Chapter 30 Drifts and glaciation

Introductory

The whole of the surface of Anglesey bears the marks of glacial action of one kind or another: whether the features and strile due to glacial erosion, or the presence of sheets of material due to glacial deposition. The phenomena to be described in this chapter will be more easily, grasped if the cardinal facts are briefly summarised at the outset. They are as follows.

1. That the general direction of the glacial stripe is from northeast to south-west.
2. That the greater part of the surface is covered with glacial drift, chiefly boulder-clays; though there are considerable deposits of sand and gravel.
3. That the transport of the drifts has been in the same southwesterly direction.
4. That with the materials of local origin are mingled many that are foreign to the Island, most of which are from localities in and around the Irish Sea basin to the north and north-east of Anglesey.
5. That in a tract bordering the Menai Strait, and about three miles in width, erratic blocks also occur which have come from the adjacent mountain-land.

Manifestly the Island has been traversed by ice in a generally south-westerly direction. That from the mountain-land is admitted to have been land-ice: but the conclusions of the present writer concerning that of the Island in general will be kept, as far as possible, separate from the descriptions of the phenomena.

Modifications of the surface

Striation

Along the coasts (with the exception of that of the Strait) striation is frequent and easy to detect, and this is also the case on some of the higher hills of harder rock, such as Holyhead, Bodafon, and Parys Mountains, while striated floors of several yards in extent are well-preserved at a good many places.<ref>A list of 850 records is preserved in the library of the Geological Survey.</ref> But, though ice-worn features are to be seen everywhere, many of the rocks do not retain striae well, so that inland they are for the most part only to be found for a few inches from the edge of the boulder-clay. Many, too, are on quartz-augen, and are so fine as to need a low sunset light, or rubbing with fine clay, to make them visible.

General direction

Apart from variations due to purely local causes, the normal direction over the greater part of the Island is a few degrees to the south of south-west, with oscillation, sometimes a little to one side, sometimes a little to the other, of this normal. But in the northern, districts, as far south as Rhosgoch Station, and as far west as Cemlyn Bay, the normal itself becomes south-south-west. A general view 'of the path of the ice is given in the chart ((Figure 325), p. 710).

Striae have been detected crossing the summits of all the higher hills with the exception of Nebo and Llanddona, which consist of rocks not well adapted for retaining them. The directions are: Holyhead, south 10° west; Garn, south-west; Parys, south 25° west; Eilian, south-south-west; Bodafon, south 30° west; Mynydd Llwydiarth, south-south-west; Bwrdd Arthur, south (not quite on summit, and a little deflected). Those on Holyhead are at 720 feet above sea level, the rest at about 500 feet.

Deflections

Of the really local variations, all but three can be ascribed to the form of the surface. These are-

1. Cross-hatching (very rare generally) in the Penmon district, where a normal south-west and south-south-west series are superimposed upon a series running south 20° east.
2. On the high platform above Llangristiolus, overlooking the deep hollow of the Malldraeth Marsh, strim run nearly due south (and in one instance south-south-east) over a space of about one square mile; and there is a group in line with this across the marsh at Newborough.
3. A series at Llanfwrog run about south 10° east, and seem to be later than the normal ones. But that may possibly be due to a creep of the lower portion of the ice into Holyhead Bay.

Deflections due to the form of the surface are, on the small scale, quite frequent: but the following cases are of more importance.

1. From a normal of south-south-west, to west-south-west on the face of a small crag of picrite at the roadside along the north face of Mynydd Eilian.
2. From a normal of south-west, to west-south-west under an escarpment in the Carboniferous Limestone at Moelfre.
3. From a normal of south-west, to west along some narrow creeks in the Old Red Sandstone.
4. From a normal of south-west, to south-east in a gap running south-east and on its north-east side, at Capel Gorllas, Holyhead. The surface is undercut.
5. From a normal of south-west, to south-south-west and in one place to south 10° west on and immediately overlooking the South Stack, Holyhead.
6. From a normal of south-south-west, to south-west along old cracks on the western side of Amlwch Port's mouth (Figure 307). The crack is only about four inches deep, yet in it the striae conform to its trend, while just outside they have fanned out 'to the normal south-south-west.
7. ***The Deflections of Trwyn-dwlban*** — Most remarkable of all are the deflections at Trwyn-dwlban, Red- Wharf Bay. These are on Carboniferous Limestone, in the trumpet-shaped mouths of the pits in which stand the pipes of contemporaneous sandstone described at p. 613. On the landward part of the foreshore, the mouths of these pits, and the limestone generally, are beautifully ice-worn, though the heads of their sandstone plugs are (now at any rate) for the most part rough and angular. On passing across these pits, the strie curve round, resuming their normal direction when they emerge from them. In the case of one pit, about six feet in diameter, the striae sweep completely round in the moat-like hollow surrounding the plug, until on its south-southwestern side they are pointing more than 20° north of west, as shown in the ground-plan, (Figure 308). (Plate 43) shows some of the deflected striae within the pit. On the broad and gently convex surface of the limestone just outside the hollow they have the normal direction (which, in the Plate, is from the right-hand end of the note-book to the small round hole at the branching cracks) (*cf.* p. 745), so that the deflection in a space of some two yards is nearly 90°. Undercut furrows (see below) occur close by, so that the agent which produced these phenomena must have adapted itself, as a practically plastic body, to every irregularity in the surface of the rock.

Miniature Crag-and-Tail — That ice-flows are deflected about hard outstanding objects is well known, and this frequently occurs about the lenticular quartzites of the Mona Complex. But 140 yards north-west of Porth Cadwaladr on the coast south of Aberffraw, and especially on the northern slopes of Parys Mountain, in gritty schists and gritty cleaved shales respectively, there are cases, not so much of deflection as of the production, in solid rock, of 'crag and tail' on a scale almost microscopic. Little grains of quartz in the fine schists and shales stand out from the smooth striated surface, no bigger than pins' heads; yet not only are their north-eastern sides polished, but on the south-western side of each is a 'tail',of the softer matrix of the rock, protected by the little hard grain.<ref>A specimen of this, with the direction of glaciation marked upon it, is preserved in the Museum.</ref> Some of the miniature onset-sides are slightly undercut.

Furrows and undercut surfaces

Large furrows can be seen in 24 places, fine examples occurring at Dinas Trefriw, Cerig-yr-eryr (Folding-Plate 13), Amlwch Port (Figure 307), Mynydd Eilian, Trwyn-dwlban, and Careg-lydan. Some of those at Careg-lydan and at Dwlban are actually undercut, each time on the southern side. At Trwyn-dwlban (Figure 309) striated faces of limestone are undercut so as to overhang as much as two and a half inches; the inclination of the roof, measured by clinometer, being

15° to 30° from the vertical. Undercut surfaces occur also at Capel Gorllas near Holyhead, at Felin-wen south of Valley, and Huslan cliff (where boulder-clay lies beneath the roof) (Figure 310), (Figure 311). Closely connected with these phenomena is the fact that where bosses of rock are near together, as in the Llanddona district, the gneissic tract of Craig-yr-allor, and other places, leaving north-east to south-west passages only a few yards wide with steep walls 10 to 20 feet in height, these walls are smoothed and rubbed as well as the onset-sides of the bosses.

Modelling of the surface

The well-known onset-and-lee<ref>This seems a convenient English equivalent of 'stoss- and lee-seite', or of the Cumbrous 'roche moutonnée'.</ref> features characteristic of glacial erosion are general,, the rock usually emerging from the drift in groups of steep-sided, oval bosses, rubbed off and smoothed at their north-eastern ends and usually along their sides as well, but presenting precipitous crags towards the south-west. The prevalent coincidence between the directions of strike and glaciation has lent itself to a strong accentuation of this type of featuring, which attains, indeed, an extreme degree of development where, as in Holy Isle and parts of Aethwy, the pitch of the minor folding is also north-easterly. It can, however, be found also in places such as Craig-yr-allor and the district between Beaumaris and Llanddona, where there are obliquities of 45° or even 90°, showing that glacial erosion could under certain conditions (see Chapter 34) overcome the natural effects of strike.

Even the higher hills have been modelled in the same manner; Holyhead, the highest of them all, showing, when viewed from the south-east, a typical onset-and-lee profile (Figure 339). But by far the most interesting glacial modelling in the Island is that of the sea-cliffs of the northern coast, especially those between Amlwch

Port and Point Lynas, where the steep seaward dip of the hard flaggy schists, plunging into deep water, has protected the land from under-cutting, the waves washing up instead of breaking. Here cliff after cliff, headland after headland, are (Figure 312) as rounded as the knobs in the floor of a Highland valley, while the striae preserved in their sheltered crevices demonstrate the direct frontal attack of the ice upon the land, exactly at right angles to the trend of the coast. The conditions are exceptional, alike for the production and the preservation of the features. There can hardly be another district in the British Isles where the impact of ice, rising from a sea-basin against a steep and rocky land, can be so vividly realised as here.

Shattering

Over extensive tracts in the west and south-west, particularly those that lie between Valley and Llanrhyddlad, the surface of the rock is not smooth but shattered. This shattering proceeds to the depth of several yards, and all stages can be studied, from rock in place, with blocks lifted slightly out of position, through a breccia of the same rock, into boulder-clay containing erratics as well as local material. Excellent sections are exposed in the bays of the western coast from the Alaw's mouth to Porth Swtan, as well as inland; but by far the finest is at the southern end of Porth-delisc. A gently undulating lowland has been cut by the sea into cliffs of boulder-clay some eight or ten feet high, curving round to the south end, where rock rises a yard or so above high-water mark. It is mica-schist, dipping north-west at variable angles. Bands in this schist, as they rise to the sub-glacial surface, are disrupted along joints, and if the foliation dip be high, driven an inch or two to the south-west along the joint-plane (Figure 313). Where the dip is moderate, long bands (sometimes as thin as half an inch) gently bending, can be seen in the act of breaking up into angular fragments (Figure 314). Then, a trifle higher, these are thrust over each other, and the rock passes into a breccia, in which the larger pieces, now becoming somewhat oval, are still inclined in the same direction. This breccia graduates up, in the course of two or three feet, into true boulder-clay, the stages being: first, breccia pure and simple, with pure schist debris as a matrix, then breccia with a clayey matrix, then large blocks of mica-schist in stony clay, then true boulder-clay with foreign stones, rubbed and striated. Sometimes shattered rock rises to the cliff top; sometimes erratics are driven down into the breccia; sometimes shivery corrugated bands of the schist fade off into boulder-clay, bits being torn from them all along, the local material beginning to become rounded in the upper parts of the section. There is no line of demarcation whatever between rock in place and true, typical boulder-clay, so that every stage of the formation of that deposit, by plucking of the local material, and kneading of it in with a clay containing already ice-worn erratics, can be studied in this sea-cliff.

The heavy pressure on the boulder-clay is evident at Ty-moel (Ceirchiog), at Tryfil high boss, and other places, where, beneath two to four feet of it, good-sized erratic blocks have been rammed down into decomposed granite.

A different effect of the same pressure is shown at an interesting section (Figure 315) on the great dyke of Capel-mawr (see pp. 175, 692), 333 yards south of Plâs-bach, a mile and a half north-east of Bodorgan Station. Just below the lane, about three feet of boulder-clay rest on the steep brow of a boss of dolerite. At the surface, spheroids of the dyke-rock are involved in this clay, but it steals down into irregular and winding fissures between unmoved spheroids for two or three feet more. Besides this, moreover, veins of boulder-clay (Figure 315), with various erratics, have been driven in so as to lie vertically beneath a roof of dolerite still in place, though undermined. The reality of the phenomenon described as 'plucking' has been called in question. Here it can be seen, arrested when well-nigh complete. A little more, and this block would have been 'plucked', and carried forward as a boulder.

The condition of the Pre-Glacial surface

This is not often thoroughly fresh and sound, the state of preservation of the rocks, though greatly superior to that which is prevalent in southern, being inferior, even where protected by boulder-clay, to that which is commonly found in northern Britain. The condition of some of the crystalline schists of the Mona Complex is comparable with that of corresponding rocks in Scotland, but very few specimens can be obtained from its gneisses (p. 143) that will bear being set beside the brilliant plutonic products that may readily be collected in Ross or Sutherland. This probably results, not merely from a less intensity, but from a briefer period of glaciation, for it is reasonable to suppose that the ice of this region developed later and withdrew earlier than did that of Scotland. Yet any considerable depth of thoroughly decomposed rock is rarely seen. At Porth Swtan, Llanrhyddlad, however, the Gwna mélange is so decayed (p. 283) that it can be dug with a spade to a depth of 70 or 80 feet, though it is covered by some 30 feet of boulder-clay. This, it is to be remarked, is a sheltered place under the lee of Mynydd-y-garn, where the old Pre-Glacial surface would be protected from the scour of the ice. The rocks on the western side of forth-wen (pp. 311, 472) also are decomposed to about 50 feet, and this again is a sheltered place, the headland of Torllwyn rising high above them- to the north; while similar decomposition has developed in a similar situation (p. 308) at the Lifeboat Station, Cemaes.<ref>The decayed parts of the Nebo Gneisses (p. 599) were almost certainly covered by Old Red Sandstone during the Glacial Period, and only laid bare by Post-Glacial marine erosion.</ref> No leniency of glaciation must be inferred from these cases of decomposition, all of which are due to shelter. For even in severely glaciated Eastern Sutherland some 30 feet of decayed rock<ref>E. Greenly, Notes on the Sutherland Goldfield'. *Trans. Edin. Geol. Soc., vol.* Vii., 1895, p. 104.</ref> survives in a sheltered valley at Kildonan.

The Pre-Glacial was far more rugged than the present surface, rugged as that of ten is. Buried rocky bosses are often revealed below the boulder-clay on coast-sections of country that is now gently undulating; while every now and then (Figure 316), (Figure 317), (Figure 318) one can see that it fills little hollows even on the very summits of the knobs, as well as between them (Figure 319), and (Figure 320) flattens out what seem to be their sides. In like manner, whenever sections have been opened in the narrow tracts of smooth land that wind in and out between the rugged bosses, they have always revealed some depth of boulder-clay.

The drifts

The greater part, of the surface is covered with glacial drifts, _ yet there are considerable tracts that, are comparatively bare, the chief of which are:

1. The Carboniferous Plateaux of Penmen.
2. A long narrow tract overlooking the Strait from Menai Bridge to Beaumaris. This then turns north by Baron Hill to join
3. The Llanddona highlands, with Mynydd Llwydiarth. From this again another narrow tract extends along the side of the Malldraeth Marsh to the sea at Llanddwyn.
4. The Carboniferous Plateaux north of Llanddyfnan.
5. A narrow tract along the floor of Gwna Vale.

6. The Gneisso-Granitic region about Gwalchmai.
7. The greater part of Holy Isle, including Holyhead Mountain.
8. Mynydd Bodafon.
9. A long strip, curving from Carmel Head to Llaneilian, and including the hills of Garin, Parys, Nebo, and Eilian.
10. The sea-board front Wylfa Head to Point Lynas.

All these "driftless" areas of the one-inch map, however, are really full of hollows filled with boulder-clay; and, conversely, there is hardly a square mile of drift-covered land in the Island in which knobs of rock do not appear. In fact, the Drift Edition of the one-inch map is a generalisation from a one-inch first-draft that was found (in view of the great number of 'solid-geology' lines) too complex for engraving. A large number of bays and outliers of boulder-clay were therefore abolished, and most of the bare tracts represented as continuous, which they are very far from being. When it is remembered that the first-draft was itself highly generalised from the six-inch maps' used in the field, it will be seen that the published draft is but an abstract of an abstract; and it is certain, in any case, that the proportion of drift-covered country is greater than it was possible to show thereon.

Yet the Glacial deposits must have been enormously reduced, first, probably, by melting-waters, and since then by marine erosion. At the end of the Glacial Period, there is little doubt that Anglesey was enclosed all round in a setting of boulder-clay. The width of this, to north and north-east, may not have been many hundred yards; but to the south-west, especially under the lee of the higher parts of the land, it may, on the crag-and-tail principle, have been as much as two or three miles, adding considerably to the extent of country that rose above the present level of the sea.

The thickness of the wider sheets of drift must be considerable. Deep sections are rare inland; but on the coasts, especially in Beaumaris Bay and the many bays of the west, 30 or 40 feet are not uncommon, and as much as 130 feet with no bottom visible are found at Mynachdy, while at Llanddona there seems to be more than 150 feet for a short distance.

Boulder-Clay

By far the most widely spread of the glacial deposits are the boulder-clays; of which there are two, a Blue and a Red.

The Blue is a perfectly typical till, tough, hard-packed, and full of stones, which are held tightly in the matrix. Some of them are large, especially those from the Carboniferous Limestone. All that are capable of receiving stria; are striated; but many of the schists do not lend themselves to striation, while the shales from the Ordovician series crush. Those furnished by the Carboniferous Limestone are as fine examples of ice-worn stones as could be seen anywhere.<ref>One from Beaumaris was taken to Llansadwrn Churchyard and placed as a headstone to the grave of Ramsay.</ref>

Impersistent seams of sand and gravel, an inch or two thick, occur occasionally, but they form an insignificant portion of the mass. Sometimes they are disturbed and torn. The blue colour is only seen in the deeper sections; for in most even of the sea-cliffs, it has changed to a dull brown or brownish grey.

Red Clay — Along the eastern margin of the Island a red boulder-clay appears. It is seen in most of the-coast-sections from Bull Bay to Beaumaris, and is traceable inland as far as a line joining those places and drawn through Parys Mountain, Llandyfrydog, Llanfinnan, Pentraeth, and Llaniestyn. It is not quite so dense, or so closely packed with stones as is the blue clay, the blocks being also rather smaller. But it is, none the less, a true tough till, its boulders are striated in the usual way, and so is any pavement of rock upon which it rests.

In 14 sections where the blue boulder-clay is also seen, the red lies above it, separated sometimes, as at Penmon and Llienawg, (properly 'Lleiniog', see note to p. 753) by considerable beds of sand and gravel; sometimes by thin, impersistent streaks of sand; more often by none at all. As this red clay is traced along the fine suite of sections between Penmon and Beaumaris, its colour gradually fades, and at last almost- disappears. Its other characters, however, still persist; and at Ty'n-y-caeau, Menai Bridge, a clay with these other characters, but with only the least possible tinge of red, overlies glacial gravels, beneath which a blue boulder-clay was formerly exposed. It thus appears that the colour is (as will be shown on p. 716) merely a local accident (see also pp. 752–5, 757), and that this deposit is, in reality, a true

Upper Boulder-Clay.

Correlation of the Western Boulder-Clays — Such being the case, we may expect to find that it has a wide extension westward; and that, at least, the upper parts of the grey boulder-clays of the west ought to be correlated with 'it. But, in the absence of a distinctive colour, or of a separating sand or gravel (rarely though sometimes present in the western drifts) (Figure 328), this cannot be expressed on the maps, and it may be long before the difficulties of the problem can be overcome. The deposit may be even more extensive than has been suggested. For along some nine-tenths of the eastern coast the lower member is absent, and seems to have been swept off by the agency which deposited this upper one. That which has happened in the east may also have happened in the west, and if so, then by far the greater part of the drifts, even on that side of Anglesey, may have to be assigned to the Upper Boulder-Clay.

Sands and gravels

These are to be found in all parts of the Island, but considerable developments are known only in the Vale of Llangoed, the Pentraeth country, and along; the Menai slopes to the south-west of the Suspension Bridge. Large or small, however, they display the same characters wherever they are found, characters well known in glacial gravels everywhere, being highly false-bedded, rough, irregular, and sometimes tumultuous ((Plate 44) and (Figure 335)), with boulders occasionally as much as 11 feet in length; no single bed extending far, and the coarser gravel scarcely stratified, though sands close by may be finely bedded.

One important series lies between the blue and the red boulder-clays, and may be as much as 20 or 30 feet in thickness. But it may die away rapidly, beds of limited extent being sometimes exposed between the clays. Very likely some of the obscure gravels visible inland, whose limits are extremely difficult to trace, may be such masses, just reaching the surface for a few yards at a time. Quite as often (p. 704), the whole series is absent altogether. At Menai Bridge and Penmon, parts of it are so unstratified as to look from a little distance quite like boulder-clay, from which they there hardly differ save in the nature of the matrix; while at Lleiniog they show signs of passing into that material by increase of argillaceous matter. Some of their great irregularity may be ascribed to the pressure exerted upon the upper boulder-clay, which in one case at any rate (Figure 328) is driven down through them as an intrusive tongue<ref>*Cf.* J. Geikie. 'Great Ice Age'. Ed. 3, 1891, pp. 360–3. Figs. 69, 70.</ref>, suggesting that their absence may sometimes be due to glacial erosion.

Besides these there are gravels which, though resting upon the blue, are never known to be covered by the red boulder-clay, and, as these frequently give rise to mounded (see p. 706) or terrace-features, they must be regarded as a later series.

Moraines

On Holyhead Mountain there are several banks and mounds that look very much like moraines, and which appear, moreover, to be composed exclusively of local quartzite blocks. One extends from side to side of a steep little valley that comes towards Twr, precisely in the manner of a terminal moraine. It would be interesting if, in spite of its moderate height, one or two small glaciers had lingered, or for a short time formed, upon this exposed and lonely hill.

Special physical features of the drifts

For the most part the drifts are disposed in broad, smooth, gentle undulations with no pronounced features. In fact, wherever the nature of such land could be ascertained from clear sections, it has almost invariably been found to be composed of boulder-clay. There are, however, three exceptions that are of special interest.

Eskers

The Llanddyfnan gravels rise into a fine group of eskers, covering about a square mile, besides which there are a few at Nanner and other places. They are steep, sometimes elongated and winding mounds, rising sharply as much as 40 or 50 feet above the general level, and with the usual irregular internal structure as well as the external form of typical eskers.

And it is to be noted that, after the manner of eskers, they stand upon the watershed of the Island, close to where that is trenched by the Redwharf–Malldraeth hollow, but at levels of 100–130 feet above the sea, which is many feet higher than the water-parting on the trench at Hendre. Their distribution is independent of the features of the country, and it is certain that they must have been dellosited by waters moving along channels whose bounding walls have disappeared.

Bluffs or Terraces

Along both sides of the Vale of Pentraeth run bold bluffs with winding fronts, which might be called terraces, but that there are no good level features at the top. They are composed of torrential gravel, and their brows are very nearly at the 100-foot contour, while their feet rise from boulder-clay which lies in the bottom of the valley, so that they are by no means true valley-gravels. They are at considerably lower levels than the adjacent eskers of Llanddyfnan, but they overlook the spot where the main watershed of the Island is cut across by the deep trench at Hendre bog, being some 20 feet above its present surface, and probably (Chapter 34) some 40 feet above its rocky floor. Their positions being determined by the valley flanks, they must be subsequent to the eskers; but it is evident that their formation also must have been controlled by the presence of barriers that have passed away.

Drumlins

In the Northern country, between the rocky hills along the sea and the driftless Barrier (No. 9, on page 703), as well as in the parts of the North Central country (for these terms see Chapter 31) that lie seawards -of a curve drawn through Llanrhyddlad, Llanddeusant, Llyn Llywenan, and Bryngwran, there are great developments of boulder-clay drumlins, and smaller groups are found in other parts of the Island. In the two districts aforesaid, all the hills of any size, with the single exception of Llanfaethlu, *are* drumlins, and not rock-features at all. They are very numerous (Figure 324), (Figure 332), more than 200 having been mapped in the north and west; parted usually by rather narrow valleys; and are large, oval, smooth, green hills, attaining sometimes a length of a mile, and a net height of 150 feet above the hollows.

That they really are drumlins is proved by a fine series of coast sections. At Penrhos, Valley, Penial, Castell, Trefadog, and Borthwen, on the western, and at Mynachdy, Llanrhwydrys, Cemlyn and Cemaes on the northern coast, the sea has cut into 11 of these hills, and shown them to be composed of boulder-clay from top to bottom. On the similar hills inland, where there are no good sections, nothing but boulder-clay is to be seen anywhere, in spite of their size and steepness.

They are, indeed, singularly steep, their sides sloping at (average) angles from 6° or 8° to 15°, and a curious feature is that they are apt to rise into somewhat peaked summits, growing steeper towards their tops (Figure 321), (Figure 322)<ref>Since this was written, an excellent study of the subject has been published by Mr. W. B. Wright (*Geol. Mag.,* 1912, p. 153) noting this feature on some Irish drumlins, and ascribing it to growth along the median line.</ref>; while here and there faint terrace-features can be traced along their sides (Figure 322). When deposited on southern slopes they are much steeper and much higher above their valley floors at the southern than the northern end (Figure 323).

That they are features of deposition, not of denudation, is evident from their smoothness and their independence of the Post-Glacial erosion. Post-Glacial streams cut into them occasionally, trenching them sharply, and destroying the smoothness of the drumlin surface. They do not appear to be moulded about risings of the rock, two of them actually standing over Pre-Glacial hollows.

They are almost invariably elongated, and the major axes of their usually elliptical ground plans (Figure 324) lie north-east and south-west, coincidently, that is, with the direction of the glacial striae.<ref>A mathematical investigation of their curves in the three dimensions might throw some light on the dynamics of their formation.</ref> To this there are some exceptions, which are discussed in Chapter 31.

There is good reason to believe that this drumlin-moulding was a relatively late episode in the glaciation. Mr. Wright urges that the crests are due to continuous growth until glacial stagnation set in. Further, we shall see (p. 733) that a crested example at Llanfwrog is oriented along a late series of striae cross-hatched upon an early one; also that at Beaumaris (p. 755) there is a drumlin composed of the red upper boulder-clay moulded over a low dome of the blue. There is little doubt (pp. 705, 755) that the true upper boulder-clay is really present in the north and west, so, in spite of the lack of distinctive colour, we may expect to find that the upper parts of the drumlins, especially their crests, are composed of it.

The composition of the Drifts

The composition of the boulder-clays is continually changing, never remaining the same for more than a mile or two at a time. And, as is usually the case with boulder-clays, the dominant material, whether boulders or matrix, is derived from the formation upon which it lies, or which occurs a short distance away in the direction whence the strip point, that is, in Anglesey, somewhat to the north-east. Thus, the boulder-clay of an Ordovician area contains chiefly Ordovician, that of a Carboniferous area Carboniferous boulders, the clay of such areas being dark, plastic, and tenacious; while over a district of the Mona Complex, boulders of the schists are by far the most numerous, the clay being rather lighter, less tenacious, more gritty and rubbly. At the same time clay and stones from the areas of the north and east have crept for a mile or so on to districts lying to south and west of them, which are composed of different rocks, stones reaching, as might have been expected, a good deal further than clay, the more durable of them passing all across, and indeed far beyond the limits of the Island.

Erratics

The Drifts of Anglesey contain a wonderful variety of stones. This is due partly to the exceptional number of different rocks that occur in the Island itself, partly to the number of localities from which extra-insular erratics have been derived, most of the countries that surround the Irish Sea having contributed something. Indeed, what with the vavied local materials, those from Carnarvonshire, and those that are not from Wales at all, it would be difficult to find a district in which more complex intermingling and inter-crossing of boulders has-taken place than in Anglesey. Granites, diorites, andesites, felsites, igneous rocks indeed of almost all types, with hard old greywackes, sandstones, shales, cherts and limestones, abound in the drift, particularly on the Northern, Eastern and Straitside margins, and it may be long before all these can be identified and assigned to their true place of origin.

Insular erratics

It will be sufficient to enumerate some of the more conspicuous trains or streams of boulders. The approximate limits of a few of these are laid down on the chart, (Figure 326). To furnish such a stream, a rock must have an outcrop rather limited in area, as well as, of course, be sufficiently enduring, and sufficiently marked in character to be identified with ease. The widespread formations, therefore, are of little use in this connexion; but it may be remarked that the crystalline schists and Ordovician shales are conspicuous by their absence from nearly all the drifts of the eastern coast. Over the central parts of the Island, as far west as Tycroes, boulders of the Carboniferous sandstones are so numerous, out of all proportion to the extent of their outcrop, as to suggest that some outliers of these beds, thin enough to be torn up and destroyed by the scour of the ice, must have existed in this area at the beginning of the Glacial period.

Each train widens out as it goes along, and on reaching the western coast may be as much as three times the width of the outcrop from which it was derived. If the chart (Figure 326) be compared with that of the striae (Figure 325), it will appear that the axis of a boulder-train coincides with the local direction of striation: but that, owing to this fanning-out, tts margins transgress that direction at narrow angles.

The principal trains are as follows:

1. Hornblende-Picrite (Figure 326) — These boulders are by far the largest and most striking in the Island of those that have travelled any distance. One of them, measuring 14 by 10 by 8 feet, is a conspicuous object from the railway, on its western side, about a mile and a quarter south of Llanerchymedd (Plate 45). An historical interest attaches to those at Pen-carnisiog and Barclodiad-y-gawres (Pen-y-cnwc) because the existence of the hornblende-picrite in the Island was first discovered by means of them, and thin sections from them are figured by Dr. Teall (*Brit. Petr.,* Plates VI, IV). The stream is compound, for it comes from three sources, viz. Mynydd Eilian, the Llanerchymedd country, and the isolated intrusion near Trescawen; the trains from which coalesce into a single broad one whose boulders are scattered along the western coast from Aberffraw to the Crigyll.

2. The Bodafon Quartzite (Figure 326) — This peculiar purplish quartzite does not furnish large or conspicuous boulders, but a train of them can be traced also to the western coast, partially overlapping that from the hornblende-picrite, but keeping generally a little further to the east.

3. The Old Red Cornstones (Figure 326) — Nearly coincident with the last is a stream of blocks of the cellular purple cornstones from Penrhoslligwy. In (Figure 326) they. are combined with those of the Bodaf on quartzite, both being shown by the same stipple.

4. The Coedana Granite reaches, *in situ,* to the western coast; but boulders are found as far to right and left as Aberffraw and the River Crigyll, showing that its train is fanning out westward like the other ones.

5. The Carboniferous Limestone of Pennion has sent off a number of boulders to the south-west, many of which are finely ice-worn at Beaumaris. Close to the escarpment they are unsmoothed, and at Lleiniog are the two largest erratic blocks in the Island (Plate 47), one measuring 24 by 10 by 10 feet.

6. Garth Ferry Grits (Figure 326) — The hard white Arenig grits of Garth Ferry have sent off a narrow stream, westwards, to Llandegfan Windmill, and blocks occur in the gravels west of Menai Bridge, some as far as Aber-braint.

7. The Ordovician Conglomerates of Bod-Deiniol, Llanbabo, have invaded the country to the west as far as Stryd-y-facsen, showing that, in addition to fanning out, the axis of movement must have been east-north-east to west-southwest, which accords with the direction of the striae..

8. The Northern Gwna Quartzites (Figure 326) — Boulders of these, accompanied by, a few of the associated limestones, are found all over a wide tract of country in the north and west, bounded eastwards by a line drawn from the western side of Bull Bay almost exactly along the curve of the striation as it sweeps across the Island. Large boulders of them are to be found near Holyhead, mingled with those of the Holyhead Quartzite,--for which they might at first sight be mistaken. They can, however, be dis- tinguished with a little care. On their way, the northern quartzites were reinforced by those of Llanfaethlu, which cannot easily be distinguished from them; and there is, accordingly, an extraordinary abundance of quartzite boulders along the eastern side of Holyhead Bay.

9. Mynydd Mechell Felsites — These were overtaken, as it were, by the boulders from the northern coast, and carried along with them, so that, south of the Carmel Head thrust-plane, a felsite coincides with a quartzite-stream. Boulders from the dolerite dykes, of course, accompany them, but, as dolerites occur rather widely, some of these may be from other sources.

10. Parys Mountain (Figure 326) — A narrow train of the peculiar silicified rocks has been traced to the south side of Cors y Bol; and isolated blocks of the same type have been found as far as Caergeiliog, which is in the line of transport that might have been expected.

11. Holyhead Quartzite (Figure 326) — A short but beautifully definite stream passes over the moors of the South Stack from Holyhead Mountain. No boulders of this rock have been seen on the coast south of Henborth cove, which is exactly where a line drawn from the most southerly outcrop of the Quartzite, along the direction of striation, reaches the sea. North of this they rapidly become very numerous. Moreover, the first to appear belong to the massive type which is confined to the marginal belt above Twr, and when we pass beyond a line drawn from the limit of that belt along the direction of striation these are replaced by the foliated variety.

12. Church Bay Tuffs — Some boulders of these from Trefadog are found (Figure 326) at the extreme northern tip of Holy Isle.

The axes of all these 12 streams conform with wonderful exactitude, as may be seen by comparing (Figure 326) with (Figure 325), to the direction of striation.

13. An Exceptional Transport — About half a dozen fragments, all of them small, of Old Red cornstone, and one or two. of bedded jaspers that resemble those of Amlwch, have been found between Penmon and Beaumaris, indicating a transport from north-west to south-east, which may be ascribed to the agency of floating ice (see p. 719, citing Mr. Lamplugh) at an early stage of the Glacial Period. But as these blocks must themselves have then been caught in the normal south-westerly transport, their original journey must have been along the coast towards the end of Puffin Island, that is to say, in an east-south-easterly direction.

Extra-insular erratics

These are not distributed in definite trains, but some are more abundant in, some confined to, certain districts. Only a few of the numerous extra-insular rocks that occur as boulders in the Island have been studied.

1. Rocks from the Carnarvonshire Mountains are plentiful all along the shore of the Strait, the porphyritic felsites of the Bala Volcanic series being the most numerous; and they increase enormously in numbers towards Aber Menai. One large boulder, measuring eight by four by four feet, stands at Hologwyn, and was identified by Dakyns as from those lavas. They have been found at Llangoed cliffs, Pen-hesgyn, Gaerwen, Newborough, and other places about three miles from the Strait, but not further (Figure 326), from which we obtain an approximate limit for the invasion of the Island by mountain-land ice. A curious circumstance is that the hard old breccias and tuffs of Bangor, though so near to Anglesey, have not been found in it as boulders, which brings out the interesting fact that it was not proximity tb the Strait, but elevation above sea-level, that determined the carriage of Carnarvonshire boulders into Anglesey.

2. Garnetiferous Felsite of Lake-land — *A* small piece of this from the boulder-clay of Holyhead Bay (p. 734) was identified by Dr. Harker as having come from somewhere in the central mountains of the Lake Country', and there is a larger one (p. 749) at Amlwch.

3. Other rocks from Lake-land have been identified by various authors. They include the granitoid rocks of Eskdale, Wastdale, and Ennerdale, andesitic lavas and tuffs, and the quartz-felsite of St. John's Vale.

4. The Galloway Granites have furnished the most notable boulders of the Island. All over the northern districts they are often to be seen, with their foliation and characteristic sphenes, and a few have been found along the Menai Strait. One at Porth yr Ysgaw (Plate 46) is six by three by two feet; and another near Llantrisant Rectory (p. 734), now broken up but still in place, must have measured some eight by five by five feet, the largest extra-insular erratic in Anglesey. This one, besides the peculiar sphenes and the foliation contains the aplite veins that are also a feature of the rock. It was examined by Drs. Horne, Peach, and Teall, who think that it may have come from the eastern slopes of Criffel, where the foliated margin of the granite is traversed by an acid vein. Others have been identified (p. 763) by Dr. Horne.

5. The Riebeckite-Eurite of Ailsa Craig in the Firth of Clyde can generally be found by a little searching in the drifts of the north-east and north of Anglesey, and has been obtained as far south as Newborough. The boulders do not often exceed a few inches in diameter.

6 Tertiary Gabbros — There are a few boulders that can safely be traced to the Western Isles of Scotland. One of them is a beautifully flesh normal gabbro (p. 734); and in another (p. 737) Dr. H. H. Thomas has noted the granulitic results of thermal alteration that are known at the contacts with the granophyres of Skye.

The above-mentioned erratics are from well-known and visible sources, but even more interesting, perhaps, are certain others whose sources are not now visible.

1. Fragments of Recent Marine Shells are not uncommon in the red boulder-clay of the east and north-east coasts, and have been found inland in the same clay as far as Croesfryn on the new railway. Most of them are too small for identification, but the following forms occur [Af. 729–730, 3728a, &c.]:

Cyprina sp.

Astarte sp.

Tellina balthica *Linn.*

Tellina sp.

Donax vittatus (*da Costa*)

Aporrhais sp.<ref>This form is recorded by Ramsay from Penmon (*Geol. N. W.*, p. 276), but the specimen has not been traced.</ref>

They are quite abundant at Traeth Bychan and along the Moelfre cliffs, and are manifestly derived from the deposits of the sea-floor to the north-east, from which direction the striae show that the ice which produced this boulder-clay was moving. On the western coast, in spite of excellent sections, shell-fragments are very rare and small.

2. Carboniferous Limestone in the North-East District — Scattered over the country about Rhosgoch and Llanerchymedd are many fragments of Carboniferous Limestone. These could not have invaded that district if carried by ice moving in the direction ipdicated by the striae from any exposure of that rock in the Island. It seemed possible that they might have been brought in imperfectly burnt lime used for agriculture in former times. At Porth y Gwichiaid, however, the boulder-clay contains ice-worn Carboniferous Limestone with crinoids, and conglomerate of Carboniferous type. From no visible outcrop could these boulders have been derived, and it is evident that they have come from out of the sea. If, now, we produce the base-line of the Carboniferous Limestone from where it reaches the coast to the little island in Dulas Bay where the tower of shipwreck-refuge is, we shall see that it is curving somewhat to the north and west, instead of running out on a north-east strike as might have been expected; and if we further produce this line, following the curve thus indicated, we shall find that it sweeps round the north-east of Anglesey at no great distance from the land. This, then, is the source of the boulders of Porth y Gwichiaid, and this is the source of the much more numerous boulders that are scattered far and wide over the country about Rhosgoch and Llanerchymedd.

3. Red Sandstones and Green Marls — Fragments of soft red sandstone often showing facets of secondary quartz, with all the other characters of the well-known Triassic Sandstones, abound in the red boulder clays of the Eastern seaboard. Moreover, with them occur many blocks of pale green mudstones, and in some of these are cubic pseudomorphs after rock-salt. There can be no doubt, therefore, that they are mainly derived from beds of Triassic age. And, further, that in the grinding up and incorporation of these red beds we have an explanation of the red colour of the boulder-clay of the eastern margin of Anglesey. In the drifts of the western coast they are unknown.

4. Coal Measures — Fragments of coal, as well as of shale and sandstone of Coal Measure types and nodules of Coal Measure ironstone, are frequent in some of the eastern drifts.

5. Chalk Flints, usually light in tint, abound in the boulder-clay of the east. They are often quite large, but for the most part slightly rolled, their surfaces being full of pits and dimples. Hard chalk is also recorded. Flints, like shells, are rare and small along the western coast.

6. Cherts — Over the whole of that part of the Island that lies north-west of a line drawn from Dulas Bay to Valley, are countless thousands of boulders of black chert, banded chert, cherty banded shale, and banded chert with limestone, that are certainly extra-insular. For the only outcrops of the banded cherty group at the top of the Carboniferous Limestone (pp. 609, 636) are confined to the south-east of the chert-boulder country. Now banded cherts of the chert-boulder type occur in the Posidonomya beds of Dublin. Search was therefore kindly made by Mr. J. O. Hughes for fossils in these boulders, at Cemaes, and with complete success. The following forms [Af. 719–25, 795–814] were identified by Dr. Wheelton Hind:

Crinoid rings

? Athyris planosulcata (*Phill.*)

Chonetes sp. *McCoy*

Orthotetid

Productus spines

Cf. . Posidoniella laevis (*Brown*)

Posidonomya membranacea

Fish tooth

There can therefore be no doubt that they are derived frot, the Posidonomya zone of the Carboniferous system. The cherts [(E10303) [SH 259 818], (E10325) [SH 517 853]–(E10326) [SH 514 848]] are also rich in sponge-spicules, which Dr. G. J. Hinde describes as partly simple curved rods, partly hexactinellid, and of Carboniferous types.

***7.* The Glacial Gravels of Ty'n-y-caeau** are full of shale that has yielded Arenig and Llanvirn zone-fossils (p. 431), which must have come from the bed of the Menai Strait.

It is evident that the last seven classes of erratics have been brought from the floor of the sea that lies to the north-east and north of Anglesey. A discussion of their bearings will be found in Chapter 33.

Insular and extra-insular Drifts

The only glacial deposits that are of strictly insular origin are the little moraines of Holyhead Mountain. Even the great boulder-streams of Anglesey rocks (pp. 709–12) are no exception to this, for many of their boulders are still embedded in clays which contain foreign stones, and all the other drifts of the Island are, so far as is known, of mixed origin. Along the eastern margin and in the Penmon country, however, where the lower and upper boulder-clays are sharply contrasted in colour (p. 704), there is a marked difference also in the nature of their contents. The lower boulder-clay, while containing extra-insular material, is not rich in it, but is crowded with Carboniferous Limestone which, if not strictly insular, can have come but a short distance. The upper boulder-clay of those tracts, on the contrary, is rich in extra-insular material, to which indeed, it owes its colour: while insular material, often subordinate, seems in some places to be absent altogether. In these parts of the Island, therefore, while both the drifts are to some extent of mixed origin, the lower boulder-clay is mainly insular, the upper- boulder-clay mainly extra-insular in derivation.

Dependent upon this, moreover, are their other characteristics. The lower one is evidently derived in great measure from glacial action upon the copious products of old Pre-Glacial decay (p. 702). Hence the dominance of insular material, and at the same time, the relatively large size of its stones, and the high proportion of stones to matrix. When, after an interval, ice again advanced upon the Island, it would not find the same profusion of easily-erodable decomposition-products, far less of which, accordingly, would mix with the sweepings of the sea-floor. Hence the high proportion of extra-insular material in, and red colour (p. 704) of the upper boulder-clay. But most of the sea-floor (see Chapter 33) was composed of a friable Mesozoic series, containing few hard bands of any thickness; whence the relatively small size of the stones, and the low proportion of them to the matrix. In the east, therefore, where the two boulder-clays are well contrasted, it is possible to assign reasons for the difference between their characters.

We have already seen how the upper boulder-clay, as it is traced westward, loses at once its red colour ancL most of its extra-insular fragments. In the course of the same journey, the extra-insular matrix also would gradually be left behind, while more stones, and larger ones, all of them insular, would be gathered, blue matrix, even, being assimilated from glacial erosion of the older drift. Thus it would insensibly part with every one of its distinctive characters, until, by the time the western coast was reached, it might well become almost indistinguishable from the true lower boulder-clay.

The gravels that are known to lie between the two clays are in great measure of extra-insular origin, and were undoubtedly deposited by torrential waters coming from the north-east.

Uplifts

As in most glaciated countries, there are cases of boulders having been lifted to levels considerably higher than those at which their parent rocks occur.

1. ***The Arenig Grit of Garth Ferry***, which scarcely rises above sea-level, has been carried up to the windmill at Llandegfan, 350 feet above Ordnance datum, in the space of about a mile and a half.

2. The Red Measures of Malldraeth, whose whole outcrop, except a little tract at Holland Arms, is deeply buried below sea-level, are found on Llanddwyn Island and Newborough, where the maximum uplift cannot be less than 240 feet.

3. The Old Red Cornstones above the Coed-y-gell escarpment reach a height of 282 feet, but fragments have been found on the summit of Mynydd Bodafon, at 500 feet above the sea.

4. Dyke-Dolerite and Gabbro that only reach the 50-foot contour in a few places, have been lifted to the summit of Rhoscolyn hill, 208 feet above the sea.

5. A great boulder of Epidotized Grit has been lifted from the foreshore of Henborth to the flank of Mynydd-y-Garn, a height of 200 feet, in a mile and a half.

6. Green-Mica-Schist of the New Harbour Beds, which nowhere attain 260 feet *in situ,* and in the direction of transport not as much as 100 feet, is found on the summit of Holyhead Mountain, 720 feet above the sea.

Carboniferous Limestone of Bryn-Gwallen

About a quarter of a mile north of Bryn-gwallen, Llanffinan, some limestone (shown on the one-inch map) occurs in a very perplexing situation. The main boundary of the Carboniferous and the Mona Complex, evidently faulted, runs ((Figure 327), and one-inch map) along the foot of a strong feature. The steep hill-side of schistose Gwna mélange is grassy and smooth; but suddenly, for a space of about 100 by 50 yards, it is littered with a crowd of great blocks of Carboniferous Limestone. Standing at all kinds of angles, the rock is clearly not *in situ.* Besides, were it an outlier, sandstone, not limestone, would be present (in this district) at the base; and to connect it with the principal mass, cross-faults have to be postulated that are scarcely credible. On the other hand it is just as incredible that the ice should have stranded a crowd of blocks in this particular place, and in this only. The most probable explanation seems to be that we are dealing with one of those gigantic transported masses that are found every now and then in glaciated regions. Suppose a tabular mass of limestone, 100 yards or so in length, to have been carried on to this hillside. It would tend to break up, in such a situation, by its own weight alone, as soon as the support of the ice was withdrawn. The pieces would slip and tumble in various directions<ref>A somewhat similar case at Glan-y-gors, Ty-croes, is described in Chapter 31., 'South Central Country'.</ref>, and we should have just the appearance that is seen to-day.

Chronology of the Drifts

The following appears to be the order of succession for Anglesey. But it must be understood that no attempt is made, in this work, to apply it outside the limits of the Island; or even to correlate these drifts with those of the adjacent mainland.

Moraines of Holyhead Mountain

Gravels of the Bluffs

Esker-gravels

Upper Boulder-clay

Penmon and other Sands and Gravels

Lower Boulder-clay

Theoretical summary

That Anglesey was traversed from north-east to south-west by heavy ice of some kind is manifest: it is manifest that this ice over-rode the summits of even the highest hills; and that all the rocks of the Island have been powerfully striated and rubbed down by it. The same ice transported the local materials from north-east to south-west, and at the same time brought a vast number of boulders from distant parts of the Irish Sea region, as well as from the sea-floor itself. As it approached the Menai Strait, it came under the influence of an agent that deflected it to the south-west, while boulders from Carnarvonshire underwent a similar deflection and were prevented from invading Anglesey for more than about three miles.

Thus far all will be agreed. Some, however, will ascribe the phenomena, with those of the British lowlands generally, to floating, others to land or glacier ice. Theory has been excluded, as far as possible, from the foregoing portions of this chapter. No confusion, therefore, need result from a statement, here, of such conclusions as appear to the present writer to be justified by the evidence.

The ice-sheet

The general view that Anglesey was traversed by a great ice-sheet which filled the shallow basin of the Irish Sea, and that this ice-sheet and the great valley glaciers of the mountain-land mingled with, and mutually deflected each other in the region of the Strait, first put forward by Ramsay, seems to be that to which the whole body of evidence clearly points.

Evidence that the ice of Anglesey was not afloat is furnished by many of the phenomena. That uplifts of boulders can be explained by subsidence during transport may be admitted. But the probability that this really happened is extremely small. Take, for example, the case of the Garth Ferry grit. Its outcrop is less than a quarter of a mile long, seldom as much as 30 yards wide, and only rises to about 40 feet above high-water mark. Floating ice (if the agent) must first have picked up a number of boulders from this little outcrop, and then, after their source had subsided beyond its reach, have kept on during the whole time that it took the land to subside 300 feet, dropping them along a particular strip of sea-bottom some two miles long and half a mile in width. The local character of the boulder-clay involves similar ideas. Again, why, if sea-shells be an evidence of general submergence, should the boulder-clay lose its burden of sea-shell fragments in its passage across the Island? Whereas that is exactly what we should expect of land-ice passing from a sea-floor across a land-surface. The local deflections observed could have affected only an agent that was closely pressed down into the hollows, as in the creeks of the Old Red Sandstone, some of which, though not more than 50 feet wide and 30 or 40 feet deep, deflect the striae as much as 45° from their general course; or as at Amlwch Port, where hollows only four inches deep deflect the striae 22°. Most curious of all, how could any but a plastic agent have swirled round through nearly 90° in the little moat-like hollows that surround the sandstone pipes of Dwlban? Nor is it easy to see how any floating body could under-cut a furrow. Lastly, nothing but an agent closely moulded to the rocky surface could have worked with such precision as to leave the almost microscopic tails of rock in the lee of the polished sand grains of Parys Mountain and Bodorgan. And, in another class of phenomena, it would surely be difficult for the impact of a floating object to tear and pluck' the surface in the manner so clearly seen at Porth-delisc and Plâs-bach.

Concluding, then, that the glaciation of Anglesey was the work of an ice-sheet, let us attempt to form a general picture of its dimensions, its movements, and its history. After a period when some at any rate of the distribution of boulders such as those of Galloway and Ailsa, with a few that are of insular origin (pp. 712, 754–5), seems to have been effected by floating ice passing along the coast in an east-south-easterly direction<ref>Lamplugh, 'Geology of the Isle of Man' (*Mem. Geol. Surv.,* pp. 345, 390).</ref>; the broad and shallow basin became gradually choked with a mass that completely buried all the hills of Anglesey to a depth that gave pressure enough to striate them heavily over their very summits.

Nothing, therefore, in Anglesey itself, not even Holyhead Mountain, affords any measure of the depth of the ice that passed across the Island. It is possible, however, to obtain some such a measure at one or two places on the north-west flanks of the mountains of Carnarvonshire. One of these is Moel Tryfaen, where the upper surface of the well-known shelly drifts<ref>*Rep. Brit. Assoc.* 1899 (1900), pp. 414–23, reprinted in *Geol. Mag.,* 1900, pp. 115–23.</ref> is at about 1,350 feet above the sea. As these drifts, however, have been the subject of much discussion, it will be well to seek for evidence of another kind and elsewhere.

Overflow notches on the Bethesda Mountains

Looking across from Beaumaris to the heights that rise between the two gaps of the Aber and the Ogwen, the seaward rampart of the mountains for about half that distance is seen to be a long, smooth-sided spur, that, beginning a little south of Moel Wnion (1,902 feet)<ref>The localities alluded to will be found on the uncoloured (mainland) portion of the one-inch geological map of Anglesey.</ref>, runs down for some two miles till it ends off above Bethesda. Its sky-line rises into three distinct eminences, called Gyrn, Llefn (1,485 feet), and Moel Faban (1,339 feet), between which it curves into gentle depressions. Behind it the bare valley of the Ffrydlas runs down south-west to join the Ogwen. Gym Wigan, a much higher spur, parts Glen Ffrydlas from Own). Llafar, and must have sheltered it, in the Glacial Period, from the great Llafar branch of the Ogwen Glacier that issued from the gigantic corries of Carnedd Dafydd and Llewelyn. All the Ogwen streams uniting, a tremendous press of ice must have passed the entrance of Glen Ffrydlas (which has not a large mountain-catchment) and surged up against Moel Faban.

Now, returning to the outer spur, the smoothly curving sky-line of the hollow between Llefn and Moel Faban is suddenly trenched by a great craggy notch, called the Ffos Rhufeiniaid, 50 feet deep where it cuts the axis of the spur, and almost 200 at its outer end. Towards Glen Ffrydlas its slope is rather gentler, the channel of the Ffrydlas water (which, however, flows in drift) being at that point about 100 feet below the floor of the Ffos. The brows of the notch are at 1,250 feet above the sea, so that the bottom of the original depression (before the cutting of the notch) may be taken at about 1,240 feet. The existing drainage cannot possibly account for the formation of the Ffos Rhufeiniaid; and it is evidently a glacial overflow channel, cut by dammed-up water from Glen Ffrydlas. The surface of the glacier at must therefore have been at that time at least 1,240 feet above the sea, and Moel Faban a nunatak not more than 100 feet above the ice. Possibly the Ogwen glacier, even if unhindered in its outward flow, may have risen to that height; but its detail has not yet been investigated<ref>Since this was written, Mr. Dewey has made a study of the glaciation of the Ogwen, the results of which (kindly communicated to the present writer) are embodied in a paper that will probably appear before the publication of this book. *April,* 1918 — This paper has now appeared in the *Geol. Mag.* Mr. Dewey's estimate of the height to which the Ogwen glacier attained, when moving with sufficient freedom to striate its floor, is 1,250 feet, a conclusion whose accord with the above (derived from totally different evidence) is remarkable.</ref>.

The Ffos Rhufeiniaid, however, does not stand alone. Half a mile to the north-east, between Llefn and the Gyrn, is another depression on the axis of the spur, which is at its lowest point 1,430 feet above the sea, the summit of Llefn being about 1,485 feet. This gap has a smooth sky-line, and carries a thin covering of boulder-clay. But on its northern side the steep, smooth flank of the great spur is suddenly and sharply scooped into by a little precipitous corrie, called the Twll Pantirial, 90 feet in depth, round which there is a rim of some 30 or 40 feet of crag just below the sky-line. With the drainage as it is to-day the Twll Pantirial is as unaccountable as the Ffos Rhufeiniaid. As a glacial overflow, however, it becomes intelligible. True, there is no notch upon the gap; but the outer flank of the spur is very steep, so that escaping water would immediately cascade. Cascades tend to cut back, not down<ref>There may also, at this height, have been a little ice upon the gap, even in summer.</ref>, and in a succession of summers the black slates, which are rather soft, would without much difficulty be scooped into this little corrie. But an Ogwen glacier moving without let or hindrance cannot have been the cause of its excavation. Consider the levels in the neighbourhood of Bethesda. The Ffos Rhufeiniaid could not have existed; Moel Faban would have been totally buried beneath 100 feet of ice; barely 60 feet of Llefn would have been exposed<ref>**Depth Of the ice upon the Mountain-Land** — As there still seems to be a wide-spread impression that Wales never developed anything on a greater scale than separate valley-glaciers, thd following evidence may serve to show that the estimates given above err on the side of moderation. In September, 1913, while searching the Harlech Grits for the pebbles of the Mona Complex described in Chapter 9, I had occasion to ascend the mountain called Y-graig-ddrwg (p. 252), whose grand eastern escarpment looks out over the Vale of Trawsfynydd, some four miles in width. Signs of glaciation abounded, but- instead of dying away as one ascended, were most pronounced upon the higher crags, and it was astonishing to find that they were manifestly the work of ice that was moving not down, but up the precipitous face of the mountain. The great escarpment itself is composed of a series of minor step-like scarps, determined by outcrops of the massive grits, often 10 feet or more in thickness. At each of these it was the upright scarp-face that proved to be ice-worn, the ledges between them being in shelter from glacial action, an effect that could only be produced by an agent proceeding upwards from below. Moreover, the strim (unable to climb vertically), were deflected, and ran along the scarp-faces at low angles upwards in a north-westerly direction, the angle being often so gentle that they were able to undercut the outcrop of any softer bed, work impossible for a descending, and achievable only by a deflected ascending agent pressing hard against the mountain-face. Even more astonishing was it to find the summit-ridge itself (which is 1,937 feet in height and forms part of the great watershed between the Vale of Trawsfynydd and the sea) an ice-worn platform or floor, powerfully striated right across from one side to the other. Here, in the lofty open, free from any confining and deflecting mountain-face, every little knob had its onset- and lee-side, leaving no doubt whatever of the normal direction; and showing in the most vivid manner that heavy ice, moving almost due west, had passed completely over the mountain. Glacial independence of local orographical conditions could hardly be more striking; and it points, not merely to a depth of several hundred feet of ice above the summit of Y-graig-ddrwg, but to very great vertical pressure along the line of ice-parting, which must have been situated a few miles to the east. At the time of the maximum glaciation, therefore, it would appear that the surface of the ice developed upon the heart of the Welsh mountain-land must have stood at a height of at least 2,500 feet above existing sea-level, a condition of things that would permit scarcely 20 mountain-tops to emerge as nunataks from under it throughout the whole of North Wales.</ref>; and, what is most important, a mile of the Gyrn Wigan spur would have been covered, thus admitting a stream of ice from the south-east into Glen Ffrydlas over full half its length to traverse it in a direction at right angles to its trend. But the features of that valley show no marks of having been subjected to such a glaciation; so that it is evident that the Ogwen glaciers, when they attained to these dimensions, must have met with an obstacle that checked their free and vigorous movement to the sea. This obstacle was the ice of the sea basin.

Is there, on these mountains, any independent evidence of its existence? There is. The hill-side below the Twit Pantirial carries much boulder-clay, which climbs up the slopes to about 1,300 feet, and in it are many blocks of the purple slates, which outcrop 300 feet below, a few small fragments of them, rubbed and striated, being found even in the drift above the Twll, at a level of 1,430 feet, more than 400 feet above their outcrop. But it will be asked: How could ice that was discharging drift upon the spur have left room for a cascade to excavate the corrie? Certainly, during active onset, that could not have happened; but when the maximum had passed, the sun could warm the hill and cause the upper layers of the ice to retreat a little from its face in the manner shown by so many views of glaciers. Water could then plunge down into the interval and excavate the corrie.

The quantity of material carried out from these two overflows must have been enormous, yet there is not the least trace of gravel fans below them, nothing but the boulder-clay, channelled a little—doubtless in the later stages of the glaciation, when heavy drifts of snow would settle in and melt from them. Had the lower slopes been bare when they were being cut out, some such fans must have been formed; but if their washings were received upon the surface of a glacier, they would have been carried away as fast as they were delivered, and never have been left upon the slopes at all.

The phenomena, therefore, of these two overflows go to show that at the time of the formation of the later one, the Ffos Rhufeiniaid, the ice of the sea-basin was resting against the flanks of the mountains up to about 1,200 feet; at the time of the older one, the Twll Pantirial, up to at least 1,430 feet; and a good deal higher when the drift upon the gap was formed, as that appears to have been compressed. The second level, it will be observed, differs but little from that indicated by the drifts of Noel Tryfaen; while the third is in accord with the results obtained upon Snaefell in the Isle of Man.<ref>G. W. Lamplugh, 'Geology of the Isle of Man', p. 361.</ref> A minimum estimate is thus obtained of the depth of the ice that passed over Anglesey at the time of the maximum glaciation. In round numbers it may be put at some 1,700 feet.

Figures, however, do not impress the mind in proportion to their magnitude. But it is very impressive indeed to stand at Beaurnaris, and, marking the little dark speck of the Twll Pantirial, to reflect that the ice of Anglesey surged up to and over that upon the ramparts of the mountains.

Movements of the ice

When the ice of the sea-basin approached the Island<ref>A chart of the general movements of the ice in the Irish Sea basin is given by Mr. Lamplugh, *op. cit.,* (Figure 103).</ref>, it was going in a south-south-westerly direction, and at once moved up the northern cliffs almost, in some places exactly, at right angles to their trend, striating them and imparting to them the rounded surface that they still retain. Soon, however, it began to feel the effect of the deflecting agent from the mainland, and in a few miles, to curve round into that south-westerly direction which may be said to be the insular normal, so that the ice that invaded the centre and south of the Island was not that which surmounted the northern cliffs, but was derived from regions of the sea-basin lying further to the east.

With it came great quantities of the rocks of the sea-floor, as well as Ailsa, Galloway, Lakeland, and many other boulders. The old decayed Pre-Glacial surface of the land was scoured off except in sheltered places, while fan-shaped trains of boulders of local rocks were carried away to the south-west and removed, often, from lower to higher levels. Boulder-clay accumulated beneath in all the hollows, and was moulded, in the broad mestern and northern valleys, into oval drumlins often more than 100 feet in depth.

About three miles from the Strait it came into touch with the glaciers descending from the mountains, and the Menai country became a zone of conflict and oscillation, from which, as conditions varied, each of the two great bodies of ice succeeded from time to time in thrusting off the other. Hence the crossing striae of Penmon, and the intermingling of mountain-land, insular, and foreign boulders.

At no time, indeed, can the plane of junction have been simple, either in the horizontal or the vertical dimension. The ice of the sea-basin doubtless presented, before the union, a tolerably even front. But that of the mountain-land was for the most part concentrated into the deep valleys of Llanfairfechan, Aber, the Ogwen, Llanberis, and the Gwyrfai, between which the ice on the heights and along the escarpment-faces could have had but little power of resistance, and was, in fact, repeatedly overcome. The plane of junction must have curved to the north-west opposite the great valley-glaciers, retreating south-eastward in the intervals between them. But we have also seen (pp. 712–13) that the transport of materials into Anglesey was determined less by proximity to the Strait than by height above sea-level, indicating that the invasion of Anglesey was accomplished, not by the lower but by the upper strata of the glaciers, which alone had sufficient *vis a tergo* to push out and override the opposition. Their plane of junction with the ice of the sea-basin would therefore have had a considerable inclination upwards in the direction of Anglesey. Combining this with the conclusion arrived at above, we can see that where the plane of junction curved but to the north-west its upper parts must have bent over in the same direction, the converse frequently taking place where it was curving to the south-east. Variations in the power of the two great ice-masses would occur from time to time, and as their sources must have been more than 150 miles apart, and subject to different physical conditions, such variations would rarely be contemporaneous. Throughout the whole period of contact, therefore, the forms of the curves, in both dimensions, will have been in a state of unceasing change in every portion of the plane, added to which the locus of the plane itself will have been shifting as unceasingly.

In the Penmon Area (p. 697) special complications must have occurred. The influence of the great Ogwen glacier must have been different from what it was farther west, and the glaciers of Aber and Llanfairfechan only would have directly opposed the sea-basin ice. From a comparison of the extent and height of their catchment-basins it is doubtful whether their combined force would amount to more than a quarter of that of the Ogwen glacier. That they did offer opposition is clear, for they carried boulders as far as Penmon. But fluctuations in the masses of the northern and southern ice would often enable the larger one to pass on. The Llanfairfechan glacier, being the feeblest, would be the first withdrawn, then that of Aber, and then the Ogwen glacier would thrust off the ice of Penmon in an easterly direction. Further west, along the valleys of Bangor, of the Strait, and of the Braint, the united ice-streams swept away to the south-west and passed out into the Irish Sea beyond Carnarvon.

The episode of recession

In the foregoing sketch, the process has, for simplicity's sake, been pictured as continuous. But (as will already have been seen from the account of the drifts, and from the table of their chronology) (pp. 705, 718), there was a serious interruption, during which the ice, both of the sea-basin and the mountain-land, receded from the Island. The extent of this recession is uncertain. Taken by itself, the local evidence does not compel us to postulate a retreat of more than a few miles from the present limits of Anglesey.<ref>No attempt will be made, in this work, to take up any position upon the general interglacial controversy, for the different views upon which the reader may be referred to the later editions of James Geikie's 'Great Ice Age', and to recent papers by Mr. Lamplugh, especially to his address to the British Association (Section C), in 1906.</ref> Torrential waters, passing between the ice-fronts and the land, can well account for the intercalated gravels of Penmon, Lleiniog, and other places. Yet the contents of these gravels indicate a minimum estimate of the retreat, for they are often red, and contain (pp. 715, 754) abundant fragments of coal, from which we may infer that rocks of the sea-floor, situated some eight or ten miles to the north-east of Penmon (Chapter 33, (Figure 338)), were freely exposed to fluvio-glacial erosion; while, on the other hand, their comparative poverty in flints may be held to suggest that the retreat was less than 25 or 30 miles.

Then, as indicated by the upper boulder-clay, came a re-juvenescence and fresh advance of the ice, that of the sea-basin once more coalescing with that of the mountain-land. No differences of importance have been observed between striae covered by the blue and strip covered by the red boulder-clay, or between the directions of transport of the materials of the two clays; from which it is inferred that the conditions controlling the movements of the ice were much the same after the recession as they were before it.<ref>But further investigation is needed, especially in the west, where the upper and lower boulder-clays have not yet been disentangled.</ref>

The decay of the ice

Then came the final period of decay, during one stage of which a part of the ice resting on the watershed became stagnant, and englacial streams within it, passing across the Llanddyfnan gap, deposited the eskers. Somewhat later, as the ice shrank back along the Vale of Pentraeth, torrential gravels grew outwards along the flanks of the valley. Still retreating, the ice-front stood for a while as a dam across the bay<ref>See p. 706 and Chapter 34.</ref>, and a temporary lake was formed, whose waters, escaping westward through the old glacial furrows that ran across the watershed, especially through the one running past Rhyd-y-saint and Ceint, cut that down still lower. When the ice retreated beyond the limits of the bays, the waters were liberated eastwards, and fluvio-glacial erosion caine to an end. Of the last stages of all, the supposed moraines of Holyhead Mountain are the only monument as yet found in Anglesey.

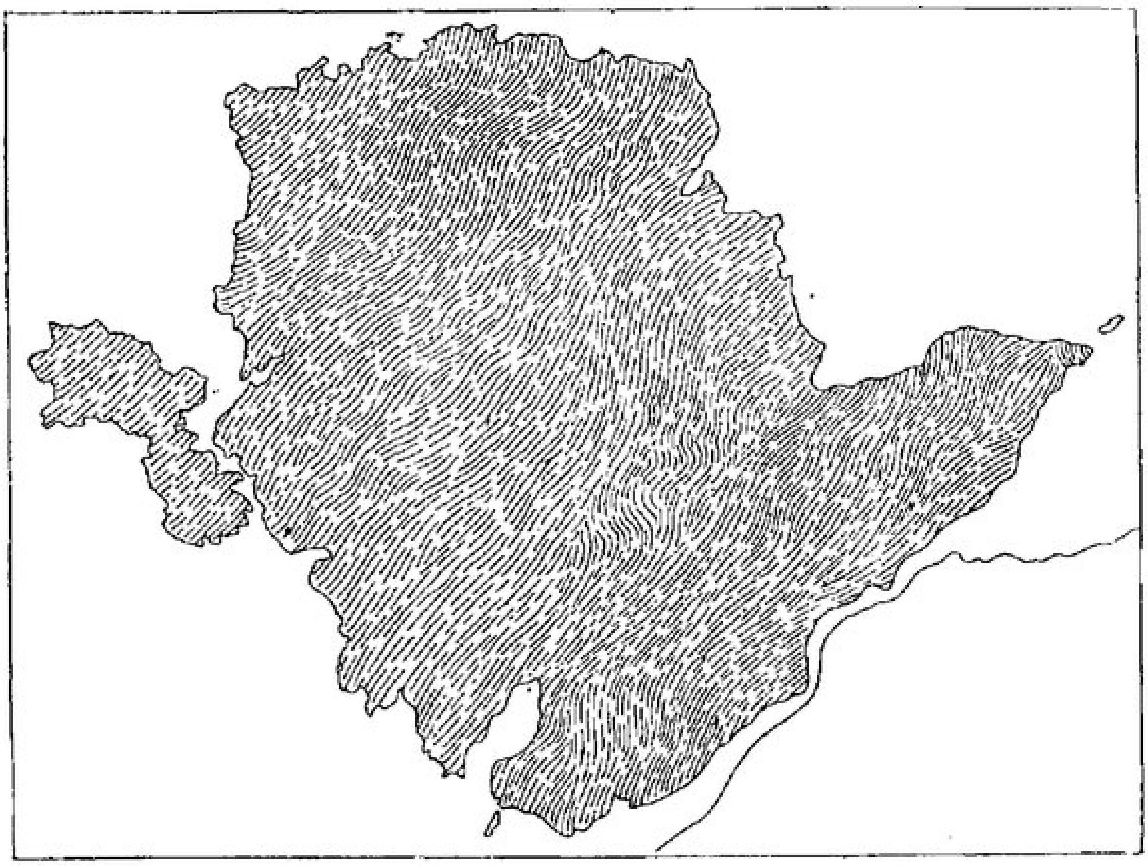


FIG. 325.—THE PATH OF THE ICE.

(Figure 325) The path of the ice. Scale: one inch = eight miles.

FIG. 307.

GLACIAL FURROW AT AMLWCH PORT.

(Figure 307) Glacial furrow at Amlwch port.

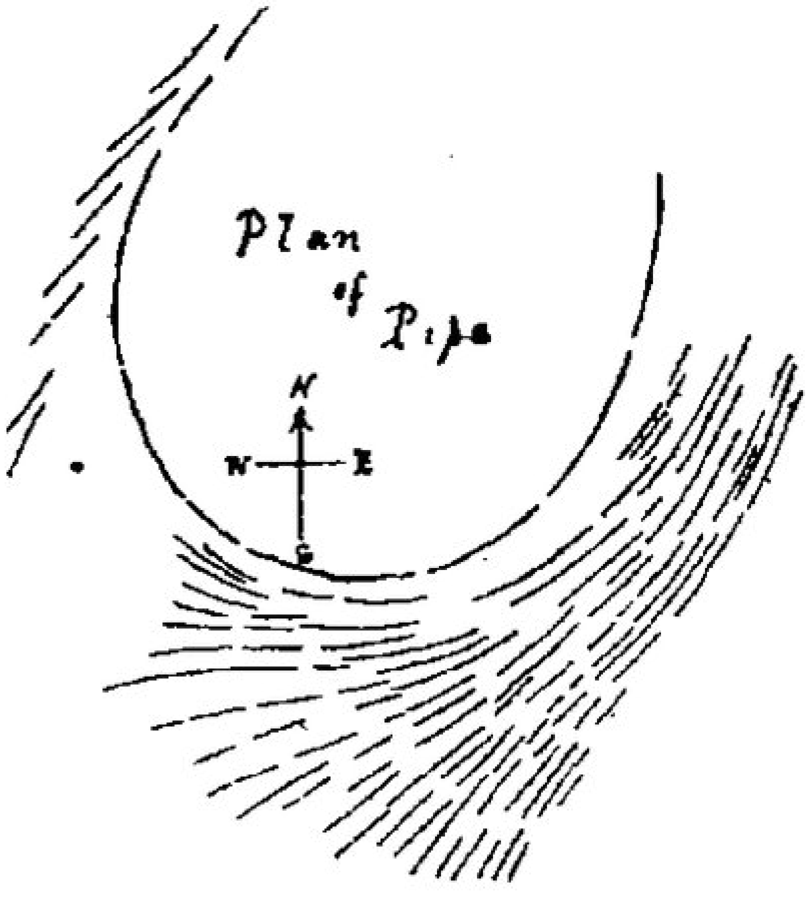
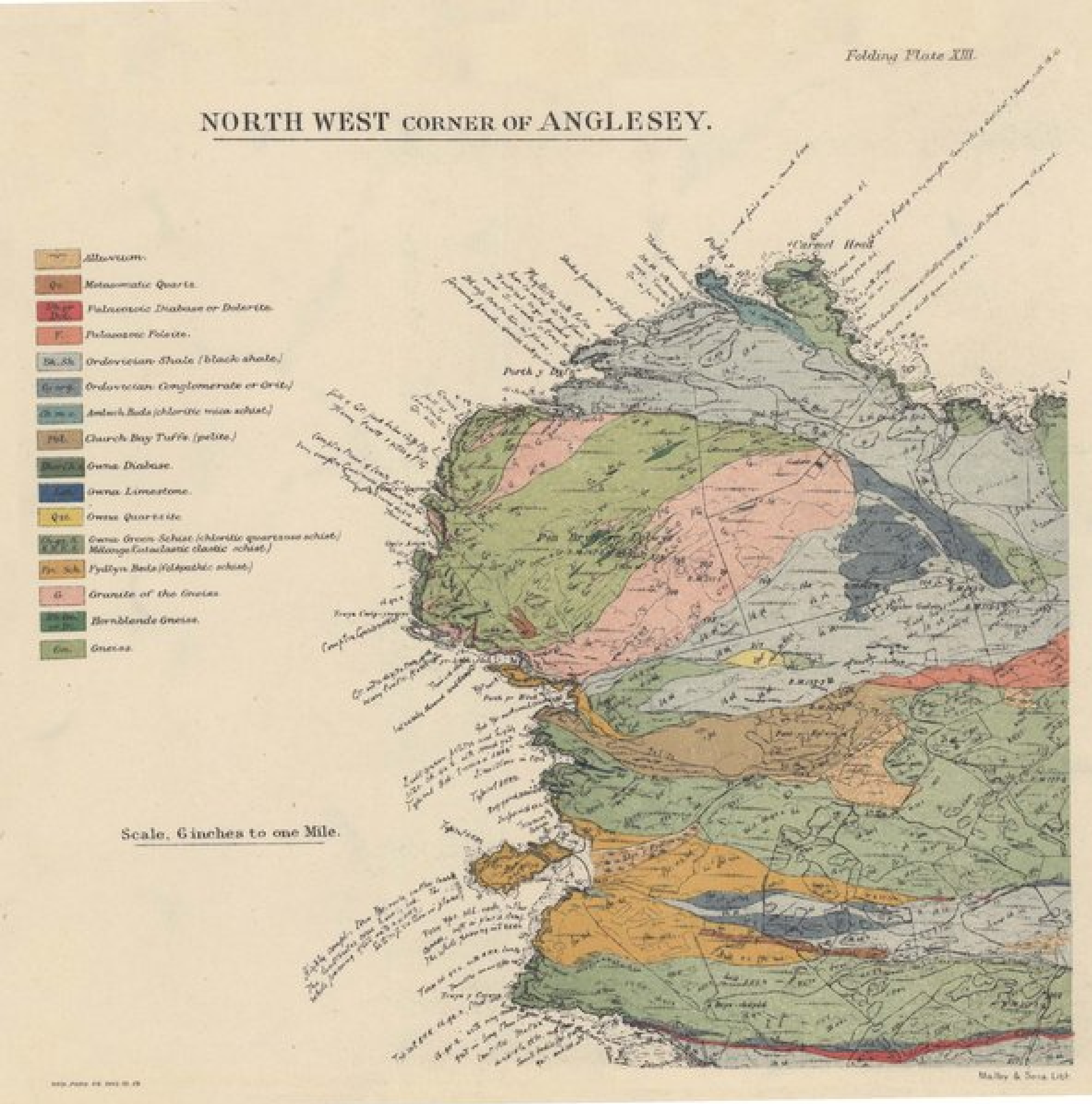


FIG. 308.

DEFLECTED GLACIAL STRIÆ AT TRWYN-DWLBAN.

(Figure 308) Deflect ed glacial stride at Trwyn-dwlban.

(Plate 43) Glacial strite deflected into mouth of pipe. Foreshore, Trwyn-dwlban.



(Folding-Plate 13) The North-West corner of Anglesey. Reproduction of manuscript six-inch map.

FIG. 309.

PROFILE OF UNDERCUT FURROW, TRWYN-DWLBAN.

(Figure 309) Profile, of undercut furrow, Trwyn-dwlban. About natural size.

FIG. 310.

UNDERCUT SHELF, WITH BOULDER-CLAY, FELIN-WEN.

(Figure 310) Undercut shelf, with boulder-clay, Felin-wen.

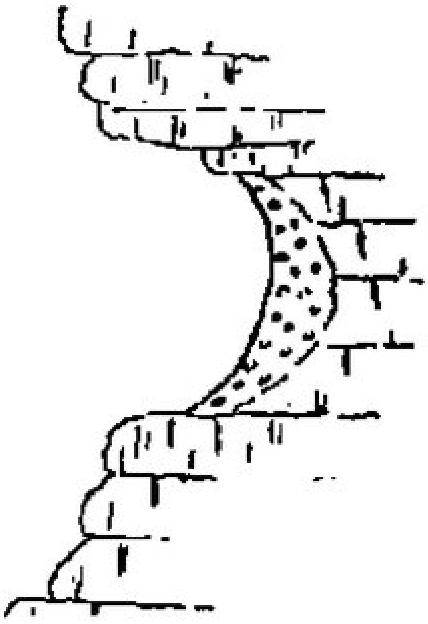


FIG. 311.
UNDERCUT SHELF,
Six feet in height,
WITH
BOULDER-CLAY,
HUSLAN CLIFF.

(Figure 311) Undercut shelf, Six feet in height, with boulder-clay, Huslan cliff.

FIG. 339.—HOLYHEAD MOUNTAIN AND THE SOUTH STACK MOOR: SKETCHED FROM THE BWA GWYN, RHOSCOLYN.

(Figure 339) Holyhead Mountain, from Rhoscolyn, and the South Stack Moor: sketched from the Bwa Gwyn, Rhoscolyn.

FIG. 312.

ICE-MOULDED SEA-CLIFF NEAR ABER-CAWELL.

(Figure 312) Ice-moulded sea-cliff near Aber-cawell. Height about 50 feet.

FIG. 313.

GLACIAL DISRUPTION AND THRUSTING AT PORTH-DELISC.

(Figure 313) Glacial disruption and thrusting at Porth-delisc. Height about one foot.

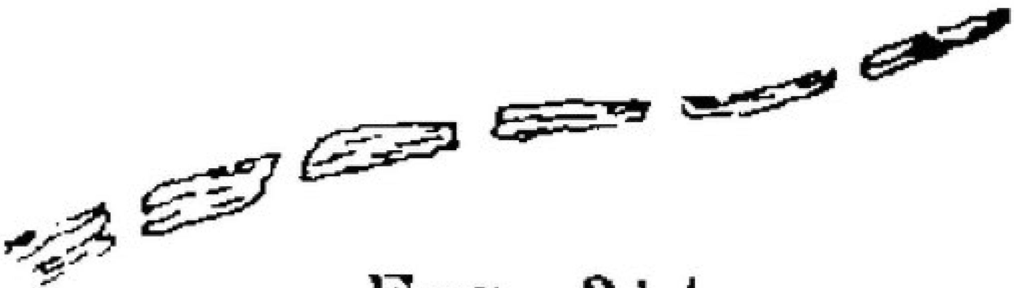


FIG. 314.

GLACIAL DISRUPTION AND DRAGGING-OUT AT PORTH-DELISC.

(Figure 314) Glacial disruption and dragging-out at Porth-delisc. Length about six feet.

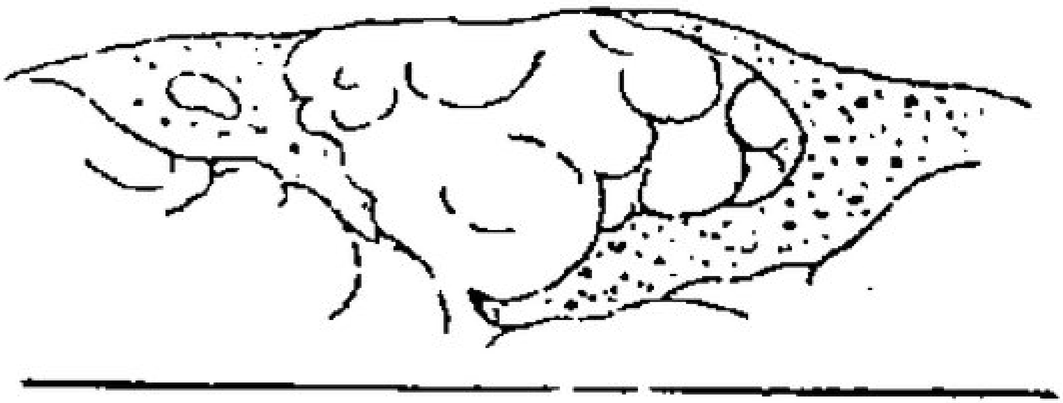


FIG. 315.

BOULDER-CLAY DRIVEN UNDER DOLERITE, NEAR PLAS-BACH.

(Figure 315) Boulder-clay driven under dolerite, near Plâs-bach. Depth about five feet.

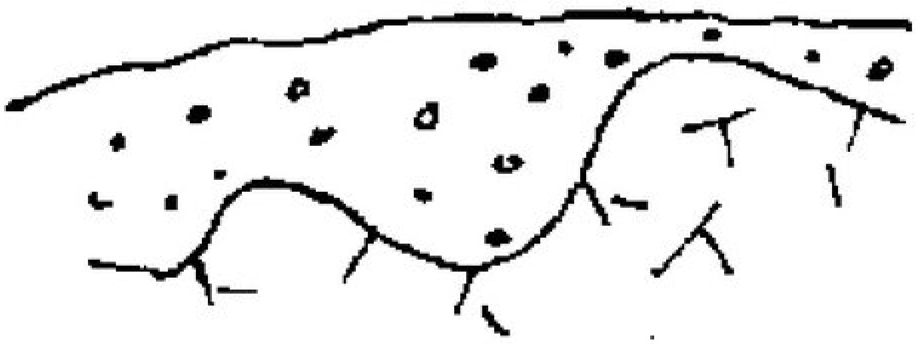


FIG. 316.

BOULDER-CLAY ON THE TOP OF A BOSS OF DOLERITE, NEAR PLAS MAELOG.

(Figure 316) Boulder-clay on the top of a boss of dolerite, near Plâs Maelog.

FIG. 317.

BOULDER-CLAY FILLING TWO-FOOT HOLLOW ON BOSS: ABOUT QUARTER OF A MILE EAST OF BODIOR.

(Figure 317) Boulder-clay filling two-foot hollow on boss: about quarter of a mile east of Bodior.

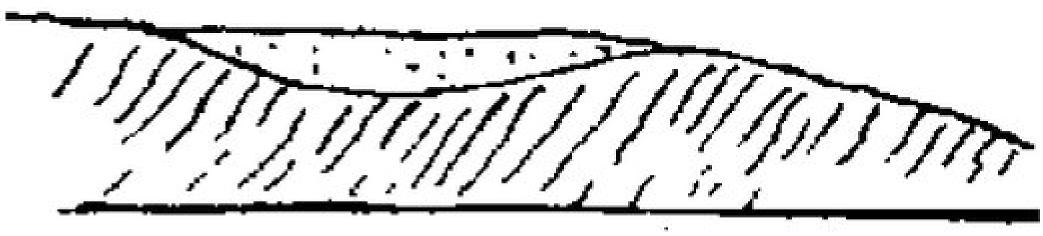


FIG. 318.

BOULDER-CLAY ON SUMMIT OF BOSS: ABOUT THREE-QUARTERS OF A MILE EAST OF CASTELL EDEN.

(Figure 318) Boulder-clay on summit of boss: about three-quarters of a mile east of Castell Eden.

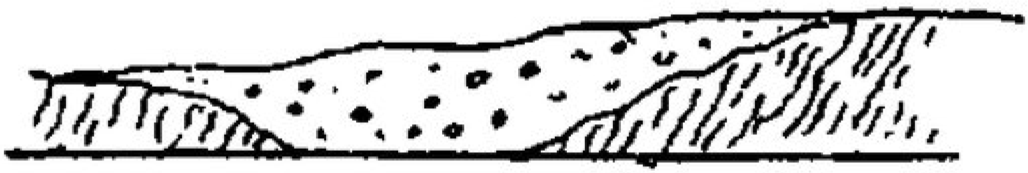


FIG. 319.

BOULDER-CLAY BETWEEN BOSSES: LLYN BADRIG.

(Figure 319) Boulder-clay between bosses: Llyn Badrig.

FIG. 320.

BOULDER-CLAY ON SLOPE OF BOSS: NEAR RHYTTY.

(Figure 320) Boulder-clay on slope of boss: near Rhytty.

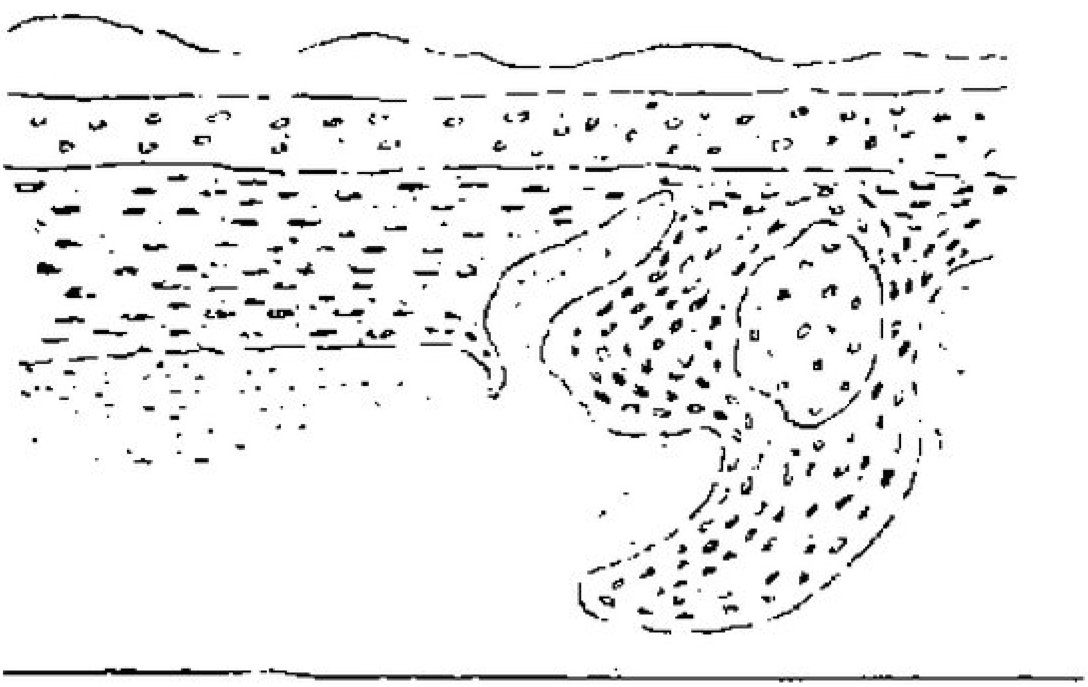


FIG. 328.

GLACIAL GRAVEL AND SAND, WITH BOULDER-CLAY.

Penrhos Beach, Holyhead.

(Figure 328) Glacial gravel and sand, with boulder-clay. Penrhos Beach, Holyhead.

(Plate 44) Glacial sands and gravels with red boulder-clay above. Lleiniog South Cliff.

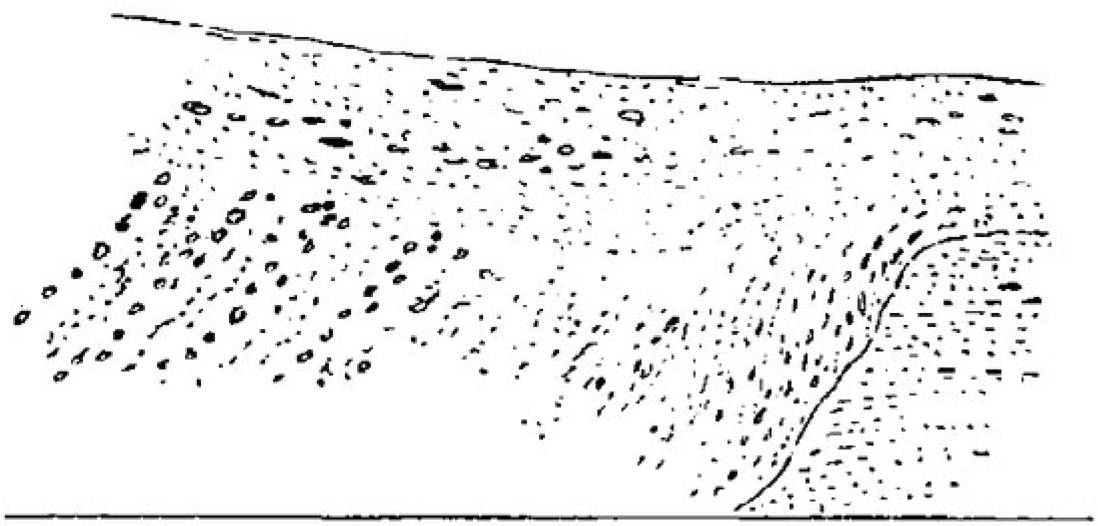


FIG. 335.--GLACIAL GRAVELS, TY'N-Y-CAEAU, MENAI BRIDGE.

(Figure 335) Glacial gravels, Ty'n-y-caeau, Menai Bridge.

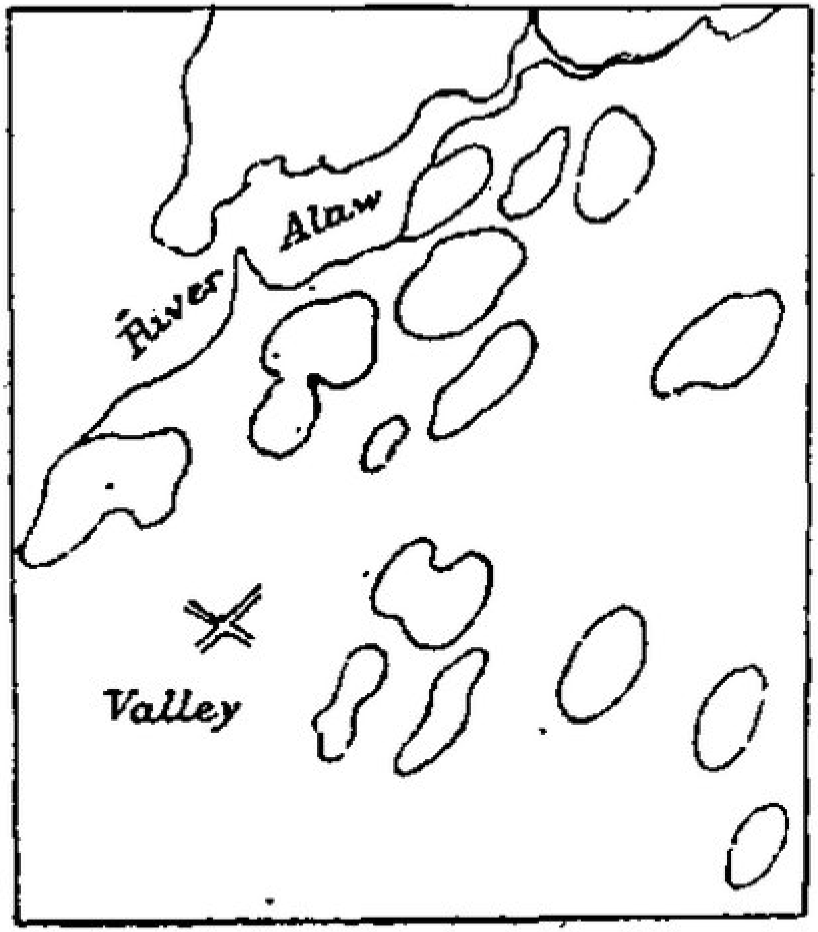


FIG. 324.

DRUMLINS NEAR VALLEY.

(Figure 324) Drumlins near valley. Scale: two miles = one inch.

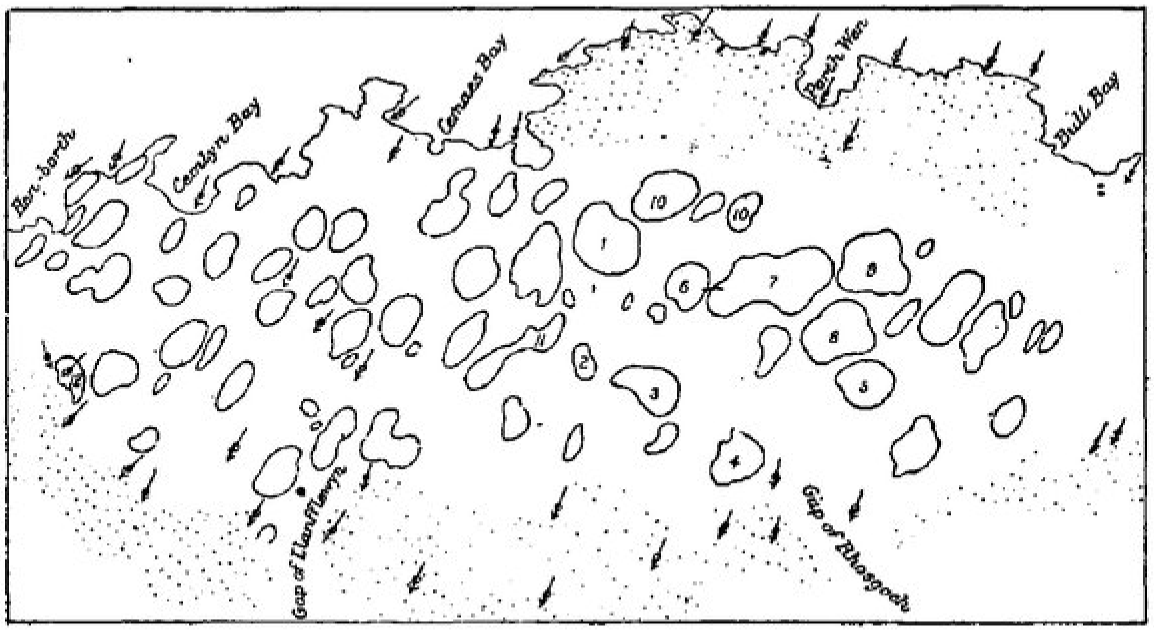


FIG. 332.—THE DRUMLINS OF THE NORTHERN VALLEY.

(Figure 332) The drumlins of the northern valley. Scale: one inch = two miles. High driftless ridges dotted. 1. Cemaes Drum. 2. Dymchwa Drum. 3. Pen-y-morwydd Drum. 4. Bodewryd Drum 5. Ysgellog Drum. 6. Oriw Drum. 7. Rhyd-groes Drum. 8. Hafod-llin Drum. 9. Werthyr Drum. 10,10 Nant-y-frân Drums. 11. Carog Drum. 12. Llanfairynghornwy Drum.

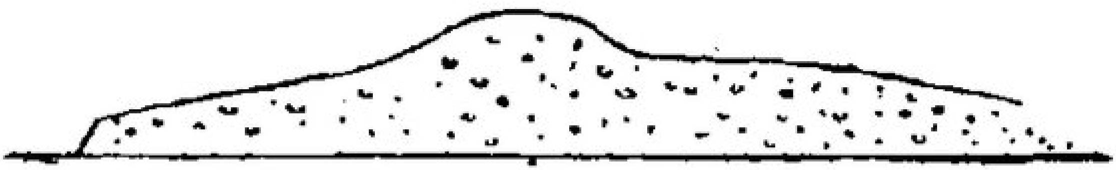


FIG. 321.

PENIAL DRUM.

(Figure 321) Penial Drum.

FIG. 322.

LLANFACHRAETH DRUM.

(Figure 322) Llanfachraeth Drum.

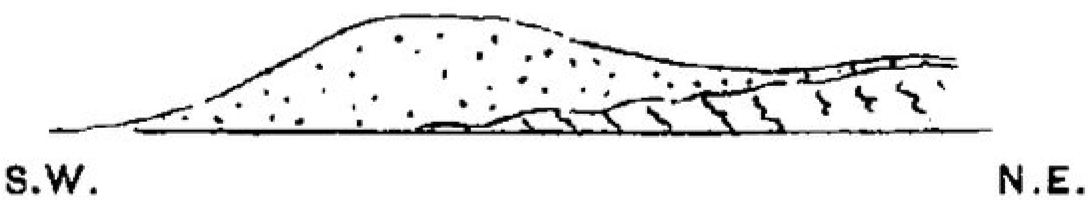


FIG. 323.

CLYMWR DRUM.

(Figure 323) Clymwr Drum.

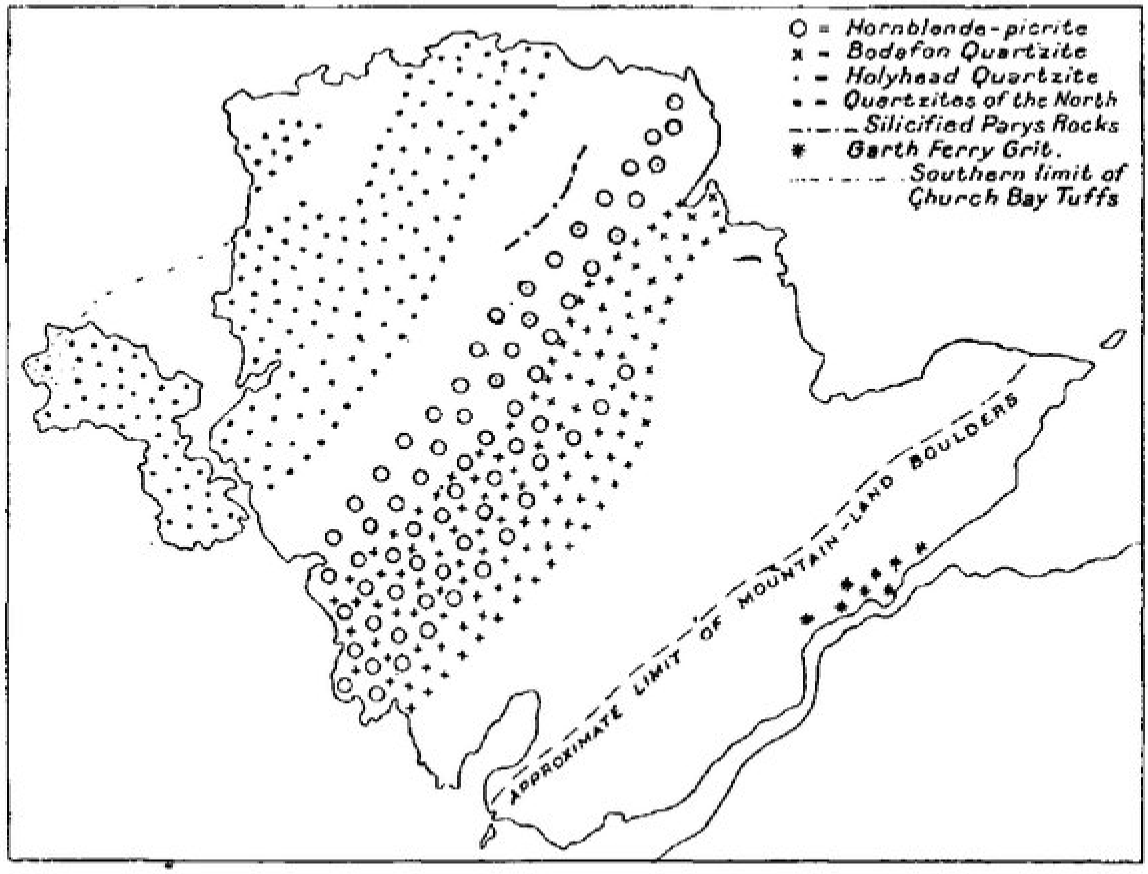


FIG. 326.—THE PRINCIPAL BOULDER-TRAINS.

(Figure 326) The principal boulder-trains. Scale: one inch = eight miles.

(Plate 45) Transported boulder of hornblende-picrite. Near the railway, Mynydd-mwyn-mawr, Llanerchymedd.

(Plate 47) Transported block of Carboniferous Limestone. Lleiniog.

(Plate 46) Boulder of Galloway granite. Porth-yr-ysgaw, Llaneilian.

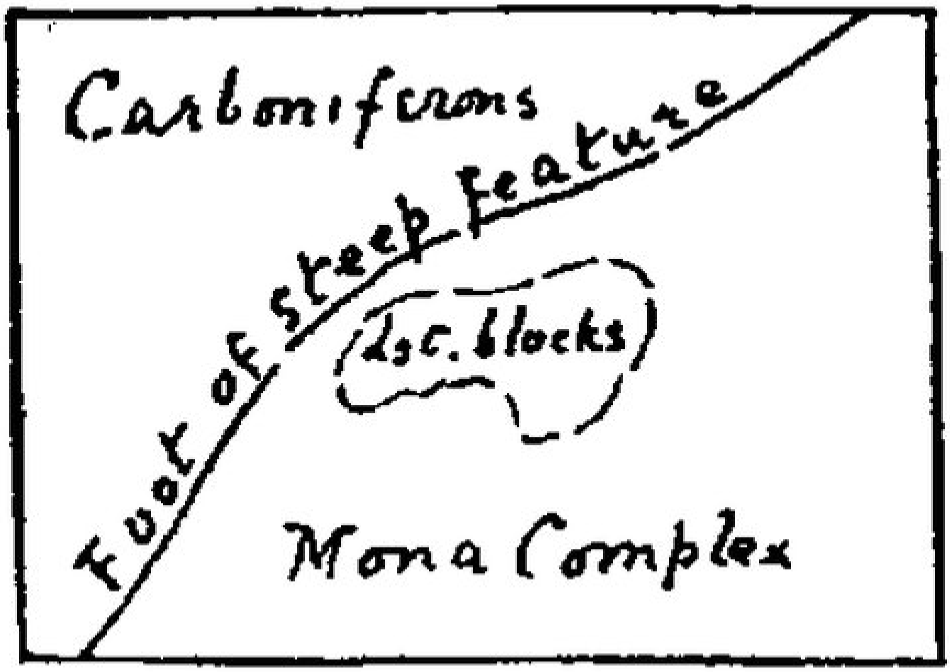


FIG. 327.

THE CARBONIFEROUS LIMESTONE OF BRYN-GWALLEN.

(Figure 327) The Carboniferous limestone of Bryn-gwallen. From the six-inch map.

FIG. 103.
DEFLECTION OF
SCOLITHUS PIPES.

(Figure 103) Deflection of the Scolithus pipes.

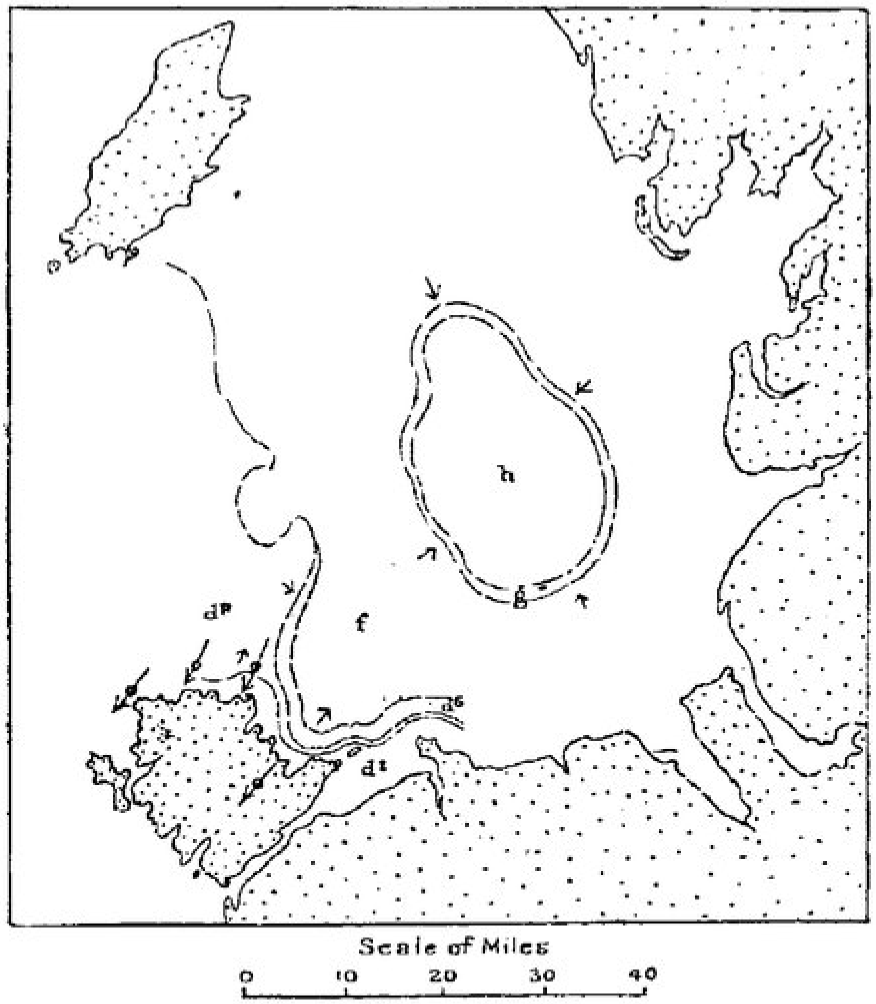


FIG. 338.—SKETCH-MAP OF THE SEA-FLOOR.

d^2 = Carboniferous Limestone. f = Triassic rocks.
d^p = Posidonomya Cherts. g = Jurassic rocks.
d^5 — Coal Measures. h = Cretaceous.

(Figure 338) Sketch-map of the sea-floor. d2 = Carboniferous Limestone. f = Triassic rocks. dp = Posidonomya Cherts. g = Jurassic rocks. d5 Coal Measures. h = Cretaceous.