

XXXIX.—*On the Great Drift Beds with Shells in the South of Arran.* By the  
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(Plates XXI., XXII.)

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THE SOUTH OF ARRAN IN GENERAL.  
CHARACTER OF THE DRIFT-BEDS THERE.  
DESCRIPTION OF THESE IN DETAIL.

1. Auchinreach Burn.
2. Glen Ashdale.
3. Torlin Burn.
4. Cloinoid Burn.
5. Slaodrig Burn.
6. Crogeréver Burn.
7. Clachan Glen.

CONCLUSIONS :—

1. Boulder-clay derived from land glaciation.
2. Ice covered the land till submerged.
3. Boulder-clay deposited in the sea.
4. „ compressed by ice, &c.

CONCLUSIONS—(*continued.*)

5. Boulder clay contains land-formed beds.
6. „ deposited as land was subsiding.
7. Subsidence extended to 1100 or 1200 ft.
8. „ was continuous, not oscillatory.
9. „ was gradual.
10. „ was it rapid?
11. No general glaciation since re-emergence.
12. Boulder-clay beds of all ages of glacial epoch.
13. Drift and Boulder-clay contemporary.
14. Relation to sea-line, a test of age.
15. No material change on the basement-rock since glaciation.

*Summary.*

The whole southern part of Arran forms a field by itself, and whatever may be the deeper connections of the agencies that have fashioned the north and the south of the island, the result is a trappean area to the south, as distinct as if it lay in another hemisphere from the north, with its granitic nucleus, and encompassing rings of stratified rock.

This district is little visited, and is almost, if not quite, undescribed; it presents, however, much beautiful scenery, and for the geologist, problems of extreme difficulty and interest, which deserve more attention than they have got.

It may be divided into two belts of tilled land and moorland, above which are the hill tops. This division corresponds roughly to three regions, the lowest chiefly of sandstone, the middle where felstone prevails over the sandstone, and the highest of greenstone.

From the sea, the land rises in a precipice, of from 50 to 200 feet in height. In general, for some two or three miles up the valleys, the rock is sandstone without fossils, and of doubtful age, but probably Permian. It is soft, fine-grained, often shaley, thinly laminated, chiefly bright red or purple, and much intersected though not much disturbed by dykes of igneous rock—large isolated masses of which also occur. This sandstone region extends from the coast to a height of from 300 to 500 feet. Its rising slope towards the interior is extremely gentle both in the valley bottoms and in the hill sides above.

From the sandstone region, the rise is generally a steep one, and marked in the burns by a waterfall. This is the edge of the felstone district, where the sandstones, though present, and often considerable in depth, occupy but a small superficies. Here the land rises in faster slopes, to a height of 1200 or 1500 feet. The felstone varies very much. In the south-east it is generally a grey yellow or pink felstone, very friable, disintegrating to soft sand with great rapidity, sometimes columnar, sometimes also amygdaloidal, and frequently markedly laminated, a quality plainly due to the unequal cooling of the mass while in motion.

In the south-west again, this felstone is sparingly present, and the prevalent igneous rock is a very beautiful felstone porphyry, with a matrix of close-grained compact felstone, sometimes approaching in texture to hornstone, pinkish and yellowish, but most often grey in colour, and containing large crystals of white orthoclase and irregular rounded granules and lumps of crystalline quartz. Above the felstones rise tabular masses of greenstone, which occasionally reach a height of 2000 feet. They are of no great extent, but have been largely eroded.

The combined result of these features is a table-land with long slopes and rounded contours, rising in hummocky elevations in the distance, and much intersected by valleys.

Over the whole of this table-land lie clays and sands.

Superficial sand-beds are not common, but occur here and there, from 50 to 570 feet above the sea. Stratified gravels and clays are to be found in the basins which occur in nearly all the valleys.

Markedly distinct from these two classes of superficial beds, is the great deposit of coarse red boulder-clay, which swathes hill and valley in a dense mantle, and gives its characteristic feature of rounded outline to the scenery. (Pl. XXI. fig. 1.)

It may be found on the very edge of the beach. It lies deep over the terrace which rises steeply from the shore along the coast line, and is only absent where this terrace towers up in a great precipice of igneous rock, as at Leac-a-breac, Benan-head and Dippin.

From 50 to 300 feet above the sea, it reaches its greatest development, presenting banks in the water-courses from 80 to 140 feet high. On the hill slopes, as might be expected, it is shallower, and in the valleys too, as they rise into the uplands, the banks of boulder-clay become smaller. Even there, however, they are still considerable, and at a height of 520 feet, I found one face of the boulder-clay 110 feet high.\*

The greatest measured height at which I ascertained the presence of the

\* I need hardly say, that the sections formed by the burns are transverse to the bedding of the boulder-clay; and, therefore, that the above measurements do not give the true depth of the deposit, but only the height of the sections.

boulder-clay was 1100 feet, or a little more (Aneroid barometer), but I remember to have seen it 100 or 200 feet higher, and I have no doubt, patches of it may be found a good deal above this, but I had not time to seek them.

From all this it will be obvious, that the boulder-clay has not been piled up in immense irregular masses, like glacier moraines, but conforms, on the whole, to all the contours of the rock surface. Even in the valleys, where, of course, it has accumulated in masses disproportionally great compared with those on the hill faces, and where therefore the contour of the surface ceases to conform strictly to that of the rock below, there are indications, in the separate beds of the boulder-clay, of the modifying influence exercised upon them by the form of the ground on which they have been deposited,—the line of the valley forming the synclinal axis of the beds. Where wide basins exist in the valleys, which is often the case above some transverse stream of igneous rock,\* the boulder-clay lies equally round its whole margin, and follows the slope of its banks.

The importance of this agreement between the lines of the boulder-clay and of the rock below is, that in glacier moraines, there is no such regular disposition of beds, and still less would such be found in the scattered droppings of floating ice.

Great irregular masses of material, resembling moraines, I only observed high up on the face of the hill, between Kildonan and Benan-head; and again, at the head of Glen Cloy, where there is a huge moraine.†

The form in which the boulder-clay beds present themselves in the burn-courses is as steep slopes thinly grass-grown,—occasionally, where water oozes over them, the face of the beds is steeper, more broken, and covered with confused heaps of stones and mud. The best view of their composition is generally to be got where the burn has cut in to the underlying rock, and the bank rises precipitously above.

In general character, the boulder-clay of the south of Arran is a coarse, red, sandy clay, full of stones, both striated and water-worn, and of all sizes, from boulders 4 or 5 feet in diameter downwards. It varies a good deal in texture, being sometimes loose and gravelly, at others dense and hard, so as to stand up in nearly perpendicular precipices, dotted over with projecting stones so firmly

\* One is apt to mistake mere erosions of the boulder-clay for true basins in the basement rock, but where there has simply been an erosion, there is of course no such agreement as that spoken of between the contours of the surface of boulder-clay and the basement rock.

† I do not think this moraine has been noticed. It lies near the head of the glen, and rises to a height of 800 or 900 feet above the level of the sea. Where the glen contracts there are, on the south side, immense heaps of huge blocks of rock tumbled down in the wildest confusion,—the same appears on the north side of the valley, and all the valley bottom is obstructed by heaps of gravel and stones. The cup formed by this is about half a mile long, and above, on all sides, the hills rise perpendicularly to a height of 1100 or 1200 feet. These moraine masses extend down to the foot of Glen Dhu, more than half a mile, and in this glen, also, is some appearance of smaller moraines. In the lower part of the Glen Cloy moraine granite boulders become frequent.

fixed, that in the water-worn gullies one may often climb far up the steep bank by holding on to them. On the whole, it is perhaps less compressed and homogeneous than boulder-clay often is; it is also occasionally traversed by bands of stones or beds of sand and clay. Towards its upper surface it is often somewhat disintegrated, and less dense than below. At times it passes upwards into a dense, fine gravel. In some places it is to be found resting directly on the rock below; but at the lower levels it is often separated from the rock by a bed of sandy clay, while at a higher level it is, in at least two instances, underlain by a very hard, densely-packed, angular gravel or coarse sand, with large striated boulders, which seems to have lain directly under a glacier.

Shells occur occasionally in considerable quantities, both in the boulder-clay and in the sandy clay (not in the glacier gravel) below, at various heights, from 80 to 320 feet above the sea. No general principle explanatory either of the presence or absence of the shells is obvious, except that they seem uniformly wanting in the beds of large stones. In the boulder-clay they are very much broken. In the laminated beds, both those which rest on the rock and those which traverse the boulder-clay, the shells, when present, though of more delicate type, such as *Ledas Naticas* &c., were less destroyed. At first, from the broken state of the shells, I thought the whole deposit must have been formed on the beach; but more careful observation showed that the inference was drawn merely from bits washed out by the rains, these being by far the most abundant. If carefully dug for, the shells may often be found, crushed indeed, yet with each fragment in its own place—two-shelled species with their valves united. Some of the large specimens of *Cyprina*, though unbroken, are indented as by a sudden violent blow. In short, the whole condition of the shells suggests that heavy stones have been dashed down on them, or that they have yielded in the bed where they lay to the weight of sand and stones more quietly piled over them.

Of species there are sixteen determined and one doubtful, besides many fragments which do not seem to belong to any of these, but are too minute for recognition.\*

As to their habitats, they belong distinctively to the coralline zone, or to even deeper water. Of the sixteen species which have been determined, seven, so far as they are known on our coasts, are never found in water shallower than 150 feet (25 fathoms); and except one, all the others, though found at a less depth, are also found in very much deeper water. The single exception was the *Litorina litorea*, but of it I found only two fragments.

In character, Mr SEARLES WOOD, who was good enough to examine them for me, pronounces them decidedly boreal. All the species, except *Turritella communis* (which is common in the Norwegian drift-beds), extend to the arctic province.

\* For list of these see end of paper.

Three—*Pecten islandicus*, *Astarte arctica*, and *Cryptodon Sarsii* (if it be really distinct from the *sinuosum*), are distinctively arctic, a character further indicated for the whole collection by the prevalence of astartes, which, both in species and individuals, greatly outnumber all others.

Vegetable remains, apparently heather stalks, were present at two places in the boulder-clay.

In general, the material of the boulder-clay is derived from the rocks of the particular glen in which it lies. Still foreign materials are not wanting. Thus, in Cloinoid Glen, I found pieces of syenite, which must have crossed the watershed between that glen and the Torlin Glen to the east, in which the syenite rock lies. In the same glen also were pieces of a very peculiar (carboniferous) sandstone, which must have come down across two water-sheds, from the Clachan Glen to the north. Fragments, too, have been brought down from the Silurian shales in the north-west, and from the granite in the north; and one bit of impure coal I found, which must have come either from the little patch of coal in the extreme north-east, or from the mainland opposite. All these wanderers have probably been brought by floating-ice.

The red colour of the boulder-clay shows how largely it is indebted to the friable red shales of the district. Hardened knots of this shale, which are always striated, are frequent; but by far the largest proportion of the stones which it contains are derived from the igneous rocks. The soft laminated felstone, indeed, which prevails in the south is not common, from its proneness to disintegration, but felstone porphyry and greenstones abound. The absence of striations on the stones from the felstone porphyry is very striking. This, however, is apparently due merely to the texture and colour of the stones, and is equally true of the whitey coarse-grained variety of greenstone.

At the lower levels the surface of the underlying rock is rarely to be seen striated, a fact partly owing to its texture, which is very soft and friable, and partly to the difficulty of getting a surface at once sufficiently exposed, clean, and unweathered. On the shore between Brodick and Lamlash, however, there are some very well-marked striated surfaces.

I have made these general remarks as full as possible, in order to avoid repetition in detail of features common to the whole boulder clay, and will therefore now only refer to individual places, in so far as they strikingly illustrate previous statements, or otherwise present something peculiar.

Below the bridge over the Auchinreach Burn, above Whiting Bay, 70 feet above the sea, the boulder-clay is 40 feet deep. It rests directly on a bed of friable shales. The stones in it are much striated; small granite boulders are frequent. At 50 feet above the sea this bank is 50 feet high, but it is only the lower 15 feet that are boulder-clay. The underlying rock is not seen here. The

boulder-clay is very hard. Through it there runs a stratum of fine clay 3 or 4 inches thick. Above the boulder-clay is a great bed of sand, in some places 35 feet thick, but diminishing rapidly in depth as the bank slopes downwards towards the sea.

At the mouth of Glen Ashdale, the boulder-clay beds lie deep over the whole hill side to the north. They are also present, but in a very ruinous state, on the south.

Between Whiting Bay and the Torlin Burn they are everywhere to be seen, but I did not examine them minutely.

In the Torlin Burn, and especially in the Cloinoid branch of it, they are immensely developed, and present the best sections I have seen in Arran. The beds also contain shells.

At the farm of Torlin, on the edge of the sea cliff, the boulder-clay rises from the beach to 110 feet above the sea. On the road above Lag, at the schoolhouse, it is 150 feet above the sea. This is just above the edge of the great red banks, which rise steep and broken from the burn, and run on uninterruptedly for a couple of miles. The first place where I found shells in these banks was on the east side of the burn, 120 feet above the sea (Plate XXI., fig. 1), and about 15 or 20 feet below the top of the bank, which is here 50 or 60 feet high.

Just below the Church of Kilmorie, the burn is crossed by a little wooden bridge. Immediately below the bridge, on the west side of the burn, 80 feet above the sea, is an extremely interesting section. The bank is 100 feet high, but is much obscured by sludge. The boulder-clay, however, can be made out in detail nearly to the top of the bank. At the edge of the burn course, the sandstone is laid bare. It is very considerably hardened by a greenstone dyke, which lies here in the burn course. The face of sandstone slopes quietly up from the level of the burn for 4 or 5 feet. If it was ever striated, the burn has effaced the markings, the whole surface having been evidently exposed for a considerable time. Its upper edge is perpendicularly broken off on an irregular line; and at the back of this edge, the curious succession of beds shown in the accompanying sketch can be made out. (Plate XXI., fig. 2). The impression which they produced on my mind was, that the under beds to No. 6 or 7 had been formed by running water under a glacier, and had been jammed in at the back of the rock by the ice moving downwards, not directly in the line of the present burn course, but obliquely across it from the north-west, while the other beds above, from No. 8 onwards, were deposited in the sea. In any case the presence of the sea during the formation of beds Nos. 10 and 11 is certain, from the presence of shells in both of them. In No. 10 I found a few unbroken *Ledas* in pairs; and in No. 11, besides fragments of *Ledas* two broken *Turritellas*, and a small bit of a *Litorina litorea*. This last bed is harder and darker than No. 13; and the stones, which are well striated, are fewer and smaller, but both beds are distinctly boulder-clay. Bed No. 10 seems to dip

under No. 11 to the west, at an angle of  $75^{\circ}$ ; but the dips in all these clay beds are very deceptive.

Above the church there is a flat open space in the bottom of the valley. In the centre of this flat a bank slopes out from the hill side above, and breaks abruptly in the middle of the field, presenting a face 20 feet high. On the top is seen coarse water-rolled gravel—below is fine clayey sand. This seems to be the wreck of the superficial deposits, which had once covered the whole flat. Just below this, in the burn course, I found, resting on the boulder-clay, a layer of fine clay, buried beneath sand and gravel, and containing dead equisetum roots, which I have no doubt are modern; but the depth to which this plant penetrates is often very deceptive. These beds seemed to form a lower member of the superficial deposits mentioned above.

In the centre of the field a boss of felstone porphyry projects above the flat. It has the form of a *roche moutonnée*, but I could not satisfy myself that it was striated.

Above this the boulder-clay banks are of great size, but I did not examine them carefully. In the upper part of the valley, at 450 feet above the sea, and near the path leading over to Lamash, I found a well striated face of greenstone. Further on, at the same height in the burn course, is a bank of boulder-clay, rising to 40 feet above the burn, but the lower part of the bank, for 20 feet, is formed of the friable shale rock of the district. Close by, however, the boulder-clay has fully this depth, and is hard, firm, and flakey in texture. This is just below the farm of Stragael. In the valley bottom here is a flat, where the boulder-clay is covered with gravel. At 570 feet above the sea, just above the farm of Stragael, is a great bed of sand with a few stones. At 800 feet above the sea, the boulder-clay banks beside the burn are still 30 feet high. At 1100 feet it is 10 feet thick; but at 1130 it is thin and sandy, and the shales appear in broken angular fragments close to the surface. On the hill-side, north from this, at 100 or 200 feet higher, it again lies thicker, but I could not examine this locality minutely. At 1250 feet there are well striated bosses of felstone.

The Cloinoid Burn is a branch which joins the Torlin Burn from the N.N.E., about a mile, or rather less, from the sea. Between the burns the land swells up in a rounded back, which is, however, very little higher than the edge of the great boulder-clay banks which line the burns. The valley is very narrow in its lower part, and the banks high and steep; but they are much obscured by debris, so that the details of the boulder-clay can seldom be followed for any distance. The best section of them occurs about a mile above Lag, from 160 to 200 feet above the sea, the top of the bank rising from 240 to 340 feet above the sea, or from 80 to 140 feet above the burn. This section extends, with interruptions, for several hundred yards. It may best be considered in two parts. The first part (Plate XXI., fig. 3), is about 80 feet high and 200 yards long. At the

bottom is exposed a small face of soft friable sandstone, above which is a dense sandy clay apparently about a foot thick, but very little of it can be seen from the debris. It is best seen at the south end of the rock, and its laminae correspond to the slope of the rock. About 20 feet above this the face of the boulder-clay is crossed by a band 2 feet thick of big stones, some of which are 2 feet long and broad. This bed runs downwards across the bank till it sinks to 8 or 10 feet above the burn. Ten feet above this is a less marked bed of stones, which, on the whole, keeps its relative position to the other, till, at their point of lowest depression, they seem to run into one another. As the centre of this section is obscured for 100 yards by a grassy bank, of course there is no certainty that these stone beds are the same throughout; they seem however to be so. If they are their dip is probably due to the fact that they were deposited on the slope of the hill side, and that the section which the burn has made is not in the line of their strike but transverse to it,—as indeed is obviously the case from the exposure of the rock where they are highest, and its concealment where they sink lower. The irregularity of the two beds relatively to each other is no more than might be expected. A close examination of these beds is impossible from the steepness of the bank, and the view of them from below, or from the other side, is unsatisfactory, owing to the debris, the irregularity of the surface, and the similarity of the colour throughout. Above this bed of stones is a layer of clay a few inches thick. Little bands of clay and sand traverse the boulder-clay, and about half-way up the bank is at one point (Plate XXI., fig. 4), a bed of stratified sand, overlaid by a stratum of boulder-clay, which last is separated from the mass of the boulder-clay above by a parting of sand. The sand-bed contained a few fragments of shells. The layers of sand curve sharply over upon themselves, as if they had been thrust forwards under a heavy weight from behind, and forced to over-ride one another. The boulder-clay resting on this sand seems to have shared in the thrust, but being less easily bent has merely swelled out into a club-shaped mass.

Between this and the next good section a considerable mass of felstone porphyry appears in the burn. Above this is by far the finest section of all (Plate XXI., fig. 5.) It is from 200 to 300 yards long, and the bank is 140 feet high. It presents two or three broad perpendicular faces, intersected by deep hollows channelled out by the running of water. The lower 20 feet or so is a debris talus. Just above this the rock crops out through the bank at one place. It is a soft, crumbly shale. It is covered by a bed much more sandy, and with fewer stones, than the rest of the deposits. It was in this bed that I found *Naticas* quite unbroken, but so fragile that they could not be got out uninjured. In it I also found a fragment of *Litorina*. The boulder-clay above the sand shows a tendency to bedding. A very marked line, apparently of large stones, crosses the whole face of the bank from 25 to 50 feet up, rising as it goes down the



burn to the south. It is very likely one of the beds of stones which we saw in the last section. There are also other indications of water-sorting in the beds both above and below. Shells were most abundant near the rock, and also high up the bank to the south end of the section.

Above this a great mass, 30 to 40 feet high, of laminated felstone, in a very shattered and rotten state, crosses the valley. The channel cut through this is only the breadth of the burn, and in this narrow passage are a few old rounded, but not striated surfaces; but elsewhere I could see none, so completely is the whole rock in a splintery state. The boulder-clay lies over the top of this rock, and comes down to the burn both above and below it. I unfortunately neglected to measure the height to which this rock barrier rises above the burn,—a point so far of importance that the rock, if it really cross the valley, as it seems, must have formed a dam behind which the glacier ice, coming down from the hills above, would be checked and embayed in the basin above. Of course it may have accumulated till it rose high enough to overflow the barrier, but the narrowness of the passage, obviously cut by water, indicates plainly that through it the ice found no egress.

Above this barrier is an open basin half a mile long (Plate XXI. fig. 6.), round which the boulder-clay lies deep. The curve of the bank all round faintly suggests a water-formed terrace, but I did not attempt to ascertain how far it keeps the same level. The lower end of the basin is about 300 feet above the sea, the upper about 330. It was in the boulder-clay bank, about 20 feet up from the burn at the lower end of this basin, that I found the last fragment of shell I met with.

Plate XXI. fig. 1, gives this bank. The lower part of the bank consists of a singularly hard, dense, dry, gravelly clay, derived from felstone porphyry rather than from the sandstones. It looks as if it had been jammed in dry against the felstone rock, to the east and south down the burn, by the glacier when in motion. In it are several large, well striated greenstone boulders. Above this hard gravelly clay, to the left, the red boulder-clay rises to the top of the bank. To the right this boulder-clay has been stripped off, and over the surface of the underlying bed is a stratum 2 or 3 feet thick of water-rolled boulders. This bed merely laps up on the edge of the red boulder-clay as it thins out on the flat. The relation of the two is indeed very difficult to make out from the debris and turf which conceal their junction in the corner at the rise of the bank; but it is better seen at the other end of the section of their junction-line, where it is exposed about 100 yards up the burn, and this is shown in Plate XXII. fig. 8. Here, as before, the hard yellow gravelly clay, about 6 feet thick, lies in the burn course, and, resting directly on it, is the bank of red boulder-clay. To the left, cut off by the burn, is seen the projecting edge of the valley flat. Here the yellow clay seems to have been eroded and buried under a thicker mass of rolled stones and gravel, which becomes thinner as it is followed down the edge of the bank to the

former section. In the angle of the bank and the flat, this bed of stones is overlaid by the remains of a bed of sand. Both of these beds seem to be superficial deposits of a later period, when the basin was occupied by a loch or inland sea-bay, the currents of which had deeply eroded the red and yellow clays.

Elsewhere in the flat other superficial beds besides these can be made out,—not indeed all at any one spot, yet distinctly enough, to a thickness of 8 feet : 1. At the bottom coarse water-worn gravel, what this rests on is not seen ; 2. Above this fine clay, with equisetum roots apparently of the period of the clay, but this is not certain ; 3. Sandy gravel ; 4. Coarse gravel ; 5. Sandy clay ; 6. Loose coarse gravel, or small rolled stones. In this last bed nearly every stone, both greenstone and felstone, was so thoroughly disintegrated that the whole bed seemed at first to be merely sand.

At the very head of this basin a burn goes off to the west or north-west, in which a deep section of the boulder-clay is given ; and between this burn and the Cloinoid Burn, just to the east of the clachan of Cloinoid, is a deep land-slip in the boulder-clay, which strongly conveys the impression of how deep the clay is.

The boulder-clay banks press closely in on the burn above this, and at 520 feet above the sea is a waterfall over the edge of a great bed of felstone porphyry, and from the foot of the fall the boulder-clay rises 110 feet perpendicular ; but above this the valley rapidly opens out to a mere depression in the contour of the hill, and the boulder-clay thins out more and more.

The next great glen to the west is that of the Scoradale Burn or Slaodrig Water, in which, and all its tributaries, the boulder-clay banks are very large. Up one of these tributaries I found a bank of the clay 130 feet high at 310 feet above the sea, and in the main burn they seem even larger. I examined them carefully, however, only in the Croghcréver Burn, which joins the Slaodrig Burn from the north-west, about a mile above the sea. At the junction of the burns, 50 feet above the sea, one gets a very good view of the mass of the beds, which are here from 90 to 100 feet high. Just above the junction is a steep but somewhat ragged face of the boulder-clay (Plate XXII. fig. 9). Here the soft shales at the bottom rise on the left to about 15 feet, but diminish in height down the stream. Above the rock are ten or twelve feet of coarse gravel and sand plainly stratified. Above this is boulder-clay 50 feet, with traces of bedding, and perhaps somewhat looser than usual. I found a few fragments of shell about the middle of the bank. They had been washed out by the rains, and I could not trace them to any particular spot. The nature of the bank prevents a very close examination of it in detail.

Just above this is a bank which a year ago presented a remarkably fine section. Being very deeply channelled by water-courses, its details were well shown, and it was also remarkably rich in shells. Scarcely a trace, however, now remains of it, so completely has it been washed away or buried in its own

ruins. The soft sandstone rock here appeared about 40 feet above the burn, and over its face lay a dark bed of fine clay, in which shells were both abundant and remarkably fresh and unbroken, the bivalves being in pairs, and retaining both their ligament and epidermis.

Above this is a long, narrow gorge, about 60 feet deep and half a mile long, cut through the soft shales in the line of their strike, which is north-west. The boulder-clay lies down the dip of the strata on the north-east. (Plate XXII., fig. 10.) At about 130 feet above the sea the gorge turns a little more westward than before, and in the angle it expands and forms a small basin, with huge boulder-clay banks 120 feet high on the north-east side. About 60 feet up, the bank is crossed by a dense bed, a few inches thick, of dark brown clay, very hard, with small gravel in it, and very rich in shells, especially *Leda* in pairs, and *Balanus* valves.

Above the gorge is a great stretch of laminated felstone, which occupies both sides of the burn-course. It is this felstone which seems to have protected the shales lower down the burn.

The phenomena of the clay-beds for half a mile above this point, which is from 250 to 300 feet above the sea, are extremely instructive and interesting, but very difficult to explain. (Plate XXII. fig. 11.)

Cut through by the burn is a bank, 7 feet high, of intensely hard yellow clayey gravel, resembling that which I have described in Cloinoid Glen, and like it, chiefly made up of felstone porphyry. Like it, too, it has all the appearance of having been travelled over by the glacier, so compressed and yet so dry and in itself incoherent is it. The upper surface of this bed seems to be quite unconformable in its slope to any of the other contour lines, either of the rock below, or of the beds above, for it dips to the westward, while the whole land is rising in that direction. It seems, in short, just like a bank that had nestled in behind the edge of the rock, and was thus preserved from the abrasion of the glacier. On this back slope of the yellow gravel lies the much redder and somewhat softer common boulder-clay, in which I found a fragment of shell. (Plate XXII. fig. 12.) Horizontally overlying this, and abutting unconformably against the yellow gravel, is a ten-foot thick bed of coarse sand, on the top of which is a layer, 3 feet thick, of very large stones. Above this is some 6 inches of fine light-coloured sand, and over all is earth. On the east side of the burn, this bed of yellow gravel (Plate XXII. fig. 11) nestles in behind a strangely isolated mass of the felstone, close above which is another rock of rotten felstone, round which the old burn-course lies. The new channel is 3 feet deeper than the old one. Some very large and well-striated boulders of greenstone lie in the yellow gravel bank opposite this point, as shown in Plate XXII. fig. 12.

Just above this, in the burn-course, there appears on the west side, a long face of felstone, which rises 4 or 5 feet above the burn. It seems glacier-worn

from its rounded form, but its whole exposed surface is utterly shattered, while its junction with the overlying clay beds is entirely concealed by debris. (Plate XXII. fig. 13.) Resting directly on it, is a confused dark-coloured bed of gravelly clay, with large angular stones crushed rather than ground, some of them striated. In this, a year ago, I found quantities of heather-stalks, but this spring, on revisiting the place, I found it a good deal more concealed by debris, and I could only find one bit of heather-stalk about an inch long, which I fairly dug out of the clay among the hard pressed fragments of stone. The discoloration of the bed, which is very marked, may be partly due to the vegetable matter, but it seems much more owing to the disintegrated greenstone and pitchstone fragments which abound. I had great difficulty in satisfying myself what this bed was, but was greatly helped by finding it again further up the burn. It is just the hard yellow gravel formerly described, and the red boulder-clay which (Plate XXII. fig. 12), along the burn, intervenes between it and the yellow gravelly clay, must be just a tongue of the boulder-clay, lying in a depression of the surface of the yellow clay.

For some way up the burn, the felstone rock forms one side, and the boulder-clay the other of the water-course; and no doubt, the yellow gravelly clay lies hidden under the debris between, for it reappears a little higher up on the opposite (*i.e.* the east) side of the burn, and there it distinctly underlies the boulder-clay. It is intensely hard, and all the stones in it are angular. From the point where it reappears, it can be followed more or less continuously for a long way, sometimes on one sometimes on the other side of the burn, but never, I think, occupying both sides at once, so that it seems to be thin. At one place, on the east side of the burn, it actually seems to underlie a considerable mass of the red and yellow soft shale rock which unexpectedly makes its appearance amidst the felstone. At the north-west corner of the mass where alone I could get a good view of their relations, the edges of the shale strata distinctly lay upon and projected over the yellow gravel beds. On the whole, the shale rock seemed either a mass projecting amidst the felstone, and into the foundations of which the yellow gravelly clay had been violently forced, or more probably a loose mass of the strata which has either slipped or been pushed over the top of this yellow clay-bed, yet without being upset or indeed very violently disturbed. Higher up again, the yellow gravelly clay is seen directly overlaid by the red boulder-clay.

Just above this, at 280 feet above the sea, the clay banks are 100 feet high. From this point, a great shallow circular basin opens up on the hill face, and all around its margin, the boulder-clay banks go sloping down into it.\*

\* Just where the burn escapes from this basin, the section of the strata shown in twenty yards of the burn-course is most curious. Descending the burn, one first reaches the junction of the felstone porphyry and the underlying sandstone. The felstone porphyry crosses the burn to the N.N.W., and unconformably overlies the sandstone from which it is parted by a greenstone dyke. The sandstone is considerably hardened. A little lower down the burn the sandstone laps up on

Between Glen Scoradale and the Great Black Water Valley there are immense beds of boulder-clay, and also of water-rolled gravels but, I only marked their presence without examining them in detail.

In the Clachan Glen, the great boulder-clay beds extend from the bridge at its mouth at 190 feet above the sea upwards for a mile and a half or two miles. At 220 feet above the sea, felstone rock appears in the burn-course, but it is all so shattered on the surface and buried in debris, that no striations can be seen. At 250 feet above the sea, the shales reappear. Here, in the open and flat valley-bottom, a bank rises 20 feet above the burn which presents the section shown in Plate XXII. fig. 14. The lower part is entirely concealed by a talus of debris, above which the shales rise perpendicularly on the left. These are partly overlaid by 2 feet of dense gravel, very hard pressed, which belongs to the boulder-clay series. Above both the shales and the gravel-bed are 3 feet of large loose stones, and 2 feet of fine sand, with earth over all. The two latter beds, that, viz., of stones and that of sand, seemed to me to belong to the class of later superficial deposits thrown down when the boulder-clay was eroded by the action of a lake or bay of the sea.

A little way behind this on the north, the boulder-clay banks rise 120 feet high, while 100 yards east, or further up the burn, they reach 170 feet. The upper part of this bank consists of hard stratified gravels, less dense than usual in the boulder-clay, and the surface below the turf has three inches of fine hard clayey sand.

By far the best sections of the drift are to be seen on the other (the south) side of the burn; for there, though hardly more continuous, they are somewhat more perpendicular and less obscured by debris than on the north side. Unfortunately, however, they are so far obscured and interrupted, that the beds which they present cannot be traced continuously for any distance. At 290 or 300 feet above the sea is certainly the best and most interesting view that can be got of them, the whole bank being cleared from the burn upwards for 90 feet. (Plate XXII. fig. 15.)

At the bottom is some 15 feet of hard gravelly clay; above this a layer of 4 or 5 feet of great stones and gravel; then 15 feet of dense finely laminated clay with fine sand, becoming more sandy towards the top. In the upper part of this, almost at its junction with the overlying bed, I found some small broken twigs of exogenous wood, crushed flat. They were lying well into the bank, between the undisturbed horizontal layers of the sand, and beyond a doubt belonged to the period of the formation of the bank. Next is a bed 8 feet thick of dense hard pressed boulder-clay, more gravelly and sandy than usual. Then follow 5 feet

the back of a mass of the laminated felstone, the laminae of which are parallel to the junction-line with the sandstone, but turn sharp round at an acute angle, where they abut against another greenstone dyke, which here occupies the opposite or left side of the burn, and which cuts through the sandstone from S.E. to N.W.

of very coarse big stones and gravel, much water-worn, and over this 30 to 40 feet of boulder-clay; the materials of which are less coherent than in any of the other glens I examined, having less clay and more stones than elsewhere, and this is a characteristic of the boulder-clay throughout the whole Clachan Glen, a peculiarity obviously due to certain specialities of the valley itself, affecting the disposition of the boulder-clay.

At 20 feet above this section, the beds are again well shown; and there the great bed of clay is either buried under the talus of debris, or is absent altogether. At this point a prodigious stretch of the banks is displayed, but too much ruined to afford much information. Most of the stones are much water-rolled, but many of them still retain traces of striation. By far the greatest number of these are greenstone and felstone porphyry, but the latter, as usual, scarcely ever *show* striations. Out of 105 stones distinctly striated, which I counted in this bank, there were,—

Greenstone,	.	.	.	.	.	28	=	27	per cent.
Knots from the soft red shale,	.	.	.	.	.	28	=	26	" "
Laminated felstone,	.	.	.	.	.	4	=	4	" "
Felstone porphyry,	.	.	.	.	.	3	=	3	" "
Soft sandstone,	.	.	.	.	.	19	=	18	" "
Green conglomerate, from the altered carboniferous strata,	.	.	.	.	.	9	=	9	" "
Hard, purply, flinty, slatey shale,	.	.	.	.	.	9	=	8	" "
Syenite,	.	.	.	.	.	5	=	5	" "
						<hr/>		<hr/>	
						105		100	

About two miles above the bridge, at 300 feet or so above the sea, is a deep narrow gorge in the valley, where the drift banks are enormous, rising 200 feet high. The gorge is formed by a great felstone dyke, and the shales which it has protected. These have made a kind of dam across the mouth of the upper valley. Both the felstone and the shales crop out in the boulder-clay banks on the south side of the burn, at various points, at 100 or 120 feet above the burn. The shales seem to be overlaid by a mass of laminated or banded felstone, which apparently has spread out from the dyke. This is best seen in a precipice on the south side of the gorge. The greatest mass of boulder-clay lies on the north side; and the top of the bank here, for 3 feet, looks like water-sorted clay and sand, beneath which are some large stones, and below this is boulder-clay. The boulder-clay banks extend up both the main valley and a side branch, which opens to the south-east, above the gorge; but they lose there the huge proportions they have below.

Before concluding this examination of these beds, I think it may be well to explain why I have so definitely spoken of them throughout, as being composed of boulder-clay. Of course, I am aware that exception may be taken to this application of the name, on the ground that these beds present traces of stratification, and contain shells. But this objection could at most only apply to the

particular portion of the clay which is stratified or shell-bearing, and cannot be held to exclude the great mass of the beds, which, in their heterogeneous stiff clay mixed with striated stones, present—if not in high development, yet beyond a doubt—all the characteristics of true boulder-clay. If parts of the beds, then, must be classed undoubtedly as boulder-clay, the whole must be so called, and the elevation of mere stratification and the presence of shells into crucial tests of what is not boulder-clay must be rejected. But, besides this, these beds belong unquestionably to the glacial period, as is proved by the striated surfaces of the rock and of the stones, and by the boreal character of the shells. Now, failing any evidence of the submergence of Arran during the glacial epoch, we may conclude that boulder-clay must have been deposited on the island; and unless it were true, as it is not, that the boulder-clay has been entirely remade, and that the existing beds are the mere wrecks of that deposit—then these must just be the boulder-clay beds of the glacial period.

Such, then, are the facts here presented to us; and with these facts before us, it is obvious that we have, to some extent, a record of the history of the land. How far can we decipher the record?

Let us start from what we know. In geologically recent times there has been a glacial period. The existence of *roches moutonnées*, of striated surfaces and of scratched boulders, proves the action of ice on the land. The presence of marine shells and of water deposits is evidence of the submergence of the land to a considerable depth. Its present state implies its re-elevation. Of these phenomena enough at least exists in the south of Arran—in the boreal shells, the striated stones, and the hard chaotic clay—to justify the belief that this district formed no exception to the general condition of the country; that any differences here are due to local circumstances; and that we may fairly bring the general information gathered elsewhere to eke out our knowledge of this district. Assuming, therefore, that in Arran, as elsewhere, the land was gradually covered by ice, let us try to conceive the result.

At first snow would accumulate on the hill tops, creeping thence as glaciers down the valleys. As it grew in depth, it would spread further and further on the slopes till the whole land was swathed deep in ice. The fact that in our country all the rock surface at all elevations, with mere local exceptions, is striated, indicates such an existence, not of glaciers merely, but of a massive ice-cake, more universal than even in Southern Greenland now. Beneath this ice-cake the soil, and all of life it supported, would be gradually harried away to the sea, any traces of it left being nests of debris nitched into corners, ground over and disturbed in every conceivable way by the ice above. Loose blocks would be carried off, corners would be rounded—the rock faces and the scrubbing-stones would be striated—quantities of stones, gravel, sand, and mud would be ground promiscuously together, and the tendency of the whole mass would be down-

wards, ever by the steepest and the fastest descent it could find, towards the valleys and the sea. At the shore the ice-cake would still sink, crushing down, and yet partly resting on, the debris which lay beneath it, until at a depth proportioned to its thickness it would at last be floated up, forming that flat terrace along the land known among Arctic travellers as the ice-foot. Beyond the ice-foot, we know what occurs in Greenland, and some of the main features are familiar even to Norwegian travellers: floating icebergs, laden with debris, driven about by winds and currents,—masses of ice floating up with a thaw, and bringing up rocks to which they had been frozen, often dropping these again at a far higher level than their parent bed,—turbid fresh water, ice cold, flowing out to sea in a shallow stream, destructive of all animal and vegetable life. At the edge of the ice-foot, a steep bank of tumultuous debris,\* shelving down precipitously to a great depth; beyond this, gravel, sand, and mud irregularly distributed, according to the currents, but in the main a fine mud always present at a distance; seaweeds rare, or only locally frequent; while, from the very edge of the debris bank, animal life in abundance, but in the tumult of the debris bank itself only exceptionally present. Such are the phenomena more or less to be found along all glacial coasts; and such, no doubt, were the phenomena of our own shores in the glacial period.

This then being so, we are entitled to say—

1. That the material of the boulder-clay is the result of land glaciation. The enormous debris torn from the abraded surface of the basement rock must have gone somewhere—the huge boulder-clay heaps must have come from somewhere. Do not the two fit each other, as the broken masses of a land-slip in the valley fit the bald rock-face on the hill above?

But besides this, the shells associated with the boulder-clay are decidedly boreal in character, and indicate just such a glacial climate as the ice-covered land implies. The shells, therefore, show that the boulder-clay in which they are found belongs to the glacial period.

2. The ice covered the land till it was submerged. This certainly implies a great severity of cold, and an enormous snow-fall, and yet this seems actually to have been the case. Had it been otherwise; had the ice-cake begun to waste off the land at the lower levels before these were covered by the sea, we should probably have found traces immediately on the rock of the debris with which a glacier is charged, and which, in melting, it would have left behind it. The ice

\* I have repeatedly lain on the edge of such a bank, at the mouth of glacier rivers in Norway—particularly at the Skars Fjord glacier, where nothing but warps would hold us, the face of the bank on which our anchor lay being too steep to afford any hold. Our bows were almost grating on the shingle, while we had 70 fathoms under our stern, and 83 fathoms, with a fine mud bottom, at 100 yards distance. The surface water was filthily turbid, bitterly cold, perfectly fresh, and not above 8 or 9 feet deep, if so much; below was the clear salt water, sensibly warmer, and swarming with animal life, both fish and mollusks.



seems rather to have been actually floated off by the sinking of the land; and the first deposits thrown down on the bared rock are marine and shell-bearing.

3. The boulder-clay was deposited in the sea. With the moving ice the debris entangled in it and under it must have been in constant progress seawards, and could never permanently have come to rest till thrust out into the sea under the ice-foot. From this consideration alone we might have inferred the deposition of the boulder-clay under water; but we have more direct evidence, for in Arran, as in some other places, the boulder-clay contains marine shells in considerable numbers, and in circumstances indicating that the animals lived and died in the bed where they now are. Obviously, therefore, the clay in which these are found was deposited under water. Corroborative proof of this fact is further found in those beds of stratified sands and clay which are, comparatively, so frequent in Arran, and which are seen elsewhere wherever an extensive section of the boulder-clay is visible. These plainly imply the action of water, but of themselves, and without the shell beds, would still have left it doubtful whether the water-action might not have been temporary and lacustrine. The two combined confirm each other's testimony to the deposition of the boulder-clay in the sea.

4. Though deposited in the sea, the boulder-clay has been compressed by ice. At the edge of the ice-foot there must have been a growing bank of debris, on which fresh heaps were constantly emptied. On a free and open slope, in such circumstances, the mass of course simply rises in height, till, the angle of slope become too great, the face of the bank breaks, and the upper part slips forward over the lower. But in the case of the boulder-clay, the massive shelf of ice above would prevent the free growth of the bank, which, partly under its own weight, and partly under the pressure of the ice, must constantly have been subsiding, to some extent undergoing compression, to some extent yielding internally and bulging out in front, so as to undergo a complete disarrangement and confounding of all its component parts, which is one of the characteristic features of the boulder-clay, and of which we may regard the bed shown in Plate XXI. fig. 4. as an unfinished and transition example. There the pressure has evidently been at once from behind and above, so that the beds have bulged out forwards, but the pressure had not been long enough maintained to work the various beds into one another.

The influence of the massive ice-foot, in working utter confusion in the bank which lay below it, must have been all the greater from the different conditions it must have assumed under the ever varying change of the seasons, and those slower oscillations of rain-fall and temperature which extend throughout years. At times it would crush the oozy mass below with an enormous weight, till the sludge was compressed almost to the solidity of stone. Again, it would be floated off, and leave space below it for the deposition of stratified sands and clays, in which even molluscan life might thrive, till a rush of debris, brought down by a

warmer summer, buried them, or a series of wetter and colder years swelled the mass of ice so that it rested again with its full weight on the bank, crushing down its surface, and, as it ground its way over the resisting mass, producing those "striated pavements" which are well known as one of the striking features of the boulder-clay.

5. The boulder-clay contains beds which seem to have been formed on the land. Such beds as those I have described at pages 528, 531, and 533 certainly give the impression of their having had a glacier lying directly upon them, and the nature of the position in which they lie confirms the impression of their having been thrust into an angle of the strata by the glacier. But whether it be true, as I believe, for these cases or not, it is obvious that instances of the kind must have occurred, and are to be looked for in all such corners, and other places of the basement rock, as could give shelter.

6. The boulder-clay was deposited as the land was subsiding. Of this fact, the proof which appeals to our senses is the sequence of the beds. From the sea-level to 1200 feet they can be followed uninterruptedly, with quite enough of stratification to leave no doubt that the beds higher above the sea are also higher stratigraphically, and rest on those below. The other proof, though not so direct, rests on even a broader and less fallible basis of fact. The mere presence of the boulder-clay, from the sea-line up to the mountains, implies its deposition during the subsidence of the land; for let us suppose the contrary, and imagine that at some period of the glacial epoch the land previously submerged began to rise. As each zone of the land successively came to the surface it would be subjected to the ice and glaciated. So long as the glaciation went on, every particle of soil would be stripped off the rock and accumulated at the sea-line; and when the glacial period passed away, it would have left our land like a bleached and ghastly skull projecting from the grave.

This obviously is not the case. The whole country more or less, except only the higher mountains, is covered with soil, the boulder-clay itself rising to 1100 or 1200 feet at least; and this is exactly what would occur under the other supposition, that the glaciation of the country, and the deposition of the boulder-clay, went on as the land was subsiding; for thus, as HUGH MILLER has somewhere shown long ago, the sea would protect the boulder-clay from the ice, while the ice-foot would shelter it from the surf, and only when the ice was gone would the higher level beds be so far wave-beaten and eroded as to supply a coating of soil to the bare rock of the hill tops, and the higher mountain summits alone would be left in the nakedness of broken and weathered rock which characterises them. And here, if adaptation of means to an end be a proof of design, we have a marked evidence of the work of God preparing the earth for man's habitation.

7. The subsidence extended from the present sea-level, and ultimately reached

1100 or 1200 feet at least. The striated surfaces (indicative of ice) at the present sea-level prove that the land, during the boulder-clay period, stood at least no lower than it does now, and the presence of the boulder-clay—a sea deposit as we have seen—proves that to a height of 1100 or 1200 feet the sea rose over the land. There is indeed some evidence that during the glacial period the land stood higher than now, and still better proof exists, in Wales especially, that the depression extended to not less than 1400 feet; but I confine myself now to the evidence afforded by the Arran beds.

8. The subsidence was probably continuous not oscillatory. Of course there may have been oscillations here, as there have been, in recent times, at Naples and elsewhere; but, so far as I know, no evidence exists of such oscillations occurring during a protracted and long-sustained process of subsidence and upheaval: and certainly no trace of such irregularity has yet been found in connection with the movements of our country during the glacial period. At the same time it is not very obvious by what evidence such oscillations, during the deposition of the boulder-clay, could be established. Still, in the absence of any strictly analogical case, we may consider that the subsidence of the land here was continuous.

9. The subsidence was gradual. As this opinion is opposed to that which I held when I read this paper to the Society, it is right that I state somewhat fully the grounds on which it rests.

The depression of the land might take place by a succession of sudden jerks or leaps, with long intervals of rest, or by a slow, steady subsidence, as is the case at present in Greenland.\*

In the former case, the ice-cake would be floated off the land as it sank, and between the top of the boulder-clay bank on which it had been resting, and the new ice-foot, there would be a zone of bare rock perpendicularly equal to the amount of the subsidence, but which, in the flatter districts, would be of considerable extent horizontally. Along the upper edge of this zone, at its junction with the ice, the boulder-clay bank would again begin to form, but all its lower expanse would lie too remote from the supply of debris to be thus covered. The glacier streams, however, floating out to sea on the surface of the salt water, would gradually drop on it the detritus with which they are always charged, and a bed of stratified sand and clay by degrees would overspread the bare rock, till the growing mass of boulder-clay buried it. Now in Arran, as I have mentioned, I found several cases of just such a bed resting directly on the rock, and buried beneath the boulder-clay; and the inference seemed to me a fair one, that these beds indicated a sudden subsidence of the land at that point. I still believe them to indicate the remoteness of the ice-cake at the time of their deposition,

\* Such jerks must of course be supposed considerable, since, if minute, the subsidence in this way would practically be slow and steady as in the other.

but I no longer think that remoteness of the ice due to sudden subsidence. Had it been so, the basement-bed of sand and clay would have run round our whole coast pretty much at the same level. But this is not true, even for Arran. The stratified beds, therefore, on the basement rock must, where they exist, be accepted merely as local phenomena, and be therefore explained by local causes, connected probably with those banks of eruptive rock which lie across the valleys, and which must have interfered with the free motion of the ice.

Thus, in the absence of any evidence of a sudden depression we accept the other alternative of steady gradual subsidence, during which each separate level must in turn have formed the shore line and lain at the edge of the ice foot, and have received the glacial detritus—the coarse red clay and stones which the ice and its accompanying streams were bringing down—while the finer detritus would be spread as stratified sands and gravels over the boulder-clay beds already deposited.

10. Was the subsidence rapid? A question I rather ask than answer. If the mass of the boulder-clay suggest long-continued formation, the comparative rarity of interstratified beds, and the merely local development of the overlying beds of sand and clay—though perhaps capable of explanation on other grounds—still seem to point to such a steadiness of climate and of currents as is hardly compatible with a very lengthened duration of the glacial epoch; and in this case the huge mass of the glacial debris would be the result of an enormous development of the ice-cake, which tallies well enough with various known facts. On the whole, this point must be considered doubtful, and its determination is probably to be sought from a careful examination of the larger shell-beds, the layers of life in which may indicate the duration of their development.

11. There has been no general glaciation of the land since its re-emergence. Had glaciers existed on the land after it rose from the sea, they would certainly have cleared the upper valleys at least, of boulder-clay, and left nothing but great transverse moraines, as is the case in Norway. (See Kjerulf on the glacial phenomena of Norway in the *Edinburgh New Phil. Journal* for July 1863, p. 8.) Instead of this the boulder-clay thins out gradually upwards, and fringes the upper valleys as a beach terrace.

12. The existing boulder-clay must represent all ages throughout the whole glacial epoch; for so long as the ice-cake was present on any part of the land the manufacture of boulder-clay went on.

13. There must be drift-beds of sand and clay resting on the boulder-clay, but truly contemporary with the boulder-clay of a higher level than that on which they lie. It may not be easy or possible to determine which of these answer to one another; but it is obvious, that while the coarser debris from the land was forming boulder-clay under the ice-foot, a deposition of the lighter detritus must have been going on from the fresh-water currents that were setting

seaward, and scattering, first the sand and ultimately the mud, with which they were charged, on the boulder-clay already spread over the lower levels. Thus these two beds, the boulder-clay formed under the ice-foot, and the stratified sands and clays deposited in deeper water, though so different in texture, would be really strictly contemporary. Of course the determination in any particular case, of which are the corresponding beds, is now the more difficult task, from the erosion of the beds at certain points, and their *remaniement* or remanufacture in others.

14. We may determine, approximately at least, the relative age of the drift-beds. Superposition, of course, implies subsequence in time, but this principle is of very limited application, and will not avail for the comparison of the boulder-clay in different districts. If, however, the boulder-clay was deposited under the ice-foot as the land was subsiding, the sea-level affords us a standard of comparison for the boulder-clay beds over the whole country. Allowing for possible differences in the thickness of the ice-foot, which would be deeper of course in the valleys than on the hill faces, and deeper also in a mountainous than in a flat region, all boulder-clay beds are contemporary which rest on the basement rock at the same level above the sea; and of two beds at different levels that is the older which lies on the rock nearest the sea-level.

15. Since the boulder-clay period there has been no material change of any kind on the basement rock of the country.

Such changes might have occurred in three ways. In the process of subsidence and re-elevation the whole face of the land might have been remodelled, and hill and valley have changed places. Such a change, or something like it, has been asserted even by so eminent an authority as the great German geologist NAUMANN. (See *Geognosie*, vol. i. p. 249.) But in our drift-beds we have casts made of our valleys as they sank under the sea, and these casts show that what are valleys now were valleys then; in other words, they assure us that the subsidence and re-elevation of the land has not been accompanied by any such protrusion of one part of the coast above another, or of the interior above the coast line, as to affect the relative contours of hill and valley.

Another form of change is that on the river beds, the erosion of which is generally attributed to existing streams; whereas in Arran we find that the burns are only now beginning to lay bare the rock which underlies the boulder-clay. If, then, making all allowance for the slight erosive power of such small streams, they have yet done so little here against sands and clays, how much less elsewhere against solid rock. They seem, in fact, to be only now beginning to occupy the old river-beds formed long ago under the ice, and in part even earlier.

The third change which has been often asserted, consists in the erosion of the older and present coast-lines by the sea, upon which calculations have even

been founded to determine the length of time during which the sea stood at the forty-foot terrace-line, and so on. Now, admitting the obvious fact of the destruction of the rock at many points of our present sea-line, it yet appears that on the whole the influence of the sea in modelling the land in recent times has been very small. In a great many cases it has not so much as penetrated the boulder-clay; and even where that has been washed away, as in the coast of the Little Cumbrae, figured and described by Mr SMITH of Jordan Hill, in his "Newer Pliocene Geology," p. 144, the striations of the rock remain with wonderful freshness. From all this it is obvious that the terrace lines of the basement rock are not due to the action of the present sea, but were given to it previous to its submergence.

In short, we find that all the latest geological changes, with their accompaniment of river and sea-action, have not materially modified the face of the country—the rock skeleton of which was moulded finally under the glacial epoch.\*

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LIST OF THE SHELLS FOUND IN THE ARRAN BEDS, WITH THE DEPTHS AT WHICH THEY LIVE ON OUR OWN AND THE NORWEGIAN COASTS, AS GIVEN BY FORBES AND HANLEY, AND BY DANIELSEN.

Name.	British.	Norwegian.
<i>Balanus crenatus</i> .	Deep water to 50 fathoms.	.....
<hr/>		
<i>Panopœa norwegica</i> .	Deep water to 90 „	Not known living.
<i>Tellina balthica</i> , (a brackish variety of } <i>Solidula</i> .)	Shore.	20–60 fathoms.
<i>Cyprina islandica</i> .	5–80 „	20–40 „
<i>Astarte elliptica</i> .	10–40 „	20–60 „
<i>arctica</i> .	80 (dead) „	10–80 „
<i>compressa</i> .†	7–70 „	10–40 „
<i>striata</i> (a variety of <i>compressa</i> .)	.....	.....

\* I cannot let this paper go without expressing my obligations for much information and many suggestions to my friend Mr GEIKIE's valuable paper on the Phenomena of the Drift. I am gratified to agree with him on the land origin of the material which constitutes the boulder-clay, and on the subsidence of the land during the formation of the boulder-clay. On some other points, too, I think we are not very far from an agreement, though I fear we differ fundamentally on many of the most important.

† I only found one specimen of this species. The shells were partially crushed, but the two valves were united, and retained both epidermis and ligament. Mr SEARLES WOOD, who was good enough to examine it for me, says it is one he does not recognise. Mr S. P. WOODWARD, who has also taken the trouble of looking at it, considers it an unusually large *A. compressa* of the variety *striata*. It is one-third larger than even the excessively large specimens of the species from the Red Crag, figured by Mr SEARLES WOOD in his Bivalves of the Crag.—(*Pal. Soc. Pub.*, vol. ii. p. 184, pl. 16, fig. 8, *a* and *c*.)

LIST OF THE SHELLS FOUND IN THE ARRAN BEDS, &c.—*Continued.*

Name.	British.	Norwegian
Cryptodon { <i>Syn. Lucina.</i> } Sarsii.	.....	20-180 fathoms.
Modiola modiolus.	0-60 fathoms.	Shore.
Leda ( <i>syn. Yoldia</i> ) pygmæa.	25-40 "	30-140 "
pernula.	{ 35-160 <i>Macandrew,</i> } "	10-140 "
	{ <i>N. E. Atlantic.</i> }	
Pecten opercularis.	5-100 "	30-50 "
islandicus.	35-100 (dead.) "	10-60 "
<hr/>		
Litorina litorea.	Shore.	Shore.
Turritella communis.	4-100. "	10-30 "
<hr/>		
Natica.	Species not determinable.	.....

*Description of Plates.*

## PLATE XXI.

Fig. 1. Lower part of Torlin Water seen from the east, 450 ft. above the sea, to show the contours of the land, the clothing of boulder-clay, and the way in which the burn-course is cut through it. The banks in the burn-course are from 60 to 120 ft. high. (P. 524-528.)

Fig. 2. Bed of various clays, &c., in the Torlin Burn, below the church. (P. 528.)

- |  |   |   |
|--|---|---|
| <ol style="list-style-type: none"> <li>1. Small gravel and minute angular stones, 3 inches.</li> <li>2. Fine clay with angular stones in upper corner, 2 inches.</li> <li>3. Sand, 3 inches.</li> <li>4. Clay with stones, 3 inches.</li> <li>5. A nest of gravel, 3 inches.</li> <li>6. Sand, 4 inches.</li> <li>7. Fine yellowish sand, 3 inches.</li> <li>8. Fine reddish sand and clay, without stones, 6 inches.</li> <li>9. A nest of gravel, 3 inches.</li> </ol> | } | <p>All this is purply and red like the shale-rocks of the district.</p> |
|--|---|---|
10. Sandy clays distinctly laminated, and slightly varying in texture; dipping under next bed, No. 11 at 75°; shells found in this, 8 inches.
  11. Very dense, dark, coarse boulder-clay, with few stones, and slightly stratified; shells found here, 5 or 6 feet.
  12. Layer of large stones and coarse gravel, 1 foot.
  13. Boulder-clay.

Fig. 3. Great shell-bearing banks in the Cloinoid Burn-course, 80 to 100 feet high. The upper part grass-grown. The centre being obscured by debris is omitted. (P. 529.)

Fig. 4. A bed of sand overlaid by boulder-clay. The whole subjected to a forward thrust under pressure. (P. 530.)

Fig. 5. Immense boulder-clay bank on the Cloinoid Burn, 140 feet high; in many places perpendicular; with shells. In the centre of the bank, the rock crops out. (P. 530.)

Fig. 6. Basin in the Cloinoid Burn-course, to the contours of which the boulder-clay conforms. (P. 531.)

Fig. 7. } These should go together, as they show the same beds, and are nearly continuous, 100 yards  
 Fig. 8. } only intervening. They both occur at the lower end of the basin, shown in fig. 6.

Fig. 7. Shows at the bottom a bed formed under a glacier. To the left it is overlaid by the boulder-clay, which to the right has been eroded, and the glacier-bed here is overlaid by a layer of large stones. (P. 531.)

# PLATE XXII.

Fig. 8. At the bottom, the same glacier-formed bed overlaid to the right by boulder-clay; to the left, both the glacier-formed bed and that of boulder-clay seem to have been eroded, and a mass of stones and gravel, like that in fig. 7, but thicker, lies on the hard glacier-bed. (P. 532.)

Fig. 9. Bed, 100 feet high, in Crogeréver Burn-course, just above its junction with the Slaodrig Burn. (P. 532.)

Fig. 10. Gorge in Crogeréver Burn, the west side being formed by the rock, the east side by the boulder-clay lying down the dip of the strata. (P. 533.)

Fig. 11. Bed of hard yellow clayey gravel, lying in behind a barrier of felstone. The burn has partly cut in between the rock and the bed, but in the distance in the fig., has turned to the right, and cut through the bank. (P. 533.)

Fig. 12. The same bed further up the burn, with overlying beds. (P. 533.)

1. The hard yellow clayey sand or gravel, with a huge striated greenstone boulder sticking in it. This bed is laminated, but not stratified on its upper surface to the left.
2. Overlying 1. Red boulder-clay, with a large boulder sticking in it, but projecting above its surface into
3. Coarse sand, 10 feet thick in parts.
4. Very large stones, 3 feet.
5. Fine light-coloured sand, 6 inches.
6. Earth.

Fig. 13. The same bed still further up the burn, and just below the felstone rock. To the left, in the burn-course, is boulder-clay. Underlying this is the hard yellow clayey gravel here much discoloured, and containing heather stalks. Above this is debris, with boulder-clay showing atop. (P. 534.)

Fig. 14. Beds in Clachan Glen, 20 feet high. At the bottom is a talus of debris. Above this, to the left, a face of the shale-rock, 2 to 3 feet high. Lying up on this to the right, 2 feet the dense gravel. Overlying this bed, and to the left lying directly on the shales (which have been stripped there of the dense gravel), 3 feet of large stones; then 2 feet fine sand. Earth atop. (P. 535.)

Fig. 15. Great banks in Clachan Glen. (P. 535.)

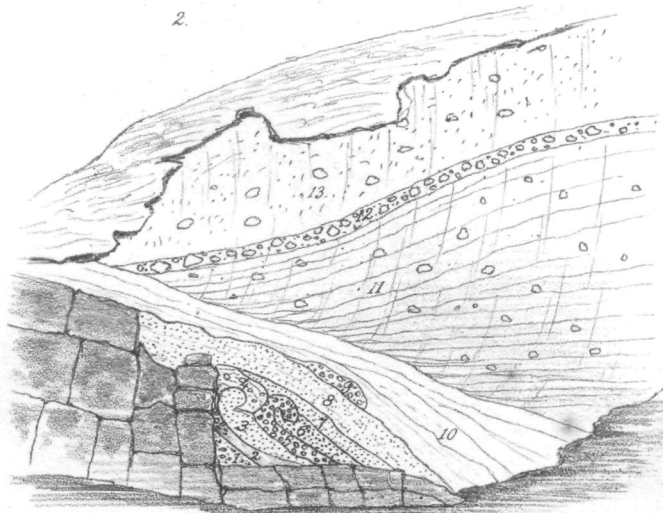
1. Hard gravelly clay, 15 feet.
2. Looser stones and gravel, 4 feet.
3. Dense finely laminated clay with fine sand, becoming more sandy towards the top, containing twigs, 15 feet.
4. Dense hard boulder-clay, 8 feet.
5. Big stones and gravel, 5 feet.
6. Boulder-clay or drift, 30 to 40 feet.



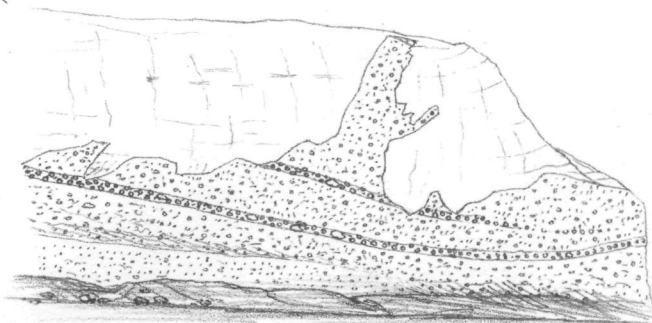
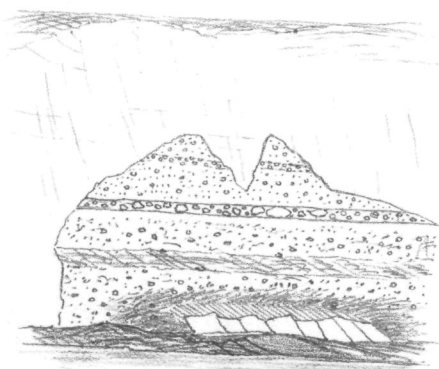
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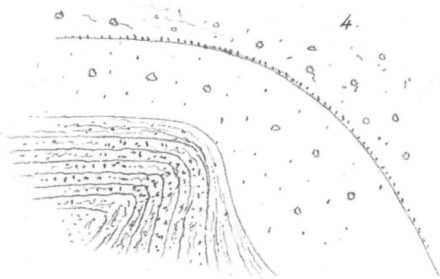
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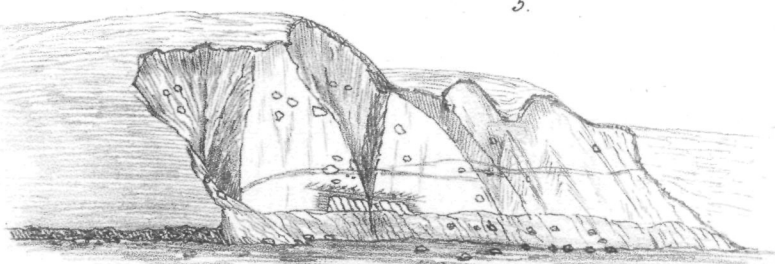
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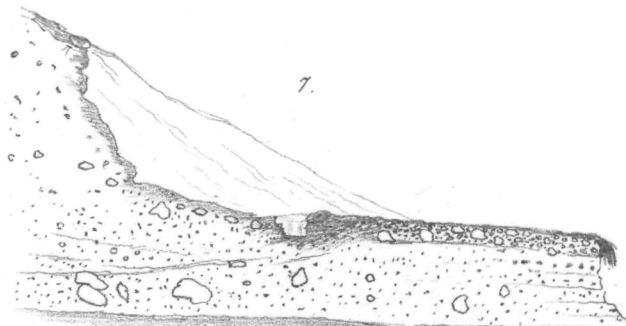
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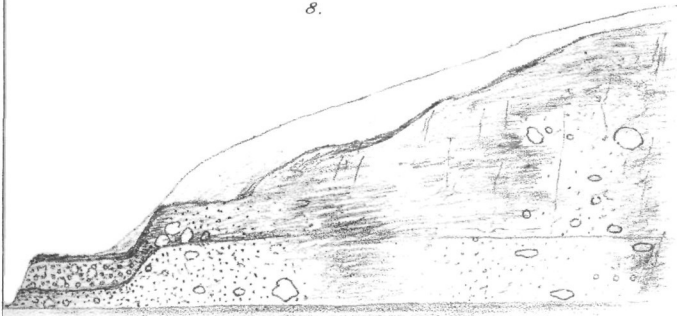
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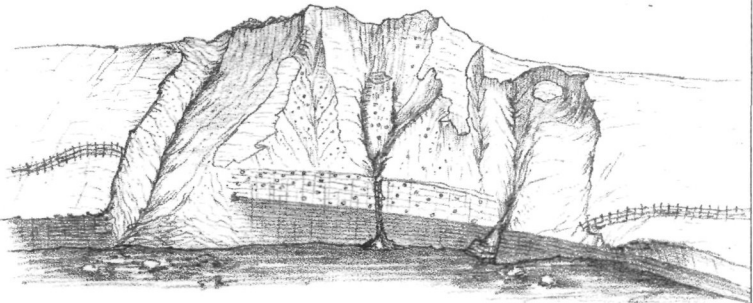
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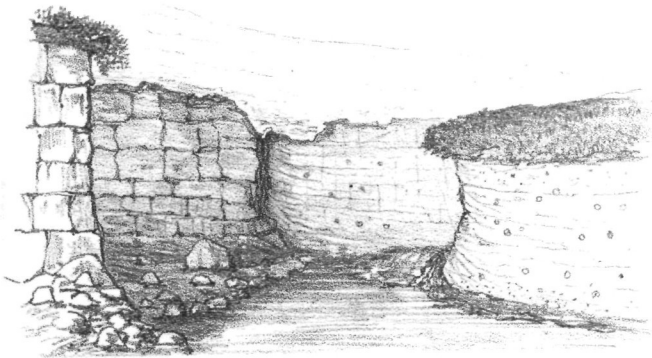
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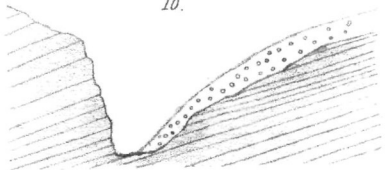
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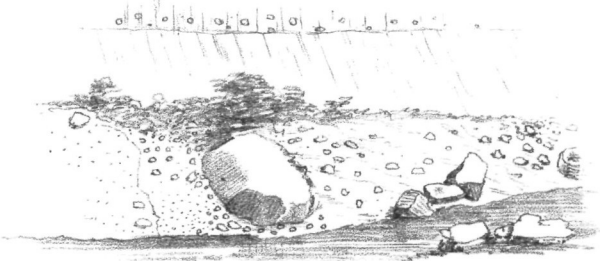
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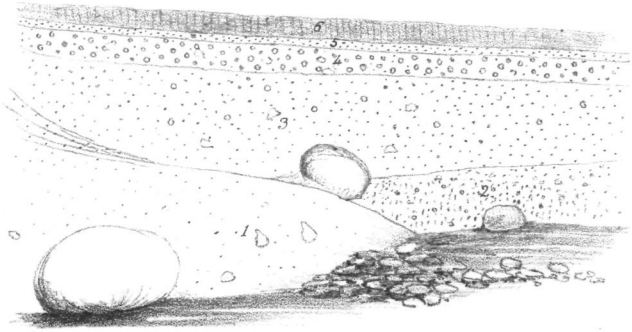
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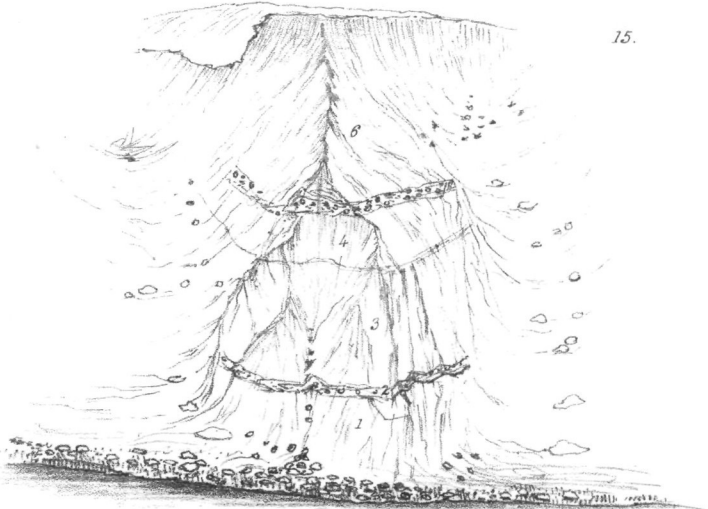
13.



12.



15.



14.

