and thickness must have required a long time for its accumulation. This clay is generally stiffest and contains least sand near the surface, so much so as to be frequently employed for making bricks and tiles. There are works of this nature at Stirling, Micklewood, Inchture, Perth, and elsewhere in the Carse; accordingly some people have confounded it with the older glacial clay, which is the stuff generally employed in Scotland for manufacturing bricks, tiles, and wares of that sort, although some of the beds of the Coal-measures are likewise used.

The fact of the Carse-clay extending up the Forth as far as Gartmore (see Mr. Blackadder's map), which is only ten miles from Ben Lomond and six from Ben Venne, and, fringing as with a smooth carpet the base of the moraine-hillocks of the Loch of Monteith, shows that it has been postglacial, and has never been disturbed by the ice. There is a remarkable absence of stones in it, even of the smallest pebbles.

The raised estuarine beds may be traced along the coast at various places, as at the Montrose basin, Aberdeen, and the mouth of the River Ythan, everywhere containing the same group of shells. The *Scrobicularia piperata* may be said to be characteristic of these beds; for it is not found in the glacial clays, and seems to have died out along the east coast of Scotland in many places where it was formerly abundant. In a fossil state it is plentiful in the raised estuarine mud of the Ythan, and also at Aberdeen, Montrose, and the Loch of Spynie, near Elgin, as well as in the Carse of the Forth. Mr. Gwyn Jeffreys tells me that it is not uncommon alive on the west coast of Scotland, and that it lives in the estuary of the Gotha, and other places on the coast of Sweden; its range, however, is essentially southward.

In tracing the distribution of these old estuarine deposits along the east coast of Scotland, I have remarked that their elevation becomes less as we proceed from the Firth of Forth to Aberdeenshire. In the basin of the Forth the Carse-clay lines the side of the valley to the height of 25 or 30 feet above the present sea-level. The old estuarine mud of the Tay reaches to about the same height. At the

* Edinb. Phil. Journ. vol. xi. p. 220 (1824).

† Edinb. Phil. Journ. vol. i. p. 393, where there is a good account of the finding of the Airthrey Whale by Mr. Bald (1819).

Montrose basin it seems to be less, or about 15 feet according to my observation, although I was unable to make a proper survey. But at the estuary of the Ythan in Aberdeenshire, where I have been able to make a leisurely examination and take measurements carefully, it does not exceed 8 feet above the limit of spring-tides; and at Aberdeen the elevation seems also to have been very little, only a few feet above high-water mark. In passing along the coast, therefore, from the Firth of Forth to Aberdeen the elevation is clearly less towards the latter point. A similar inference may be derived from an examination of the coast line generally. Near Edinburgh, as, for example, at the Craigentinny meadows, the raised beach may be distinctly seen, and has been well described by Charles Maclaren, Hugh Miller, and others, its height corresponding with the level of the Carse of the Forth. At St. Andrews in Fife, Mr. R. Walker* informs us that a mass of sandstone above high-water mark is riddled with Pholas-burrows. Between Dundee and Arbroath the old coast-line is very striking, at an elevation corresponding with the Carse of the Tay. Nowhere, however, from Stonehaven to Banff do we find evidence of a rise to the same extent, although at many points we can perceive that there has been an upheaval of a few feet. The amount of elevation has therefore been unequal, and consequently it is the land that has risen, and not the sea that has sunk.

b. *First traces of Man in Scotland.*—It is in these raised estuarine beds that the first traces of man have been found in Scotland. In his notice of the bones of a whale got in the Carse of the Forth at Blair Drummond, Mr. H. H. Drummond says, "It is a very singular circumstance that along with these bones there should have been found a fragment of a stag's horn, similar to that found along with the Airthrey whale, and having a similar round hole bored through it"†. This horn was sent, together with the bones, to the Museum of Edinburgh University. Several canoes of a primitive pattern, one of them containing a stone celt, have been found from time to time in the silt of the Clyde at Glasgow. Some of these were noticed by Mr. Robert Chambers, in his book on 'Ancient Sea-Margins,' in 1848, and more recently a very complete account of them has been drawn up by Mr. John Buchanan‡. The silt in which these canoes have occurred (more especially the one got in digging the foundations of St. Enoch's Church) is probably the equivalent of the Carse-clay of the Tay and Forth. Instances, indeed, are known of canoes having been found in the Carse of the Forth itself; but the circumstances of their occurrence have not been so well recorded.

The fact of some of the eminences that project through the Carse-clay bearing the Celtic appellation *Inch* or *Innis*, meaning an island, favours the opinion that these lands were under water during the time when that race had possession of the country, as Mr.

* Annals and Mag. Nat. Hist., 3rd ser. vol. xiv. p. 206, 1864.

† Memoirs of Wernerian Society, vol. v. p. 400 (1824).

‡ See Smith's 'Newer Pliocene Geology,' p. 160, and 'Glasgow, Past and Present,' also 'Report Brit. Assoc.' 1855, Trans. Sects. p. 80.

Chambers has remarked in his book just cited, although it would be unsafe to lay much stress on this circumstance, seeing that we find the same term occasionally applied to eminences similarly situated, which we cannot suppose to have been surrounded by water. Megginch, Inchmichael, and Inchture are all eminences in the Carse of Gowrie, which would be insulated if the tide were to cover that fertile plain. The term seems to be of less frequent occurrence in the Carse of Forth, although there are many similar eminences in it.

The species of Mollusca, whose remains occur in these estuarine beds, are all living at present, both in the seas of Britain, and also to the south of this country, while some of them are not known to live in the Arctic regions. The group is therefore different from that found in the glacial beds, and seems to have more relations to the south than to the north, indicating a climate, if anything, milder than the present. (See Appendix, No. 5.)

§ 7. Elevation of the Land to its present position.

a. *Beds of Peat and Blown Sand.*—After the deep masses of estuarine mud had been deposited at the mouth of the Tay, Forth, and other rivers, together with the corresponding gravel-beds and shingle-beaches along the coast, the land was elevated to its present level. Whether this took place suddenly, or by a gradual imperceptible movement, we do not know, and of the date of the event we are also ignorant. It has generally been supposed to have occurred before the Roman invasion; but this is doubtful; for Mr. Archibald Geikie, a most intelligent and accomplished geologist, after having made a special study of the question, has come to the opposite conclusion. I am unable to adduce anything new upon this point, and shall therefore content myself with referring to Mr. Geikie's interesting paper in the eighteenth volume of the Society's Journal, where the subject is ably discussed.

Although, therefore, we cannot tell exactly when the land attained its present level, the time is evidently remote when the extensive Carse district of the Forth was completely under water; for there seems to be no local tradition of such a state of things, and the depth of peat-moss which we find on the top of this raised estuarine mud at Blair-Drummond, and elsewhere, affords good evidence of a supramarine condition having prevailed for many centuries. Mr. Blackadder * tells us that this upper peat is from 8 to 14 feet deep in some places, and that remains of large oak-trees occur at the bottom of it, with their stumps rooted in the subjacent soil. These trees, we are informed, often bear distinct impressions of the axe, and a double row of the felled trunks have been laid to form a road across the swamp. This wooden causeway now lies at the bottom of the peat. The felling of the trees, and the construction of the road, have been ascribed to the Roman army under Severus, but I know not on what authority—probably on little else than mere conjecture. Some valuable tracts of Carse-soil have been reclaimed merely by clearing off the superincumbent peat; but large patches of it still remain.

* Wernerian Memoirs, vol. v. p. 424 (1824).

We see, then, that after the estuarine mud was raised above the reach of the tide, oak-trees grew upon it, and, since these have been cut down, a thick bed of peat has gradually accumulated over their roots. All this, of necessity, implies the lapse of much time. The extensive masses of blown sand that have accumulated on some parts of the coast since the land attained its present level afford additional evidence of the length of time that has elapsed since the event. The most remarkable of these in the district of which I am treating are the sands of Culbin in the Moray Firth, of Forvie and Foveran on the Aberdeenshire coast, and of Barry at the entrance to the Firth of Tay. These great heaps seem to have some connexion with the rivers entering the sea in their neighbourhood. Thus the masses at Culbin are probably derived in a great measure from the sand brought down by the Spey, the Findhorn, and the Nairn. Those on the coast of Aberdeenshire from what has been brought down by the Dee, Don, and Ythan, while the accumulations at Barry probably represent to some degree the sand of the Tay and the Earn.

b. Shell-mounds and Chipped Flints.—Another thing worthy of notice is the occurrence of old shell-mounds on the raised beach. Several of these occur at the mouth of the Ythan, in the desolate tract of drifted sand just mentioned, more especially on the north side of the river. There are hills of blown sand here 120 feet high. The shell-heaps are generally of an elliptical form, and from 30 to 90 yards in length. I have examined several of them, in company with my friend Mr. Robert Dawson of Cruden. We found them to consist usually of a thin stratum of decayed shells, reposing on a surface of drifted sand; but in one of them the mass of shells is 4 or 5 feet deep. These shells belong to the edible species of Mollusca now inhabiting the adjoining estuary, being chiefly mussels, cockles, and periwinkles. Mixed with them we frequently find some black carbonaceous matter like charred turf, together with pieces of burnt twigs. There are also a great number of stones, many of which appear to have been in a fire, and occasionally the sand underneath the spots where the charred turf and burnt stones occur is somewhat redder than usual, as if it had formed a hearth. Pieces of artificially chipped flint occur on the surface of some of the mounds, and are found abundantly in the immediate neighbourhood of one of them. A few of these flints lying on the mounds seem likewise to have been exposed to heat. Some teeth and split bones are also to be met with, but we found no pottery, nor anything made of metal in the Forvie mounds. The quantity of stones and pebbles on the surface of some of them is a curious feature. They seem to have a considerable resemblance, in many respects, to the Kjökkenmöddings of Denmark. Their antiquity, however, does not seem to be very great. The base of the largest of them is not 4 feet above the present reach of the tides in the estuary of the river, which shows that the land must have been as high as it is at present when they were formed. They are therefore later than the raised beaches and estuarine beds;

some of them perhaps a good deal later, seeing that there is much blown sand underneath them. I have also observed great quantities of artificially-chipped flints in certain places along the coast, both to the north and south of the Ythan, often in positions a very few feet above high-water-mark. These flints lie in many cases on a bed of smooth water-worn pebbles of the old beach, and the sharp broken edges of the flints show they have undergone none of the water-rolling that has rounded the pebbles, but have been brought there at a later time.

It is very probable that among the poorer and less civilized inhabitants the use of stone tools may have continued to a comparatively late period. No one who has seen the primitive implements still in use in some of the Western Isles of Scotland will think this unlikely. I therefore do not consider that the fact of such remains being found to be of later date than the raised beach forms an objection of any weight to Mr. Geikie's opinion as to this last elevation being posterior to the Roman invasion. A tribe of these "flint folks" seems to have inhabited this neighbourhood for a long period; for I have observed the débris of the stone manufacture, and traces of their encampments, in various places. The flints were doubtless got from the long ridge covered with these pebbles which runs inland from Peterhead.

§ 8. Conclusion and Résumé.

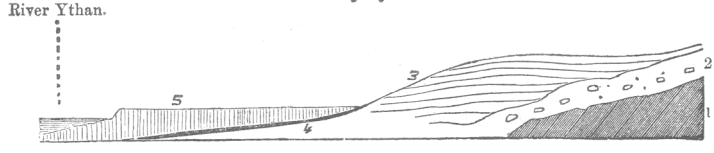
Such, then, are the series of changes which I believe have taken place since the commencement of the Glacial period. This succession has not been arrived at by picking out and putting together facts from distant places, and thereby erroneously inferring things to be successive which were perhaps contemporaneous; for we find the whole series represented in one locality. Thus, in the valley of the Forth above Stirling (fig. 9), we have (1st) at the surface the deep peat-mosses of Polder and Blair-Drummond, with their felled trees and ancient road at the bottom, all resting on (2nd) the old estuarine mud or Carse of Stirling, with its whale-skeletons and beds of estuarine shells; and below this we have (3rd) the lower peat-bed and trees of the submarine forest, or period of elevation; (4th) we have the later glacier-moraines of the Loch of Monteith emerging from beneath this postglacial series; (5th) we have the glacial-marine beds extending from Bucklyvie along the Forth and Clyde Junction Railway to Drymen, from their higher position evidently older than the moraines just mentioned, and shown to be a sea-deposit from the boreal shells they contain at Gartness; (6th) we have all along the valley, from Ben Lomond to Stirling and Edinburgh, and underlying the whole of the superficial deposits, the ice-worn floor of solid rock, covered here and there with the old glacier-mud and scratched boulders, and in this old boulder-earth, at Clifton Hall, there was found a tusk of the Mammoth.

In the valley of the Tay we have the raised estuarine mud of the Carse of Gowrie, with its bed of estuarine shells lying on the top of the peat-bed or submarine forest of the Tay at Polgavie and elsewhere. Emerging from beneath this postglacial series we have

the marine clay, at Errol brickwork, full of Arctic shells *in situ*, and reposing on the irregular surface of the azoic boulder-earth.

Even in the little valley of the Ythan we have a very complete exhibition of the series. Thus, in the section opened up by the railway, where it crosses the valley near Ellon (fig. 2), we have, commencing at the bottom (1st), the ice-worn gneiss covered by the grey glacier-mud with heavy scratched boulders all brought from the westward, and (2nd) reposing on this a mass of fine laminated red marine clay, found to be upwards of 20 feet deep at the foundation of the railway bridge; (3rd) resting on this clay at the bridge there is a mass of rough valley-gravel 15 feet thick; while, more recent than all these, we find at the estuary, fig. 10, (4th) the bed of peat with remains of trees resting on the gravel; (5th) the raised estuarine mud with shells on the top of this peat; and (6th) covering this raised estuarine silt we have heavy masses of blown sand, old shell-mounds and chipped flints, and in some places a little peat.

Fig. 10.—*Section showing the relations of the superficial Deposits in the Estuary of the Ythan.*



1. Gneiss-rock.
2. Boulder-earth, or *Glacier-mud.*
3. Fine stratified clay and sand, or *Glacial-marine beds.*
4. Stratum of peat.
5. Old estuarine beds with shells.

I therefore infer, from the evidence adduced in this and my former papers, that in Scotland there has been a succession of conditions during the Post-tertiary period somewhat as follows:—

1st. After the deposition of the Crag-gravel, and after the Mammoth had lived in Scotland, the country was covered with a great depth of snow and ice, which must have extinguished the pre-existing flora and fauna. This ice moved outwards in broad streams from the great watersheds of the country, carrying with it much stony débris and multitudes of boulders, which it left in irregular sheets, constituting the old boulder-clay or "*till*" of some authors; the ice also scratched and furrowed the rocks, destroyed the pre-existing alluvium, and exercised a considerable amount of abrasion on the surface of the country.

2nd. After this state of things had continued for a time, a depression of the land took place to the extent of some hundreds of feet, so that all the lower grounds were below the sea-level, but as to the full extent of the depression we are still ignorant. During this submergence the brick-clays containing Arctic shells were deposited, boulders were drifted here and there by floating ice, and it seems probable that the ice still covered much of the land, and even protruded into the sea along the main valleys in the form of large glacier-streams; so that the condition of the country would have been like the present state of Spitzbergen.

3rd. The country emerged from the water, but ice still lay on much of the land, and perhaps reoccupied some of the tracts over which the sea had spread, deranging by its intrusive action the marine beds of the preceding period.

4th. The glaciers at length began their final retreat, leaving behind them heaps of rough débris and mounds of gravel, more especially at those points where they halted for a time. Large quantities of rolled gravel were also strewed along the valleys by the water issuing from beneath the ice, and by the floods occasioned by rapid thaws, the absence of vegetation on much of the surface probably contributing to the effect.

5th. By this time the land attained a higher level than it has at present, so that the area of Britain was much larger than it is now, and, instead of presenting the appearance of a group of islands, formed a mass of connected land united to the Continent of Europe, the flora and fauna of which now spread into it. Woods of Birch, Hazel, Alder, and other trees covered the surface, and the Great Irish Elk, the Red Deer, the Great Wild Bull, the Wolf, the Bear, the Beaver, and probably the Reindeer, were amongst its inhabitants. In the valleys the rivers were gradually cutting their way through the masses of glacial débris to lower levels, and in doing so spread out much gravel and alluvial soil along their banks. This period is represented by the submarine forest and bed of peat underlying the Carses of the Tay and Forth.

6th. A depression now took place, cutting off the land-connexion with the Continent, isolating Ireland and the various islands, and thus stopping the land-migration from Europe. In the valley of the Tay and Forth this old coast-line was 25 or 30 feet above the present, but on the coast of Aberdeenshire not beyond 8 or 10. The old estuarine beds, or Carses, of the Forth, Tay, and other rivers were formed, together with corresponding shingle-beaches and caves along the coast. Man having by this time got into the country, evidence of his presence appears in the shape of canoes and primitive weapons of stone and horn buried in deposits of the period.

7th. A movement of elevation (whether gradual or sudden is uncertain) at length took place, so that the land attained its present position, thereby laying dry the Carse districts and old coast-line. Since this occurred much peat has been formed, and a great amount of blown sand has been heaped up on certain parts of the coast. In some districts the natives continued for a time to use tools and weapons of flint and stone, and left shell-mounds in the neighbourhood of the estuaries. Some of the wild animals were gradually extirpated, such as the Great Wild Bull, the Bear, the Beaver, the Wolf, and the Capercailzie,—the Great Elk and the Reindeer having probably disappeared at an earlier period. Since the dawn of Scottish history, and the occupation of the lowlands by the Saxon race, no noticeable change of level has been observed.

§ 9. Appendix, with Lists of Shells.

The following lists of shells owe their value almost entirely to the kind assistance I have received from Mr. J. Gwyn Jeffreys, F.R.S.,

&c., who has inspected my collection, and determined the species. The geographical distribution is also entirely on his authority.

I have inserted two species got at Elie by the Rev. Mr. Brown which are not in my own collection; for the others I am myself responsible. The names adopted are those proposed by Mr. Jeffreys. In regard to the British species I have appended as synonyms those of Forbes and Hanley where they happen to be different.

Explanatory Note regarding the Localities on the East of Scotland, referred to in the following List.

Annochie. On the Aberdeenshire coast, about five miles north of the town of Peterhead. The shells are entire, with the epidermis generally remaining; they are, however, much decayed, and are dispersed through a bed of fine clay, only a few feet above the sea-level, and passing underneath the beach. *Foraminifera* occur in this clay.

Auchleuchries. Twenty miles north of Aberdeen and seven miles inland. The shells occur in broken fragments, at an elevation of about 300 feet above the sea, in a thick mass of gravel forming the crest of a low hill. The fragments are very scarce, and occur deep in the gravel.

Belhelvie. A clay-pit close on the sea, five miles north of Aberdeen, and 30 or 40 feet above high-water-mark. The shells occur generally in fragments in a blackish stratum in the midst of a bed of laminated clay and sand. Dr. Fleming, who had visited it often when the section was better exposed than it is now, says this fine laminated clay "rests on the ordinary boulder-clay, and is covered by the usual sands and gravels."

Ednie. A bed of fine laminated clay on the north bank of the Ugie River, and four miles from Peterhead, and at no great height above the sea. The shells are scanty, and occur usually in broken fragments in a thin seam in the midst of the clay. The large *Saxicava*, however, has been got here entire.

Elie. On the coast of Fife, eleven miles south of St. Andrews. The shells are in a bad state of preservation, imbedded in clay which passes underneath the sea. Explored by the Rev. T. Brown, and the shells named by Dr. Otto Torell.

Ellishill. The shells here occurred in red clay in a railway cutting three miles west of Peterhead, at an elevation of about 120 feet above the sea, and were sent me by Mr. A. Stephen Wilson. *Saxicava* entire.

Errol. A clay-pit on the north side of the River Tay, eight miles east of Perth, and about 45 feet above the sea. The shells are entire, but much decayed. *Leda arctica* and the two *Modiolariæ* very numerous. Entomostraca of the genus *Cythere* also occur.

Gamrie. On the sea-coast seven miles east of Banff. The shells were first noticed by Mr. Prestwich, and occur in a thin seam of sand at an elevation of about 150 feet; many of them are entire. The strata of fine sand and clay in which they occur are of great thickness, and extend to a height of 300 feet or more.

Invernettie. A brickwork on the Aberdeenshire coast one mile south of Peterhead; shells mostly broken. See Quart. Journ. Geol. Soc. vol. xiv. p. 517.

King Edward. About five miles S.S.E. of Banff. The shells occur in silt and gravel at an elevation of from 150 to 200 feet, many of them entire, and some of them *in situ*; but the nature of the section is not well exposed. I have been much assisted in collecting the fossils by Mr. J. Runciman, and by the Rev. T. Milne. *Foraminifera* occur here. The great similarity of the fossils to those of Gamrie leads me to think that both shell-seams belong to the same period.

Montrose. The shells are entire, but much decayed, and occur deep down in a mass of fine laminated reddish-brown clay of immense thickness (50 to 100 feet), and not many feet above the sea-level, in the brickworks of Dryleys, and Puggiston, about a mile west of the town of Montrose. The shells were first noticed by Dr. Howden, physician to the Montrose Lunatic Asylum, who has obtained a number of Starfishes from the Dryleys section. The skeleton of a seal was got some years ago at the Puggiston pit. Minute Entomostraca of the genus *Cythere* have been detected by the Rev. H. Mitchell of Craig, and occur both at Puggiston and at Dryleys.

Tyrie. On the coast of Fife, near Kinghorn. The shells were detected by that veteran naturalist Dr. Fleming. What he named *Pecten similis* was doubtless the same as *P. Grœnlandicus*, which seems to be only a large northern variety of that shell. (See Jeffreys's 'British Conchology,' vol. ii. p. 72.)

1. *List of Shells found in the glacial beds of the East of Scotland, between the Moray Firth and the Firth of Forth.*

No.	Species and Localities.	Living on the Coasts of Britain.	Living to the South of Britain.	Living within the Arctic Circle.	Living on the East Coast of North America.	Living in the North Pacific.
1	Anomia ephippium, *Linné.* Gamrie	*	*	*	*	
2	Aporrhais pes-pelecani, *Linn.* King Edward. . .	*	*	*		
3	Astarte borealis, *Chemnitz.* Gamrie, King Edward, Belhelvie, Invernettie, Auchleuchries, Errol . . = A. arctica, *Forbes & Hanley.*			*	*	
4	Astarte compressa, *Montagu.* Gamrie, Elie . . .	*		*	*	
5	Astarte sulcata, *Da Costa.* var. elliptica, *Brown.* Belhelvie . . . . . = A. elliptica, *F. & H.*	*		*	*	
6	Axinus flexuosus, *Montagu.* = Lucina flexuosa, *F. & H.* var. Sarsii, *Lovén.* Annochie			*	*	

List of Shells (continued).

No.	Species and Localities.	Living on the Coasts of Britain.	Living to the South of Britain.	Living within the Arctic Circle.	Living on the East Coast of North America.	Living in the North Pacific.
7	Axinus ferruginosus, *Forbes*. Annochie . . . . = Lucina ferruginosa, *F. & H.*	*	*	*	*	
8	Buccinum undatum, *Linn.* Gamrie	*	*	*	*	
9	Cardium echinatum, *Linn.* Gamrie, King Edward, Belhelvie	*	*	*	*	
10	Cardium Grœnlandicum, *Chemnitz*. Gamrie, King Edward			*	*	*
11	Cardium edule, *Linn.* Ellishill	*	*	*		
12	Crenella decussata, *Montagu*. Elie	*		*	*	*
13	Crenella faba, *Müller*. Errol			*	*	
14	Cylichna alba, *Brown*. Annochie	?		*	*	
15	Cyprina Islandica, *Linn.* Gamrie, King Edward, Auchleuchries, Belhelvie, Invernettie, Elie, Ellishill	*	*	*	*	
16	Dentalium entalis, *Linn.* Gamrie, King Edward, Belhelvie	*	*	*	*	
17	Fusus propinquus, *Alder*. Gamrie, King Edward .	*		*	*	
18	Lacuna divaricata, *Fabricius*. Gamrie, King Edward = L. vincta, *F. & H.*	*	*	*	*	*
19	Leda arctica, *Gray*. Montrose, Errol, Elie, Tyrie . = Nucula truncata, *Brown*. = Nucula Portlandica, *Hitchcock*.			*	*	
20	Leda limatula, *Say*. King Edward			*	*	
21	Leda lucida, *Lovén*. King Edward			*	*	
22	Leda pygmæa, *Münster*. Annochie, Montrose, Errol, Elie	*	?	*	*	
23	Littorina squalida, *Broderip & Sowerby*. Ellishill, Invernettie . . . . . = Turbo expansus, *Brown*.			*	*	
24	Mactra solida, *Linn.* var. elliptica, *Brown*. Gamrie	*	*	*		
25	Mangelia pyramidalis, *Stromeyer*. Gamrie, King Edward . . . . . = Defrancia Vahlii, *Beck*.			*	*	
26	Mangelia turricula, *Montagu*. Gamrie, King Edward	*	*	*	*	
27	Margarita Grœnlandica, *Chemnitz*. var. undulata. Errol . . . . . = M. undulata, *Brod. & Sow.*	*		*	*	
28	Mesalia erosa, *Couthouy*. Elie . . . . . = Turritella polaris, *Beck*.			*	*	
29	Mesalia reticulata, *Mighels & Adams*. King Edward . . . . . = Turritella lactea, *Möller*.			*	*	
30	Modiolaria discors, *Linn.* var. lævigata, *Gray*. Errol, Elie			*	*	*
31	Modiolaria nigra, *Gray*. Errol . . . . . = Crenella nigra, *F. & H.*	*		*	*	

List of Shells (continued).

No.	Species and Localities.	Living on the Coasts of Britain.	Living to the South of Britain.	Living within the Arctic Circle.	Living on the East Coast of North America.	Living in the North Pacific.
32	Mya truncata, *Linn.* King Edward, Elie. . . .	*	*	*	*	*
33	Mytilus edulis, *Linn.* Gamrie, Ellishill	*	*	*	*	*
34	Nassa incrassata, *Müller.* King Edward	*	*	*	*	
35	Natica affinis, *Gmelin.* Gamrie, King Edward . . = N. clausa, *Brod. & Sow.*			*	*	*
36	Natica Islandica, *Gmelin.* Gamrie, King Edward . = N. helicoides, *Johnston, and F. & H.*	*		*	*	
37	Natica Marochiensis, *Gmelin.* King Edward . . = N. nitida, *Donovan, and F. & H.*	*	*	*	*	
38	Natica pallida, *Brod. & Sow.* Gamrie, King Edward, Elie, Errol . . . . . = N. Grœnlandica, *Beck.* = N. pusilla, *F. & H.*	*		*	*	
39	Nucula tenuis, *Montagu.* Annochie, Montrose . .	*		*	*	*
40	Pecten Grœnlandicus, *Sowerby.* Montrose, Errol, Elie, Tyrie? . . . . . = P. vitreus, *Gray, but not Chemn.*			*	*	
41	Pecten Islandicus, *Müller.* Belhelvie, Ellishill . .			*	*	
42	Pholas crispata, *Linn.* Gamrie, King Edward . .	*	*	*	*	*
43	Purpura lapillus, *Linn.* Auchleuchries	*	*	*	*	*
44	Saxicava Norvegica, *Spengler.* Belhelvie . . . . = Panopæa Norvegica, *F. & H.*	*		*	*	
45	Saxicava rugosa, *Linn.* Annochie, Ednie, Ellishill, Belhelvie, Montrose, Errol, Elie, var. arctica, large form			*	*	
46	Scalaria Grœnlandica, *Chemnitz.* King Edward .			*	*	
47	Tectura virginea, *Müller.* Gamrie . . . . . = Acmæa virginea, *F. & H.*	*	*	*		
48	Tellina Balthica, *Linn.* Gamrie, King Edward, Belhelvie . . . . . = T. solidula, *F. & H.*	*	*	*	*	
49	Tellina calcarea, *Chemn.* Gamrie, King Edward, Belhelvie, Elie, Errol . . . . . = T. proxima, *Brown, and F. & H.*			*	*	
50	Thracia myopsis, *Beck.* Errol, Elie			*	*	
51	Trophon clathratus, *Linn.* Gamrie, King Edward, Belhelvie . . . . . = Fusus scalariformis, *Gould.* = Fusus Peruvianus, *Sowerby* = Trophon scalariforme, *Searles V. Wood.*			*	*	
52	Trophon clathratus, *Linn.* var. Gunneri, *Lovén.* Gamrie, King Edward. .			*	*	
53	Trophon truncatus, *Ström.* Gamrie, King Edward = Murex Bamffius, *Donovan.* = Trophon clathratus, *F. & H.*	*		*	*	
54	Turritella ungulina, *Linn.* King Edward, Auchleuchries . . . . . = T. communis, *Risso, and F. & H.*	*	*	*		

	Per cent.
British	59·3
Southern	37·0
Arctic	100·0
N. E. American	90·7
N. Pacific	18·5

My friend Mr. Robert Dawson of Cruden, who has explored the malacology of the Aberdeenshire coast with great success, tells me that when dredging he finds a great many semifossil Arctic shells belonging to species which he never meets with alive. These he supposes (and, I think, with great probability) to be derived from glacial beds passing underneath the sea, and extending for a considerable distance out from the coast. He has kindly furnished me with the following list of these shells, in reference to which he says, "All the fossils included in the list were dredged by me off the coasts of Cruden and Slains, at a distance of from three to eight miles from land, and at the depth of from 30 to 45 fathoms. As, however, some of them (*Trophon scalariformis* and *Gunneri*, *Pecten Islandicus*, &c.) have been brought up by the fishermens' lines at the distance of thirty miles from land, I believe that the fossil-deposit, whatever it may be, extends to a great distance seaward. The reason why they are not found nearer land appears evidently to be that the sea-bottom, for at least three miles from shore, consists of fine sand, covering probably the fossil-deposit beneath. None of these species have been found by me *alive*; and from the appearance of all the specimens, I believe that none of them are alive in this district."

No.	Species.	Living on the Coasts of Britain.	Living to the South of Britain.	Living within the Arctic Circle.	Living on the East Coast of North America.	Living in the North Pacific.
1	Astarte borealis, *Chemn.*			*	*	
2	Astarte sulcata, var. elliptica	*		*	*	
3	Astyris (Columbella) Holböllii, *Beck* (=Mangelia Holböllii, *Möller*)			*	*	
4	Cardium exiguum, *Gmelin* (=C. pygmæum, *F. & H.*)	*	*	*		
5	Corbula gibba, *Olivi* (=C. nucleus, *Lam. & F. & H.*)	*	*	*		
6	Cyclostrema costulatum, *Mörch* (=Skenea? costulata, *F. & H.*)			*	*	
7	Lepeta cæca, *Müller* (=Patella cerea, *Möller*)			*	*	
8	Margarita striata, *Brod. & Sow.* (=M. cinerea, *Couthouy*)			*	*	
9	Mesalia? borealis, *Beck* (=Scalaria Eschrichti, *Möller*)			*	*	
10	Mya truncata, var. Uddevallensis			*	*	
11	Natica affinis, *Gmelin* (=N. clausa)			*	*	*
12	Natica Islandica, *Gmelin* (=N. helicoides, *F. & H.*)	*		*	*	

List of Shells (continued).

No.	Species.	Living on the Coasts of Britain.	Living to the South of Britain.	Living within the Arctic Circle.	Living on the East Coast of North America.	Living in the North Pacific.
13	Pecten Islandicus, *Müller*			*	*	
14	Rhynchonella psittacea (=Terebratula psittacea, *Lam.*)			*	*	*
15	Saxicava rugosa, var. arctica, large form			*	*	
16	Tellina calcarea, *Chemn.* (=T. proxima)			*	*	
17	Trophon clathratus, *L.* (=Fusus scalariformis, *Gould*)			*	*	
18	Trophon clathratus, var. Gunneri, *Lovén*			*	*	

2. *List of Shells collected in the clay-pits at Paisley, near Glasgow; about 20 feet above the sea.* (See page 176.)

1	Astarte compressa, *Montagu.* Common	*		*	*	
2	Axinus flexuosus, *Mont.*, var. Gouldii. A few			*	*	*
3	Buccinum undatum, *Linn.* Of all sizes, not uncommon	*	*	*	*	
4	Cardium edule, *Linn.* One valve	*	*	*		
5	Cyprina Islandica, *Linn.* Very common, and of all sizes	*	*	*	*	
6	Lacuna divaricata, *Fabricius.* Two	*	*	*	*	*
7	Leda pernula, *Müller.* A few	?		*	*	
8	Leda pygmæa, *Münster.* Not uncommon	*	?	*	*	
9	Littorina litorea, *Linn.* Four, one of them of large size.	*	*	*	*	
10	Littorina limata, *Lovén.* Two			*		
11	Littorina squalida, *Brod. & Sow.* Two			*	*	
12	Littorina rudis, *Donovan.* A few	*	*	*	*	
13	Mangelia pyramidalis, *Stromeyer.* One			*	*	
14	Mya truncata, *Linn.* Several young shells	*	*	*	*	*
15	Mytilus edulis, *Linn.* Not uncommon	*	*	*	*	*
16	Mytilus modiolus, *Linn.* Not uncommon	*		*	*	*
17	Natica pallida, *Brod. & Sow.* Five; one of them $\frac{3}{4}$ of an inch	*		*	*	
18	Nucula tenuis, *Mont.*, var. inflata, *Hancock.* Not uncommon	*		*	*	*
19	Pecten Islandicus, *Müller.* One valve			*	*	
20	Rissoa parva, *Da Costa.* A few	*	*	*		
21	Rissoa striata, *Montagu.* A few	*	*	*		
22	Tellina calcarea, *Chemn.* Common, of various sizes			*	*	
23	Trophon clathratus, *Linn.* Six; the largest $1\frac{1}{8}$ of an inch			*	*	
24	Trophon clathratus, var. Gunneri, *Lovén.* One, nearly an inch long			*	*	
25	Trophon truncatus, *Stromeyer.* Three	*		*	*	
26	Velutina undata, *Brown.* One = V. zonata, *Gould.*			*	*	

	Per cent.
British	61·5
Southern	38·4
Arctic	100·0
N. E. American	84·6
N. Pacific	23·0

3. *List of Shells from the brick-work at Kilchattan, in the island of Bute, about* 20 *feet above the sea.* (See page 174.)

No.	Species.	Living on the Coasts of Britain.	Living to the South of Britain.	Living within the Arctic Circle.	Living on the East Coast of North America.	Living in the North Pacific.
1	Anomia ephippium, *Linn.*, var. aculeata. One specimen	*	*	*	*	
2	Axinus flexuosus, *Mont.*, var. Gouldii. Eight or nine single valves			*	*	*
3	Buccinum undatum, *Linn.* A few	*	*	*	*	
4	Cyprina Islandica, *Linn.* A few	*	*	*	*	
5	Lacuna divaricata, *Fabricius.* Three	*	*	*	*	*
6	Leda pernula, *Müller.* Nine, mostly entire	?		*	*	
7	Leda pygmæa, *Münster.* One valve	*	?	*	*	
8	Littorina litorea, *Linn.* Two	*	*	*	*	
9	Montacuta ferruginosa, *Mont.* One entire valve, full size	*	*	*		
10	Mya truncata, *Linn.* Several	*	*	*	*	*
11	Mytilus modiolus, *Linn.* One small valve	*		*	*	*
12	Mangelia pyramidalis, *Strom.* One			*	*	
13	Natica pallida, *Brod. & Sow.* About a dozen	*		*	*	
14	Natica affinis, *Gmelin.* One or two			*	*	*
15	Scrobicularia prismatica, *Montagu.* One entire specimen = Syndosmya prismatica, *F. & H.*	*	*	*		
16	Tellina calcarea, *Chemn.* In great abundance and entire, of all sizes up to one inch			*	*	

	Per cent.
British	68·7
Southern	50·0
Arctic	100·0
N. E. American	87·5
N. Pacific	31·2

4. *List of Shells found in a seam of gravel at a railway-cutting between Drymen and Gartness, Stirlingshire, at about* 120 *feet above the sea.* (See page 172.)

1	Anomia ephippium, *Linn.* One	*	*	*	*	
2	Astarte compressa, *Mont.* Four entire valves and many fragments	*		*	*	
3	Astarte sulcata, *Da Costa.* var. elliptica, *Brown.* Broken pieces very common	*		*	*	

List of Shells (continued).

No.	Species.	Living on the Coasts of Britain.	Living to the South of Britain.	Living within the Arctic Circle.	Living on the East Coast of North America.	Living in the North Pacific.
4	Buccinum undatum, *Linn.* A few fragments . .	*	*	*	*	
5	Cardium echinatum, *Linn.* One fragment . . .	*	*	*	*	
6	Cyprina Islandica, *Linn.* Broken pieces very common	*	*	*	*	
7	Littorina litorea, *Linn.* Six, more or less broken .	*	*	*	*	
8	Littorina squalida, *Brod. & Sow.* One			*	*	
9	Mya truncata, *Linn.* Two hinge-pieces	*	*	*	*	*
10	Natica affinis, *Gmelin*, =N. clausa, *Brod. & Sow.* One small specimen			*	*	*
11	Pecten Islandicus, *Müller.* Many fragments . .			*	*	
12	Tectura virginea, *Müller.* One small imperfect specimen	*	*	*		
13	Trophon clathratus, *Linn.* Two specimens, not very large			*	*	
14	Trophon truncatus, *Strom.* One	*		*	*	

	Per cent.
British	71·4
Southern	50·0
Arctic	100·0
N. E. American	92·8
N. Pacific	14·2

5. *Shells of the old estuarine beds of the East of Scotland. Post-Glacial.* (See page 188.)

1	Cardium edule, *Linn.* Ythan, Aberdeen, Montrose, Forth	*	*	*		
2	Cylichna obtusa, *Montagu.* Montrose (*Rev. H. Mitchell*)	*	*			
3	Fusus antiquus, *Linn.* Forth. One specimen . .	*	*	*		
4	Hydrobia ulvæ, *Pennant.* Ythan, Montrose, Forth = Rissoa ulvæ, *F. & H.*	*	*	*		
5	Littorina litorea, *Linn.* Ythan, Aberdeen, Montrose, Forth	*	*	*	*	
6	Mytilus edulis, *Linn.* Aberdeen, Forth	*	*	*	*	*
7	Ostrea edulis, *Linn.* Forth	*	*	?	*	
8	Scrobicularia piperata, *Gmelin.* Spynie, Ythan, Aberdeen, Montrose, Forth	*	*			
9	Tellina Balthica, *Linn.* Ythan, Aberdeen, Montrose, Forth	*	*	*	*	

	Per cent.
British	100·0
Southern	100·0
Arctic	66·6
N. E. American	44·4
N. Pacific	11·1

JANUARY 25, 1865.

William Grylls Adams, Esq., M.A., Fellow of St. John's College, Cambridge, Lecturer on Natural Philosophy in King's College, London; and Capt. Stewart Smyth Windham, 14 Connaught Place, W., were elected Fellows.

The following communications were read:—

1. *On the* CLIMATE *of the* PLEISTOCENE EPOCH *in* NEW ZEALAND. By JULIUS HAAST, Ph.D., F.G.S.

[This paper was printed in No. 82, p. 135, by order of the Council.]

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2. *On the* ORDER *of* SUCCESSION *in the* DRIFT-BEDS *of the* ISLAND *of* ARRAN. By JAMES BRYCE, M.A., LL.D., F.G.S.

THE island of Arran has long been celebrated for the number of rock-formations, sedimentary and plutonic, which it contains, and for the varied relations in which they are displayed. A new interest has lately been imparted to it by the discovery of fossils in its superficial beds. Deep accumulations of clay, gravel, and sand had long been known to exist in its southern glens; but no one had examined them, either in the hope of finding fossils or with the view of working out an order of succession among the beds.

The fossils are shells chiefly of Arctic species; and the fortunate discoverer was the Rev. R. B. Watson, of Edinburgh. An account of the discovery was laid by him before the Royal Society of Edinburgh, on the 4th of January, 1864, and published in brief abstract in the 'Proceedings' of the Society in April of that year. The paper itself did not appear until five months later*. From this abstract, which came into my hands soon after its publication, it appeared that the entire mass of beds, often above 100 feet thick, was designated as Boulder-clay, and that the shells were not assigned to any particular place in the deposit. Now as this view was opposed to that which I held in common with most geologists of the west of Scotland, namely, that the entire mass of beds ought not to be embraced in one term "Boulder-clay," and that the Arctic shells have a peculiar position, I was anxious to examine the Arran beds for myself, in order to test the accuracy of the view, under the favourable circumstance of having a district wholly isolated from connexion with any other. It is but justice to Mr. Watson to say that when I mentioned to him my intention of visiting Arran in order to examine the beds, he at once, in the most frank and cordial manner, made known to me all the localities in which he had found the shells, and gave me other information which saved me much time and labour on my first visit in May last. I found in a few hours ten of the seventeen species discovered by Mr. Watson.

* "On the Great Drift-beds with Shells in the South of Arran," by the Rev. Robert Boog Watson, B.A., F.R.S.E., Trans. R.S.E. vol. xxiii. part 3.