Chapter 7. The tectonics of the Mona Complex

Introductory

To walk even for an hour over the rocks of the Mona Complex is to realise the intensity of the earth-movements to which they have been subjected. Folding, thrusting, and shearing meet the eye on every hand; the very body of the Complex is pervaded by them. The amplitude of the visible folds is usually small, seldom as much as a yard or two, save at the South Stack, where it exceeds 400 feet. The master-structures, however, are on a still greater scale, are nowhere visible, and can only be inferred. But the difficulties encountered are excessive. In the Alps there are well-established fossil zones, as well as rocky valleys thousands of feet deep. In the Scottish Highlands, though fossils fail, and metamorphism has set in, there are still valleys from 3,000 to 4,000 feet in depth. In the Mona Complex not only do fossils fail us, not only has metamorphism set in, but there is a great metamorphic zone, the Pemnynydd Zone, that is not a stratigraphical horizon at all, but which, superinduced upon true horizons, tends to obliterate them and to introduce no small confusion. Moreover, the Complex does not emerge as one continuous tract, but in a number of tracts, isolated from each other by Palaeozoic rocks. Above all, there is the low relief of the land, a 300-foot platform with broad shallow valleys, and with large tracts cut down to nearly sea-level. Even the higher hills afford no help, except at the South Stack, where the great scale of some of the folds is revealed. Indirect methods, therefore, are the only ones available, and by the use of them light has been obtained.

In view of the difficulties above stated, however, the interpretations about to be put forward are, for the most part, put forward only with very great reserve, and will doubtless be extensively modified by succeeding investigations.

The maximum primary structures

Evidence for inversion

The key to the structure, as to the succession, is in Holy Isle. The succession there seen, it may he recalled, is:

Holyhead Quartzite	
South Stack Series	Stack Moor Beds
South Stack Series	Llwyn Beds
New Harbour Group	Thin spilitic tuff at junction
New Harbour Group	Celyn Beds
New Harbour Group	Soldier's Point Beds

The argument that follows does not depend upon whether the succession be read upwards or downwards in a chronological sense, but, to save circumlocution, the chronological order for which evidence is given on p. 165 will be assumed to be correct, and the Quartzite spoken of as the highest member. It must be borne in mind also throughout that the pitch is persistently to east-north-east in this region.

The isle is traversed by two master-faults, which range from north-west to south-east. The first, which may be called the North Stack fault, comes in from the sea at the North Stack, runs along the cliff's foot, and, crossing Holyhead Mountain, passes on by Plas Meilw to Porth y Post. Reappearing at the Bwa Du, Rhoscolyn, and passing the church, it runs out to sea in Borth Wen. The other, which may be called the Namarch fault, appears first at Porth Namarch, and, passing through the town of Holyhead, reaches the coast again in Tre-gof creek. Thence it runs along the Strait of Holy Isle, and a discussion of its true course in that channel will be found on p. 211. Both faults are downthrows to the north-east.

The hade of the North Stack fault is seen at the Bwa Du and at Porth y Post, hut a much finer section is that on Holyhead Mountain, at the curve of the Gigorth cliffs. Looking southward from the North Stack Signal Station, the fissure of the fault can be seen high up on the mountain side, a dark chasm, hading to the east about 10° from the vertical (Figure 33).<ref>There is a photograph in the Survey collection (No. 1288) A1288 that shows this chasm quite clearly. But it was taken late on a summer evening, and would not furnish a satisfactory reproduction for this volume. (Figure 33) is therefore substituted.</ref> The chasm can be visited From above. Its walls are very even, and seem from that view-point to hade at 15 or more. It is perhaps 100 feet deep to the steep scree below, is 10 or 12 feet wide, and filled with breccia from side to side. Further details are given on p. 256. The fault determines the stupendous cliffs of the Quartzite (Plate 16), and where it crosses the mountain gives rise to a strong line of Quartzite crags, which, seen in profile, are a conspicuous feature for many miles. Its throw is visibly 500 feet, but must really be a considerable multiple of that, as might indeed be expected from its 10 feet of breccia.

The Namarch fault is well seen at Porth Namarch. Its chasm in the main cliff is choked with fallen blocks, but about 34 yards to the north a large buttress of the South Stack Series has been left by the sea against the quartzite wall, and there the fault is clearly exposed, hiding east at 12°–15° from the vertical (Plate 17), and (Figure 34). The massive quartzite presents a smooth face, and the ends of the beds of the South Stack Series are distinctly dragged up as they sink down eastwards on the fault. There is very little breccia, but a slight schistosity parallel to the hade is induced in the sinking rocks, as if the fault were somewhat compressive, connected with which may be its ability to curve rather unusually in ground-plan. Its throw cannot be less than 720 feet, but must, like that of the North Stack fault, be vastly more than that.

Now, as soon as the behaviour of these faults comes to be considered, a number of anomalies appear. At the mountain, the North Stack fault brings down the Quartzite against the South Stack Series, but the Namarch fault brings down the South Stack Series against the Quartzite. The North Stack fault is consistent with itself for a mile and a half, bringing down first the Quartzite against the South Stack Series, and then the upper (Stack Moor) division of that series against the lower or Llwyn division; but opposite Henborth it suddenly brings down the New Harbour Beds against the South Stack Series, and continues to do so all the way to Porth y Post. At Rhoscolyn the order of superposition is in opposite directions on the two sides of the fault. On the western side the South Stack Series is overlain by the Quartzite; on the eastern side it is overlain by the New Harbour Beds.

In the country between the two faults there are also anomalies. On the Rhoscolyn anticline (which is bisected by the North Stack fault) the South Stack Series rises and pitches beneath the New Harbour Beds, the little spilitic tuff-schist running round the curve of the anticline at the junction of the groups. About Holyhead, on the contrary, the New Harbour Beds pitch under the South Stack Series on a succession of folds, the thin spilitic tuff winding to and fro along the sharply curving junction. In the same district, the Namarch fault, instead of bringing down the Quartzite against the South Stack Series, brings down the Soldier's Point division of the New Harbour Beds. At Holyhead Mountain, finally, it brings down the Soldier's Point beds (as well as the South Stack Series) even against the Quartzite.

These anomalies cannot be reconciled by ordinary isoclinal folding, even though that be on the great scale that is revealed on the western coast, still less by normal folding.<ref>As far back as the summer of 1907 I had the advantage of taking my friend Mr. Clough over some sections in Anglesey, and mentioned to him some of the anomalies of the North Stack fault, upon which he replied that it would seem as if there must be inversions and recumbent folds like those then known in the Scottish Highlands. The Cowal Memoir (see, in particular, (Figure 47) and (Figure 52) of that work), it will be remembered, appeared in 1897, and Dr. Horne's interpretation of the Fannich folds in 1900. The classic work of Bertrand was published in the years 1883–5, his posthumous essay at the end of 1907; Lugeon's great paper in 1901. The remarkable paper by Mr. E. B. Bailey appeared in 1910. To it the reader may be referred for an interesting history of the development of this branch of geology. </ref> They can be reconciled only by postulating very extensive inversions.

The maximum primary folding as revealed in Holy Isle

A fundamental point is that both pitch and faults must be combining to bring in higher and higher horizons in a north-easterly direction. Let us first, then, consider the portions that lie to the south-west of the North Stack fault. At the Stack Moor, outliers of the Quartzite rest upon the South Stack Series ((Figure 28). At Rhoscolyn, infolds of the Quartzite are seen several times to rest upon the South Stack Series (Folding-Plate 2), from beneath which in turn emerge the New Harbour Beds. So the order on this side of the fault is, all along, the normal one, with the Quartzite uppermost. On the other side of the fault, at Rhoscolyn, the order is, as we have seen, in the opposite direction, the New Harbour Beds resting on the South Stack Series. An explanation, therefore, can be found if we suppose that on the two sides of the fault in the Rhoscolyn area we see parts of two limbs of a great recumbent fold, the limb seen on the north-eastern side being inverted. But the north-eastern side is the downthrow side. The inverted limb, consequently, is the upper limb. The fold composed of these two limbs may be called the *Rhoscolyn Recumbent Fold.* It must have a horizontal amplitude of at any rate seven miles. Holy Isle affords no evidence of the directions of gape and close, but some evidence is available from elsewhere, which will be given further on (p. 177). Anticipating that evidence, let us assume that it closes to the south-east and gapes to the north-west.

In the country between the faults, the South Stack Series goes down on the north side of the Iihoscolyn anticline, and the New Harbour Beds then hold the surface for more than three miles, after which the South Stack Series reappears. But in this district it is now resting upon the New Harbour Beds which, with the little basic tuff at the junction of the groups, keep on pitching under it. The order in this district is therefore the reverse of that on the Rhoscolyn anticline, and is once more normal. The Holyhead district, consequently, cannot be on the same recumbent limb as is the Rhoscolyn anticline. Yet neither can it be the same limb as that of the western coast, for although it is on the down throw side of the North Stack fault, New Harbour Beds are (instead of Quartzite) brought down against the South Stack Series (p. 172), where the direction of throw seems to be suddenly changed. We must, in fact, be dealing with the under-limb of a second recumbent fold, which is tectonically higher than the Rhoscolyn Fold. it may be called the *Holyhead Recumbent Fold*. The limb has descended northwards from above the level of erosion, and, continuing to descend, causes the New Harbour group to disappear, near Capel Gorllas, under the lower (Llwyn) part of the South Stack Series, and that to dip under the Stack Moor beds, which are followed by the Quartzite of Holyhead Mountain, all in the normal upward order of succession.

A question then arises as to where we pass from the Rhoscolyn to the Holyhead Fold, but it cannot be answered with precision, for the position must be somewhere in the three-mile tract of New Harbour Beds that forms the middle of the Isle, beds that are evidently doubled on themselves. An approximate indication can, however, be given, for though nearly all are Celyn beds, vet, about the alluvial belt that may be called the Tre-Arddur gap, are some flaggy psammitic rocks that are referred to the Soldier's Point horizon, and as these are to be expected in the core of the roll-over, the change of tectonic horizon may be placed in the Tre-Arddur gap. If, however, the roll-over between the two great folds were unbroken, it should take in as its core the whole of the lower part of the Mona succession, whereas nothing appears but New Harbour, and those almost entirely Celyn beds, the Soldier's Point beds being reduced to a small fraction of their normal thickness. We must therefore postulate a powerful rupture at this tectonic horizon, and as the roll-over has closed to the north and its upper limb is rolling southward, the slide is doubtless a thrust, which may be called the Tre-Arddur Thrust-plane. The extent of Celyn beds is indeed remarkable, but when rocks, especially crystalline schists, are powerfully folded, it may often be seen that the more yielding seams are packed and pushed forward in the cores of anticlines to lengths out of all proportion to their thickness, while innumerable minute thrust-planes appear in them, which may cause no rupture in the stronger beds outside (Figure 43), (Figure 44), &c. The Celyn beds, and even the Soldier's Point beds, being highly pelitic, would behave in this way on an enormous scale when caught in the cores of master-folds, and doubtless this is the cause of the width of their outcrop. An effect of the Tre-Arddur thrust-plane is to reduce to moderate dimensions the thickness of the folding masses towards Holyhead Mountain, and thus enable the faults to bring in more tectonic horizons than they could otherwise. Even as it is, their throws must be measured, not in hundreds but in thousands of feet.

We come now to the Namarch fault. The pitch going on as usual on both sides of it, and the fault itself being a downthrow on the north-east, it is doubly evident that whatever we meet with on that side must be something higher in the Complex than anything yet met with. Yet, instead of the Quartzite, it brings down, against the South Stack Series, New Harbour Beds of Soldier's Point horizon, which must, consequently, be on a higher tectonic horizon than the uninverted Celyn beds of Mynydd Celyn and Tre-fignath. They must be on the upper limb of the Holyhead Fold, and must be inverted. The Holyhead Recumbent Fold gapes to the north-west. A portion of its core is brought up (see pp. 210–2) on a thrust-plane at the Breakwater. The South Stack Beds of this core are those which are brought down against the Quartzite of Holyhead Mountain by the Namarch fault.

It seems hardly too much, then, to say, as regards Holy Isle:

(1) That the existence of recumbent folding on a great scale can be demonstrated.

(2) That the evidence admits of a consistent interpretation of this folding, and brings to light the presence of two recumbent master-folds, the Rhoscolyn and the Holyhead Folds, which are successive tectonic horizons<ref>For a section through Holy Isle, see (Folding-Plate 3), which should be read in conjunction with the lower two-thirds of the diagram, (Figure 35), p. 180. For other sections see (Folding-Plate 1), (Folding-Plate 2), and Chapters 8, 10.</ref>.

(3) That this hypothesis reconciles all the six anomalies enumerated on pp. 172–3.

The two faults, in fact, enable us to overcome the difficulty presented by the low relief of the land. They function as 'windows', revealing to us lower and lower tectonic horizons of whose existence we should, but for them, have been quite ignorant. Another 'window' is the Rhoscolyn anticline, but for the glimpse through which we should never have suspected that the New Harbour Beds of Rhoscolyn were on a different tectonic horizon from those of Holyhead. The lower limb of the Rhoscolyn Fold is the lowest known, the foundation-tectonic-horizon, of the whole Complex. The rest are all true *nappes de récouvrement.*

The maximum primary structures on the Main Island

Now recumbent folding on the scale thus revealed in Holy Isle can be no mere local phenomenon. It must be the master-structure of the Complex as a whole, and is, accordingly, to be sought for on the main Island. But when we cross thither the clear bedding and conspicuous pitch desert us. Nevertheless, interpretations of the Western and Northern Regions are possible which, though not of the same order of validity as that of Holy Isle, are tolerably reliable. The Middle and Aethwy Regions are far more perplexing, partly because of the presence of the Penmynydd Zone of metamorphism, which tends to confuse the tectonic horizons.

In the Western Region and the Northern Inliers

No third master-fault is known beneath Beddmanarch Bay, the Soldier's Point beds reappearing; so the Western Region is to be regarded as on the same tectonic horizon as the district in Holy Isle that lies to the north-east of the Nainarch fault, and thus as au extension of the upper limb of the Holyhead Recumbent Fold. But in that case we should expect to find the succession inverted. Accordingly, not only are the New Harbour Beds followed by the Church Bay Tuffs, but from Llanfaethlu to Llanrhyddlad the map (as well as such dips as are to be seen) clearly indicates that the Tuffs are pitching eastwards below the Gwna Beds. On the foreshore at Porth Swtan the Tuffs are seen to pass beneath Gwna Beds (pp. 159, 212). just beyond, near Clegyr-mawr, the Tuffs not only dip under the Gwna Beds, but run under them along the great cliffs, the eastward pitching Gwna Beds above them just failing to reach the cliff's brow. Confirmation of the inversion is found in the fact that metamorphism falls off as we pass from the New Harbour to the Gwna Group, crushing and autoclastism at the same time being substituted for folding. No other fold has been detected, so the whole Western Region is placed on the upper inverted limb of the Holyhead Recumbent Fold, which may be referred to as 'The Nappe of Holyhead'.

At the Garn Inlier the succession is undoubtedly inverted, metamorphism in like manner degenerating upwards, and folding being replaced by crushing. In the Fydlyn Inlier an anticline of Gwna Beds rises (pp. 214, 289) from beneath the Fydlyn Group, thus demonstrating that the succession in that inlier is inverted. (Folding-Plate 10). No evidence to the contrary (indeed such as there is points to the same conclusion) is to be found in the Gader, or even the Corwas, Inlier. All these inliers are therefore placed on the same tectonic horizon as the Western Region.

In the Northern Region

We now come to the Northern Region. That is completely isolated by the Post-Ordovician Carmel Head thrust-plane, so some of the results arrived at in Chapter 18 with regard to that great rupture must be anticipated here. There is a complete succession from the Coeden to the Gwna Beds, and the Gneisses are also present. To determine the tectonic horizon, we must first enquire whether the succession be in normal order or inverted. Now, even more conspicuously than in the Western Region, metamorphism degenerates from the Coeden to the Gwna Beds. In the same direction also folding very strikingly gives way to autoclastism, the Gneisses themselves being heavily crushed (p. 216). Inversion is therefore to be expected. Accordingly, where the Skerries Grits reach the sea at Llanrhwydrys, we find that they are taken in upon a boat-shaped infold and rest upon the Amlwch Beds. Further, the effect of the Hell's Mouth fault upon the Ordovician rocks, which appear for a mile more to the south on its western than on its eastern side, shows that it must be a downthrow to the northwest. But the same downthrow brings Gwna Beds against the Skerries Group; so that the Gwna Beds must overlie that group. The succession is inverted. An inverted succession, on whatever fold it be, must be upon an upper limb. The only tectonic horizons admissible, therefore, are the upper limbs of the Rhoscolyn, the Holyhead, or the next succeeding recumbent folds. To which it belongs will depend upon the action of the Carmel Head thrust-plane in relation to the tectonic horizon of the Western Region. Now the Carmel Head thrust-plane, though at one place horizontal, is everywhere an overthrust from the north, bringing the Northern Region of the Mona Complex not only forward but upward over the Ordovician rocks, and so, *a fortiori,* over their underlying floor, which is the Western Region of that Complex. Higher tectonic horizons than that of the Holyhead Fold are thus excluded. To bring up lower horizons, the angle of thrust, would have to be much greater than it is; besides which, the grade of metamorphism on the Rhoscolyn Fold is much greater than anywhere in the Northern Region, vastly greater than the lower grades found there. Lower horizons are therefore also excluded. The only tectonic horizon that is admissible, consequently, is that which we have in the Western Region itself, the Nappe of Holyhead. Now the higher parts of the Western Region are at its northern end, so that it is slowly dipping northwards. The Carmel Head thrust-plane being a low up-thrust, with a very great horizontal displacement, we should expect it to bring in somewhat lower parts of the limb than those that are seen in the Western Region. Accordingly, we find the Coeden and Bodelwyn beds, northern facies of the Llwyn and Celyn beds, horizons that are never seen between the Carmel Head thrust-plane and the Namarch fault. The Northern Region, then, is regarded as a still further extension of the Nappe of Holyhead. But there is reason to suspect, as will be seen on pp. 219, 317, that the first parts of the succeeding recumbent fold just appear on Dinas Cynfor and on the Middle Mouse.

Evidence for directions of close and gape

The reason for supposing that the Rhoscolyn and Holyhead Folds close to the south and gape to the north can be given with advantage at this stage of the argument. On the most northerly known part of the Holyhead Fold, now the Northern Region, the South Stack Series and the New Harbour Group develop well-marked northern facies, which have been called the Coeden and the Amlwch Beds. These facies have been carried southward on the Carmel Head thrust-plane. Let us now prepare, with pliable materials, two model-diagrams of the folds, colour them for the several facies where those are known to exist, arrange one model so that the two folds close to the north and gape to the south, and the other so that they close to the south and gape to the north. Then let us pull both models out straight, so as to restore the state of things before the folding. We shall find that on the first model the facies do not develop in the right directions, and that the Carmel Head thrust-plane could not bring the Coeden and Amlwch facies from the north at all. On the second model we shall find the directions of development of facies and the effects of the Carmel Head thrust-plane to be in agreement with what is seen in Nature. It will be found, further on, that this hypothesis as to close and gape agrees with the distribution of the north-western and southeastern facies of the Skerries and Gwna Groups.

In the Middle Region and its Ancillary Inliers

Turning to the Middle Region, determination of the tectonic horizons present is attended by far greater difficulties, and it must be clearly understood that the interpretation proposed is not put forward with the same confidence — is indeed only to be looked upon as a provisional hypothesis. Let us first consider whether horizons below the Nappe of Holyhead can be present. At first sight, the crystalline state of the Pernnynydd Zone of metamorphism suggests a low tectonic horizon, but there is good reason to think (pp. 200, 222) that it is due, not to depth alone, but to combined thermal and dynamic effects, operating at higher levels. The Coedana granite, having been undoubtedly preceded by folding and deformation (pp. 98, 166–7), is regarded as later than the primary recumbent folding. The eastern Skerries and Gwna rocks are, in the same region, scarcely re-crystallised at all. Further, the Holyhead Group never appears, which it could scarcely fail to do if the Rhoscolyn Fold had risen. Thirdly, the whole region is on the downthrow side of the Namarch fault, and such pitch as there is is still to the north-east. Fourthly, there is no sign of any gigantic dislocation between this and the Western Region. At Llyn Traffwll, an inlier of this one comes actually against the Western Region, and in that district there is known to be a Post-Ordovician steep overthrust which drives the Mona rocks upwards. Lower tectonic horizons may therefore be rejected. Higher horizons than that of the Western Region may (as far as Gwna Vale) also be rejected. For in the western part of the Middle Region the succession seems to be inverted, because the Tuffs (now hornfelsed) pitch under the Gwna quartzite of Bodafon, and because the Gneisses are much more mylonised than the adjacent rocks and therefore likely to overlie them. Thus, to bring in a higher inverted limb, the displacement running past Llyn Traffwll would have to be enormous. And thirdly, the higher the horizon we invoke, the greater are the difficulties of explaining the Penmynydd Zone. By far the most likely horizon, then, is that on which the Western Region lies, the inverted Nappe of Holyhead. It is in any case brought down a good deal, as its inverted Gneisses are now on a level with the New Harbour Beds of the Western Region, which accords with the probable magnitude of the Post-Ordovician thrust. This limb is regarded as extending as far as Gwna Vale. Thither, the pure western Gwna facies is traceable, unadulterated by the least sign of change.

Along Gwna Vale, however, the eastern facies appears quite suddenly. So suddenly, indeed, that the two facies lie on the same line of strike, and the western actually reappears at Plâs-bach and other places as inliers among the eastern. Moreover, the eastern facies is there fully developed, with its lavas on as great a scale as anywhere, full of nodular jasper and one of them accompanied by the ashy rose limestones. Further, they are succeeded by the Tyfry Beds, the eastern facies of the Skerries Group, which are but slightly deformed. It is evident that another tectonic horizon has come in. For the reasons just given, lower ones are inadmissible, so it must be a higher one. Now there is a marked decrease in metamorphism from the Engan to the Llanddwyn spilites of Ceinwen, and from them to the Tyfry Beds, which indicates that the succession is no longer inverted but in chronological order. It must therefore be on the lower limb of the fold that succeeds the Holyhead Fold. This may be called the *Bodorgan Recumbent Fold.* On it, and on its lower limb, the remainder of the Middle Region is supposed to lie. But were it unruptured, the whole of the Fydlyn Group and also the Gneisses would appear. they are missing, and therefore the lower part of the fold must be cut out by a powerful rupture which, as it is produced in connexion with the southward roll-over, may perhaps be called a 'thrust', the Bodorgan Thrust-plane (Folding-Plate 6) This tectonic horizon is therefore *sans racine,* and may be referred to simply as 'The Nappe of Bodorgan'. About the Plâs-bach Inlier its position is known to within some forty yards, the two facies being recognisable only about eighty yards from one another, but elsewhere it cannot be fixed with such exactitude. Even in the Plâs-bach area, the precise plane is not known, being now merely one of countless foliation-planes, possibly also masked by the Pen-mynydd metamorphism.

The Deri and Nebo Inliers of the Complex belong to the western Middle Region, and must be upon the Nappe of Holyhead. The western Gwna facies never reappears, and the Pentraeth Inliers, consequently, cannot be on any lower tectonic horizon than the eastern Middle Region, and as the Tyfry Beds appear to be uppermost, they are placed also on the Nappe of Bodorgan.

In the Aethwy Region

The Aethwy Region has at first sight an aspect of less complexity; but there is little doubt that this is treacherous, the Penmynydd Zone being developed on a great scale, and the persistent planes all superinduced as well as intensely corrugated, so that we are farther here from the possibility of detecting reliable original divisional planes than in any of the other regions. The high crystalline grade of the Penmynydd Zone once more suggests a lower tectonic horizon. But we are still on the downthrow side of the Namarch fault, and the pitch is still to the north-east, bringing in less and less altered material. Now, if we again take a model of the recumbent folds of the Complex, and open it out as before, it will appear that the eastern Gwna facies, which first appears on the Bodorgan Fold in the Middle Region, cannot be found on the Holyhead or lower folds. That facies is developed here in full force, and it therefore follows that the Aethwy Region must be placed on the Bodorgan Recumbent Fold (see also footnote, p. 227). And, as the Aethwy Penmynydd Zone is correlated for the most part with the Fydlyn Group, the succession on the pitch will be uninverted, in which case it must be upon the lower limb, the Nappe of Bodorgan. The Llanddwyn Wedge, however (p. 228), brought in, manifestly, upon a slide, called the Newborough slide, is regarded as a fragment of the upper limb, and consequently the highest tectonic horizon of the Mona Complex in Anglesey.

The chart ((Figure 100), p. 238) embodies what is considered to be the geographical distribution of the successive tectonic horizons.

Amplitudes, facies, and recapitulation

We thus recognise the existence of three main, or (to adopt an adjective first used in the classification of the thrust-planes of the North-West Highlands of Scotland) maximum ' primary recumbent folds, the Rhoscolyn, the Holyhead, and the Bodorgan Folds. They close to the south and gape to the north. A subordinate recumbent fold is also known, the Breakwater Fold; the beginning of another, which may be called the Gynfor Fold, appears on Minas Cynfor and the Middle Mouse. In the diagram (Figure 35), the maximum folds have for the sake of lucidity, been drawn unruptured. But it is unlikely that any of them are unruptured; there is evidence of several ruptures, chief of which are the Tre-Arddur thrust, the Breakwater thrust, the Gwyndy thrust (p. 221), and the important Bodorgan thrust-plane. All these are primary thrust-planes, products of the movements which produced the maximum recumbent folds themselves; they have in some cases certainly, in all cases probably, been long since transformed into (if indeed they were ever anything else than) pure foliation-planes, indistinguishable from the rest of the foliation. What other folds may once have overlain the Holyhead and the Bodorgan Folds, giving them the needful weight and cover, we do not know. But it will be seen in Chapter 9 that we are not wholly without evidence, both of their existence and their nature.

Amplitudes — If the foregoing views be correct, it is possible to arrive at minimum estimates of the horizontal amplitude of these recumbent folds. The fragment that remains of the Rhoscolyn Fold extends from the North Stack (for the islet, as will appear on p. 207, must be placed on that fold) to the south coast of Holy Isle, so that the horizontal amplitude must be at least seven miles. How much further it extends is not known, for the rest of the lower limb has been destroyed by the sea. The Nappe of Holyhead, from where it disappears on the Bodorgan inliers to the north side of the Gader Inlier, is fourteen miles in length. To this must be added the width of the Northern Region, which is more than four miles. But that region has (see Chapter 18) been carried southwards on the Carmel Head thrust-plane a distance of at least twenty miles, which must therefore also be added. The total known length of the Nappe of Holyhead is therefore as much as thirty-eight miles. But, as will presently be seen, this measurement is of country that has been driven together by innumerable folds and thrusts at more than one epoch, so that its present can hardly be more than half its original extent. It is probably, therefore, not an excessive estimate to put the real horizontal amplitude of the accessible part<ref>The true locus of close has never been found, and is doubtless outside Anglesey.</ref> of the Holyhead Recumbent Fold at something like sixty miles. The amplitude of the Bodorgan Fold is not known. From the Menai Strait to the furthest outcrops of the Engan spilites at Trefollwyn is about seven miles, but the violent contrast between the two Gwna facies near Bodorgan shows that the same tectonic horizon must extend many miles beyond that; and it may be as extensive as any. Possibly the Gynfor over-roll, regarded as merely subordinate, may really be the beginning of the Bodorgan Fold.

Facies — An interesting feature is the part played by facies. In the establishment of the correlations between the several members of the succession from region to region, facies presents an obstacle to be overcome. But once overcome, it is the greatest of aids in the interpretation of the structure, at any rate on the main Island, for without it the existence of the third great recumbent fold, the Bodorgan Fold, would never have been suspected; and the directions of close and gape would have remained unknown. And the manner in which differing facies, on four different horizons, which must originally have been many miles apart, have been brought close together by the combined action of the recumbent folding of the Complex and of the Post-Ordovician Carmel Head thrust-plane, is most remarkable.

Recapitulation — Such is the working hypothesis that is proposed for the maximum primary structures of the Mona Complex. It is really based on the evidence of Holy Isle. In that region, the wonderfully precise horizon afforded by the little spilitic tuff (pp. 157, 209, 264–7), the persistence of the pitch, and the unequivocal character of the two main faults, permit the existence of widespread inversions to be demonstrated, and the presence of two master-folds established. That once made secure, there can be no doubt that the Nappe of Holyhead extends to the Western Region, but evidence from the local structures is less clear than in Holy Isle. That the Northern Region is also on the same tectonic horizon has to be established by indirect evidence, which, however, makes any other fold inadmissible. So far, the conclusions reached are tolerably secure. But those put forward for the Middle and Aethwy Regions are of a lower order of validity, and the tectonic horizons indicated cannot be regarded as so well established. Nevertheless, the sudden change of Gwna facies at Bodorgan shows that recumbent folding is still in progress, and on a great scale. Whatever, therefore, the difficulties of interpretation, the principle of recumbent folding is, we need not doubt, that which dominates the structures of the whole of the Mona Complex.

The major, minor, and minimum structures

The major secondary folds

In the foregoing argument the maximum primary folds have been treated, for the sake of lucidity, as though they were tolerably simple, as though their axial planes were approximately plane superficies. But that is far from being the case. In reality, the planes of their axial cores, and therewith also the whole tectonic succession of prodigious thickness, have been driven together by powerful movements and thrown into a series of secondary folds and thrusts that is of extreme complexity. These are called the major secondary folds and thrusts. Not that there is likely to be any break or sharp distinction between the primary and secondary structures, all of which are doubtless effects of the same impulses. Yet there is a distinction. A primary thrust, for example, will not cut across tectonic horizons higher than its own, and may be folded in its turn. A major secondary thrust, itself approximately plane, may not only cut and displace a primary thrust, but cut through more than one tectonic horizon. The major secondary folds are for the most part isoclinal, but in a few cases are symmetrical about vertical axes. They are of great amplitude, and revealed for the most part by the mapping. In one section only are they visible directly to the eye.

The Major folding at the South Stack — This is in the range of great sea cliffs that look down upon the South Stack, and attain at one point a height of 445 feet. 'There can hardly be a finer section in the British Islands for the study of both great and minute folding, of the relations of the one to the other, and of both to the planes of concordant and transverse foliation, as well as of the crystallisation induced by dynamic metamorphism'.<ref>A remark made un the spot by Dr. Flat, whom f lied the advantage of taking there in 1907.</ref> The South Stack Series on the lower limb on the Rhoscolyn primary Recumbent Fold is here thrown into a magnificent suite of major secondary folds. Very fine views are to be had from the South Stack itself, as is seen in (Plate 1) (Frontispiece); but only of a quarter of a mile of cliff. The remainder of the cliff, and the due proportions of the whole, can be seen only from the sea. After several failures to obtain a boat to go along that dangerous coast, I was offered, by the great courtesy of Capt. McKinstry, secretary of the Holyhead Lifeboat 'Committee, the unique advantage of a permission to take the Holyhead Steam Lifeboat there when it went out for exercise. The result was the section given in (Folding-Plate 1). Its details are doubtless open to improvement, as it had to be drawn, bit by bit, from the lifeboat in a somewhat heavy rolling sea, but this is the first time that there has been all opportunity to draw this wonderful section at all. Some of the great single folds sweep up the whole height of the cliffs near Ellen's Tower with an amplitude of between 300 and 400 feet. Opposite the South Stack some of the axes are nearly vertical, admitting of local dips to the south-east, but the folding becomes isoclinal at Ellen's Tower, and still more pronouncedly so with the rise of the Llwyn beds at Yentas rock, beyond which the visible amplitudes also decrease (Folding-Plate 2) and (Figure 36).

Other major folds

Studies of the major secondary folding ill the several regions will be found in Chapters 8, 10; in (Folding-Plate 1), (Folding-Plate 2), (Folding-Plate 3), (Folding-Plate 4), (Folding-Plate 5), (Folding-Plate 6), (Folding-Plate 7), (Folding-Plate 8), (Folding-Plate 10); and in (Figure 91) (Figure 92) (Figure 93) (Figure 94), (Figure 99), (Figure 156) (Figure 157) (Figure 158). Here, therefore, only a few cases will be quoted that serve to bring out its nature and its magnitude. On the western coast at Rhoscolyn, the same recumbent limb as at the South Stack is thrown into a series of large isoclines, with one symmetrical anticline, beyond which an isoclinal infold faces north-west. (Folding-Plate 2). The cliffs are not high enough to show their full curvature, but seen from a boat, their existence and their nature is quite evident. The Rhoscolyn anticline beyond the fault has already been utilised in evidence of the primary structures. The upper limb of the Rhoscolyn Recumbent Fold is folded over it. Near Stryd, Holyhead (Folding-Plate 3), the Holyhead Recumbent Fold is thrown into a succession of secondary major isoclines with amplitudes that reach 1,100 feet at the base of the Llwyn beds. The Tre-Arddur thrust-plane also must be folded over the whole of this major series. In the Western Region the major secondary folds are again isoclinal, but face northwards (Folding-Plate 4). About Llanrhyddlad their amplitudes must be 2,000–3,000 feet. The major folding in the Northern Region (Folding-Plate 5) is yet again isoclinal, but faces southwards. The amplitudes are not known, but must reach 2,000 feet or more. They must, however, be cut off at moderate depths by the Carmel Head thrust-plane, and their lower parts left behind some twenty miles to the north of their present outcrops. The major secondary folding in the Middle Region (Folding-Plate 6) is on a great scale, and highly complex. It differs from that of the other regions in its axial inclination, which is persistently very steep and in some cases vertical, so the major structures are not isoclinal. Such inclinations as there are are fan-like. The Bodafon anticline (Figure 156), owing to the strong features of the quartzite, is perceptible as an anticline in the field (Figure 154), the only inland major fold that is so. The limbs dip off a vertical axis in both directions; yet it is compound, and a succession of large isoclines on its eastern limb (Figure 157)–(Figure 158) face to the north-west. It folds the Nappe of Holyhead, and its amplitude at Mynydd Bodafon is about 1,000 feet; but with the rise of the pitch increases to the south-west, and together with the plunge to the adjacent synclines must be 6,000 to 8,000 feet. The primary thrusts are folded. The Gwyndy thrust-plane (see p. 221) must roll over the Bodafon anticline and down into its deep flanking Caradog and Bodwrog synclines. That the Bodorgan thrust-plane is mightily folded is certain, from its repeated rising on the Plâs-bach and a suite of adjacent inliers; and, as it is the parting-plane of the Nappes of Holyhead and Bodorgan, those must both be folded together by these major secondary flexures. The major secondary folding in the Aethwy Region (Folding-Plate 7), (Folding-Plate 8) is on as great, perhaps on a still greater scale, and is isoclinal. But the isoclines face each other towards an axis along which the structure becomes synclinorial. A major secondary synelinorium is therefore superimposed upon the Bodorgan primary Recumbent Fold.

Major Thrust-planes — Amongthe major secondary thrust-planes, the Bodfardden thrust-plane, driving northwards and waxing eastwards, nearly abolishes pitch in the southern part of the Western Region. In the Northern Region it is not always easy to distinguish the thrusts of the Complex itself from the great Post-Ordovician thrusts. But there is reason to think that the Wig (see p. 216) and Caerau thrust-planes (Folding-Plate 5) belong to the major secondary movements of the Complex, and they must both be of great magnitude. They are carried forward by the Carmel Head thrust-plane. Other thrusts have developed along the Bwlch infold of the Sherries Grits. The Trwyn Bychan thrust-plane (Figure 95) (which is at one place horizontal) and several higher major thrust-planes throw the steep foliation of the massive Church Bay Tuffs into bold sigmoidal curves. In the Middle and Aethwy Regions the highly inclined thrusts that are known may be ancillary not to the secondary but to the primary folds, and their steepness duo to their outcrops happening to be on the limbs of the steep secondary anticlines. But someareno doubt secondary thrust-planes, among them that which cuts out the eastern limb (p. 222) of the Bodafon anticline. As (to anticipate) the minor, ternary, thrusts have been 'healed' by crystalline metamorphism, there can be little doubt that the major secondary thrust-planes have been likewise healed, and that they have long become pure foliation-planes.

An abstract of the major secondary folds and thrusts is given in (Figure 99), p. 236.

The minor or ternary folding

This is the folding, which, with amplitudes ranging usually from two or three inches to two or three feet, is directly visible to the eye, and is such a feature of the Complex. Only in the massive Sherries Group and Holyhead Quartzite, in the plutonic intrusions, in the Gneisses, and in the Middle Region generally, is it inconspicuous.

As the major folds are superimposed upon the maximum recumbent folds, so are the minor superimposed in their turn upon the major folds. But as the major folds are not recumbent, but at tolerably high axial inclinations, the relations are different, are indeed frequently in reverse order, the axial inclination of the minor being often lower than that of the major fold upon which it is imposed. These relations can only be seen in the great sections at the South Stack, on the coasts (especially the south coast) of the Llwyn-y-berth promontory, and at Rhoscolyn. At the South Stack, the great sweeping folds shown as if smooth in (Folding-Plate 1), are never really smooth, but are perpetually wrinkled all along their course, as seen in the Frontispiece (Plate 1). All the- wrinkling is isoclinal, and its axes dip at lower angles than those of the major folds, the mutual relations in different parts being admirably seen on the major anticline that is exposed in the chasm that outs into the Stack on the southern side. Along the southern cliffs of the Llwyn-y-berth promontory (Figure 37) the general dip of the beds is at high angles to the north-west, sometimes even vertical, what is seen being really a part of the limb of a steep major isocline whose amplitude is greater than the height of the land. But the vertical beds are thrown into a rapid succession of minor isoclines with amplitudes of only a few feet, whose axes dip at angles of 10° to 45°. These are folds of the stronger grits, those of the lepidoblastic partings being more rapid. A remarkable feature of the relation of the minor to the major folds is that whereas at the South Stack and at Rhoscolyn, some of the major folds are not purely isoclinal but have limbs that dip to the south-east (Folding-Plates I, IT); the minor folds upon those limbs are still isoclinal, retaining ((Figure 38), (Figure 39)) the same axial inclination as on the isoclinal major folds.

Types of minor folding

The minor folding may be classified as (1) Symmetrical, (2) Isoclinal, (3) A-clinal, (4) Polyclinal.

Minor Isoclines in the South Stack Series. Near Porth Rhwydan, Holy Isle.

1. Symmetrical— Folding in which the limbs dip symmetrically away from a vertical axis (Figure 40), (Figure 41), (Figure 42), (Figure 43) is not common in the Complex, but is found along some tracts of moderate extent.

2. Isoclinal — This is (Plate 18) (Plate 19), (Plate 20), (Plate 11), and (Figure 44), (Figure 45), (Figure 46), (Figure 47), (Figure 48), (Figure 49), (Figure 50), (Figure 51), (Figure 52), (Figure 53), &c. far the most prevalent. It is universal in Holy Isle, almost universal in the Northern Region, general though less conspicuous in the Western Region, and strongly developed over much of the Aethwy Region. More perfect isoclinal folding than that of the New Harbour Beds. of Holy Isle can hardly be imagined (Plate 19). The fine Celyn beds in particular display it in a wonderful manner. On the rugged moors of Mynydd Celyn, for example, the whole mass is folded so thoroughly and so rapidly that one cannot look in any direction without seeing isoclines laid bare in sonie aspect or other (Figure 47), and there are dip-sections of great beauty every 10 or 20 yards. The smallest average amplitudes are in these lepidoblastic Celyn beds, where they are usually a few inches: the largest are among flaggy Soldier's Point and Coeden Beds, where they range to 10 feet. The axial inclination is moderate, often about 45°, but tends to be steep in the Coeden beds ((Figure 132), p. 298), and perhaps lowest in the Celyn beds. As a rule there is no great disparity between the length of the limbs, but peculiar long straight limbs are seen on the fine sections at Point Lynas (Figure 52) and about Porth-y-felin, Holyhead (Figure 53). In the Middle Region, where folding is comparatively subordinate, a short fold may be seen at intervals of several yards upon steeply dipping folia. In fissile beds the curvature is often very sharp, yet beautifully sinooth. There is the usual tendency tothinning and thickening in different parts of the fold, lepidoblastic seams becoming extremely attenuated on the limbs and packed into the anticlines to mangy- times their original thickness.

The curious foldings of the quartz-seams call for further study, which will need the aid of thin sections, and will throw much light on the metamorphic process. They are not perfectly conformable, but cut somewhat across the folia while folding with them, and that, often very sharply. It is not easy to believe that they could be folded so powerfully without internal reconstruction, yet it is not merely the older ones (now granoblastic and incorporated) that behave in this way, but the later ones that are still venous in texture. It would seem (E10154) [SH 252 830] as if the curvature were due to their following lines of weakness in the already folded rock. But those now granoblastic have evidently been themselves folded. Foliation-planes in the act of rolling over anticlines often show a fine striation, and when a thin sheet of the older granoblastic quartz is present, the striation can be seen to be a local nemablastism, indicating the direction of stretching, but is usually a mere film upon the plane. Now this direction does not seem to be at right angles to the strike, but slightly oblique. On Mynydd Celyn, for example, it is at about 65° to the strike, which is east-north-east to west-south-west, the nemablastic striation running steadily from north-west to south-east. There appears therefore to have been some degree of torsion, yet the strike itself is wonderfully steady.

3. A-clinal — Minor-folding on axes that have no inclination is occasionally seen, and might be called, indeed, recumbent minor folding, but the term 'A-clinal ' will be found useful. Such may of course be a mere local horizon-tality of isoclinal folding, but what is chiefly meant is a corrugation of beds or folic that are dipping vertically when considered as a whole. It appears first as a mere unsteadiness of the vertical planes, and intensifies into sharp corrugations with horizontal axes (Figure 54), (Figure 55), (Figure 56). The vertical structures appear to have been subjected to lateral oscillation under heavy weight.

4. Polyclinal — The fold-axes in this type are both vertical, horizontal, and inclined this way or that way; and all close together, for the folding is extremely rapid; conveying to the eye an impression of confused and irregular crumpling from no particular direction, an impression intensified by a kind of quivering, a lack of decisive and steady sweep in all the curvature (Figure 57), (Figure 58), (Figure 59), (Figure 560). It may be that the 'polyclinal' type (as it may conveniently be termed). results from isoclines having been, as it were, 'spoilt by the same lateral oscillation that induced the a-clinal type upon the vertical dips. The polyclinal type has as persistent a strike—as the isoclinal.

Pitch

The pitch of the minor folding is in one steady direction (except at faults and around the basic intrusions) all over Holy Isle, and over most of the Aethwy Region, but undulates a good deal in the Northern Region. For the most part it is at moderate angles of about 10° to 15° or 20°; but along the north-western edge of Aethwy is often higher, and on Mynydd Llwydiarth as much as 40° to 60°. There is a line in the same hill, along the base of the large hornblende-schist (pp. 229, 375) where it rises to 90°, and as the folding is there extremely violent (Figure 61) there must be powerful torsion in the horizontal dimension.

Thrusting

Surprisingly little thrusting has developed upon the minor folds over most of Holy Isle. Bed after bed will attenuate until so thin that it would seem as if cohesion must give way, and yet they still hold together, the fold remaining unbroken. Here and there, however, micaceous beds lying horizontally between strong hard ones tend to fold rapidly upon themselves, and the folds to rip out into small thrusts, beautiful examples being seen (Plate 20) on Salt Island. About the Tre-Arddur gap, in particular, where a large primary thrust-plane, the Tre-Arddur thrust-plane, must emerge, a crowd of minor thrusts appear (Figure 62), (Figure 63). In the Northern Region, great numbers of minor thrusts develop (Figure 64) in connexion with the major thrust-planes that throw the steep foliation of the Trwyn Bychan tuffs into sigmoidal curves. The perfect long-limbed isoclines of Point Lynas gradually disappear westwards, and are replaced by a steady northerly dip, well seen about Cemlyn Bay. At first sight this looks like an ordinary stratification-dip of the flaggy Amlwch Beds, but on closer inspection it is found that no bed is traceable more than a few yards.

In reality, the simple-seeming flags are riddled with innumerable minor thrusts, but these are at an extremely acute angle to the bedding (Figure 65), sometimes actually parallel to it, so that the thicker beds are split by thrust-planes up the middle and carried torward parallel to themselves, until presently the thrust-plane curves a little and cuts one of the halves gradually off. A curious modification of the process is shown in (Figure 66), where a thin grit has been stretched and ruptured, pelitic matter filling in the spaces, but without destruction of the general bedding-nlane. Another modification, which is frequently seen, is by oblique minor thrusting that causes adjacent beds to interdigitate (Figure 67), a relation that appears, indeed, on the large scale, and imparts a characteristic form to many outcrops. Doubtless these phenomena are due to attempts to superimpose minor isoclines upon a long limb of some large major isocline, where the impulse was nearly parallel to the general dip. Evidently they are stages of the process that elsewhere produced an autoclastic mélange. But they are not a mélange, for the bedding is far from being destroyed.

Principles of Autoclastic Mélange — The essential characters of an antoclastic mélange may be said to be the general destruction of original junctions, whether igneous or sedimentary, especially of bedding, and the shearing-down of the more tractable material until it functions as a schistose matrix in which the fragments of the more obdurate rocks float as isolated lenticles or phacoids. Now this condition is general throughout the higher tectonic horizons of the Mona Complex, which, *at that time,* were in the zone of fracture, so that all attempts at minor folding resulted only in thrusts or other ruptures. By the accidents of recumbent folding and erosion, most of the Gwna Beds that are known to us are on those horizons, and are consequently in the condition of mélange, to which they lent themselves readily by reason of their very heterogeneous character. The early stages of development may be seen in the Tyfry Beds of the Pentraeth Inliers (Figure 68), on Twyn y Parc in the Bodorgan headlands, and especially well at the top of the Fydlyn Group ((Figure 32), p. 161). At the top of that massive deposit the thin alternating beds come on, these are soon stripped into phacoids transversely to the bedding; which rapidly becomes imperceptible, and they thus pass into typical autoclastic mélange. An excellent little section showing perfectly a rapid breakdown of bedding into mélange by shearing nearly parallel to the dip, is to be seen at Llangristiolus, 160 yards east of the late dyke, and 60 yards north of the footpath to Llan-fawr. The characters of the autoclastic phyllite-and-grit mélange have been described on pp. 65–6, for a sketch of it was necessary to a petrological sketch of those sediments, which are hardly known in any other state, as well as to one of the Gwna Green-schist. Here we are concerned with the structure as such, and therefore only with the Autoclastic General Mélange, which includes all the members of the group. It is developed on a great scale in all the Regions except Holy Isle. In the eastern Middle Region, for example, nothing else is to be seen along 11 miles of strike, and in the eastern Aethwy Region it occupies 20 square miles of country. In a country of this kind, the larger masses are found to be arranged as trains of lenticles overlapping *en échelon.* (See the diagram, (Figure 69), as well as (Figure 1), (Figure 5), (Figure 165), (Figure 166), (Figure 169), (Figure 188) (Plate 7), (Plate 22), and the parts of the one-inch map about Pentraeth, Llaniestyn, and elsewhere.) The major axes of the lenticular cores are slightly curved, the form of the line being highly characteristic,—a sigmoidal curve approximating to a straight line. Upon a map, the masses that can be separated out appear as if embedded in a homogeneous and structureless matrix. But this country-rock is itself built up of interdigitating lenticular bodies; and, could we take in the whole region at a glance, it would present itself to us as a mélange of torn and sheared lenticular masses of all sizes, from such as are two or three miles in length to the smallest that the eye can see, of spilitic lava, diabase, quartzite, limestone, jasper, and grit, floating in an undifferentiated but schistose body that is a weft of all the more easily deformable elements, itself pervaded throughout by the same lenticular structure.

The minimum or tessary folding

As is the major to the maximum, the minor to the major, so is the minimum related to the minor folding, upon which it is in like manner superimposed. It is perceptible only in the lepidoblastic fissile seams, and appears in the field as a very fine rippling on the brilliant foliation-surfaces. Perhaps it is most highly developed where a lepidoblastic seam, underlying a strong hard band, is packed up to many times its original thickness into the core of an anticline. Like the minor folding to which it is ancillary, it may be symmetrical, isoclinal, a-clinal, or polyclinal, and also pitches with the minor folds. Thrusting may develop on it, especially in connexion with packing, and usually fails to disturb the curve of the minor anticline as developed in the overlying hard band. Thrusting of this kind, when rapidly repeated, is identical with strain-slip-cleavage (Figure 70). Minimum structures may be recognised even in autoclastic mélange, in the form of a fine augen-structure, usually to be found in the schistose matrix. But the minimum folding can be effectively studied only under the microscope (E9828) [SH 540 770], (E10142) [SH 227 796]–(E10143) [SH 214 796], (E10149) [SH 232 819]. (E10158) [SH 215 815], and (Plate 21), Fig. 1–3 and needs much further study, especially in relation to the crystallisation. In some cases, a curve appears to be accomplished by apposition of mica-plates that are still straight and extinguish separately. But in others no separate extinction has been detected, the shadow sweeping round the curve as the nicols are rotated, so that the mica-crystals appear to be really curved. Yet they show no sign of optical strain, for in the straight limb just outside the anticline, while in optical continuity with the crystals of the curve, their extinction is perfectly normal and parallel. In very finely lepidoblastic seams the amplitude of the folds may be extremely small, needing a one-fifth-inch objective to be made clearly visible. Tn one such rock from the South Stack Series on the lower limb of the Rhoscolyn Recumbent Fold (Plate 21), Fig. 3, (E10158) [SH 215 815], therearefolds that are distinctly recognisable as folds, whose width is barely measureable on the millimetre scale of the stage, and can hardly exceed 0.01 millimetre.

Structures of the second and third generations

The Valley thrust-planes and the foliation of the Western Region

The foregoing structures, though classified for convenience sake as from primary to tessary, are all (as has been indicated already) directly related to one another, are all products of one and the same system of dynamic impulse, and the classification may have no chronological significance. There are, however, structures that are the products of an independent impulse or even impulses, and these can be shown to be superimposed upon the original series. The beautiful isoclines of Holy Isle begin to fall off in regularity near Feurhos, and when we cross to the Main Island, the southeastward impulse is clearly less intense. It will be remembered that we are passing to a higher tectonic horizon. Let us follow the section on the foreshore along the Alaw from Valley Foundry to Gored (Figure 71). At first, the folding is still truly isoclinal, but the axes are persistently steeper, and the short limbs nearly vertical. Soon some of the axes become vertical, and south-easterly dips appear. The south-eastern limbs of the anticlines then become pinched in places, and small thrusts of about a quarter of an inch develop, with overdrives to the north-west. These increase in both number and intensity, until, at Gored, the banding of the Soldier's Point beds is powerfully overdriven by and violently contorted between them, while the foliation of the lepidoblastic seams is drawn out so as to be nearly parallel to them. The old isoclines have now disappeared, and the south-eastward impulse has been completely overpowered by the new north-westward one. Moreover, the now prevalent south-easterly dip is that of a new foliation, for venous quartz seams which appear along it become granoblastically reconstructed as do the older ones of Holy Isle. The same northwestward thrusting is seen, still better, on a range of crags about two miles to the south-east, which overlook the railway nearly opposite the Church by the Ford, where special dip-arrows indicate the structures. Between the thrust-planes, which may be called 'the Valley Thrust-planes', the old banding of the Soldier's Point beds is cut into short lengths and sheared into sigmoids (Figure 72), and as these dip to the north-west in most cases, they are to be regarded as parts of the old isoclines that still retain the original inclination. But they soon become violently contorted and over-folded from the south-east (Figure 73). Sills of venous quartz are introduced along the new planes, and all but the thicker ones become reconstructed granoblastically (like the older quartz of Holy Isle) and some of them even foliated. The new structure is therefore more than a thrusting, or even a strain-slip; it is a new foliation. The thrust-planes then lose their steady dip, and undulate in gentle curves (Figure 74). These grow sharper, and presently they are thrown into powerful folds ((Figure 75), *a*), round which they carry with them the already twice-folded banding (shown in the figure) of the New Harbour Beds. But the process has been carried yet a step further. Some of the folds into which the Valley thrust-planes are thrown become overdriven into true isoclines, and these now develop strain-zones of their own ((Figure 75), *h*) which can be seen in the act of tearing-out. True thrust-planes then appear, which thrust the Valley thrust-planes themselves, until at last we have sections ((Figure 75), *c*), in which folding is imposed upon folding, thrusting upon thrusting, and each upon the other. In such sections as (Figure 75), *c* it is possible to see, all in the space of a yard or two, no less than three generations of folding and two of thrusting. First, there are the remains of the old isoclines of Holy Isle, then the refolding of the old isoclines, then the Valley thrust-planes, then the folding of the — Valley thrust-planes, and finally the thrusting of those thrust-planes.

Now these remarkable phenomena are not merely local. For, when followed further, the Valley thrust-planes, appearing at closer and closer intervals, are found to be identical with the general foliation of the whole Western Region, as indicated in the diagram (Figure 76), which is therefore a later one than that of Holy Isle, and is the product of an impulse from the opposite direction. Survivals of the old one have been found in several places, and doubtless exist in many more. It is a surprising glimpse into the superimposition of structure upon structure that has taken place during regional metamorphism.

We must return to a consideration of the Autoclastic Mélange. Almost everywhere the dips of its divisional planes, though high and often vertical, are very steady. But in the Aethwy Region it is violently folded, the folding being in great measure polyclinal. And it is not merely the schistose matrix that has thus given way, but the resistant lenticular phacoidal cores. Lenticular masses of spilitic lava, of limestone, and even of obdurate siliceous grit, have been doubled sharply on themselves (Plate 23), (Figure 77), (Figure 78), (Figure 79). We have already seen (pp. 69, 124–5) that the Gwna Green-schist is but a more schistose and reconstructed condition of the Autoclastic Mélange, and that the adjacent parts of the Penmynydd Zone (though its further parts are acid volcanic matter) are identical with the Gwna Green-schist, being in a more advanced stage of the same process. Now the very same system of folding affects at once the Autoclastic Mélange, the Green-schist, and the Penmynydd schist; and the folding is not due to disturbance after crystallisation, for the most highly folded rocks of the Penmynydd Zone (E9828) [SH 540 770] are completely free from optical strain or other signs of catamorphism, and the western parts of the Autoclastic Mélange are considerably re-crystallised. There is no doubt that the whole group of phenomena is one, and that all of them, from the folding of the Autoclastic Mélange to the crystallisation of the Penmynydd. Zone, are stages of one and the same anamorphic process. We obtain a glimpse of a pause in this process. For the small augen of albite-pegmatite in the hornblende-schist are occasionally, though very rarely, a little foliated, showing that they segregated after the principal foliation had been produced, but before it was quite completed. Now it is certain that at the time when the Gwna rocks were broken-down into an autoclast, they must have been in Van Elise's crustal zone of fracture. And it is equally certain that, at the time when the Autoclastic Mélange so produced was intimately folded, its obdurate grit-phacoids doubled on themselves, its matrix converted into fine chloritic mica-schist, and the spilites and albite-diabases converted into aetinolitic epidote-chlorite-schists with, fresh ternary albite, it could not have been in the zone of fracture, it was in the zone of flowage. By some means, therefore, the mélange and all its associates must have been brought into a lower zone of the earth-crust than that upon which they lay at first. By what means could this have been accomplished? Cover by deposition of a great load of sediment is evidently excluded, for not only is there no sign of any such unconformable mass, but the period was not one of subsidence and accumulation, but of mountain-building and erosion. Suppose, however, another maximum recumbent fold to have been initiated, and another *nappe de récouvrement* to have rolled over above these rocks, then they would receive heavy cover, would be lowered in tectonic horizon, and be transferred from the zone of fracture to the zone of flowage. We have seen reason to suppose that they are all upon the Nappe of Bodorgan, and on an horizon so high it was difficult to understand how the Pemnynvdd metamorphism could he produced. On the tectonic horizon where that fold originally lay, such metamorphism would not have been possible. It wouhf he possible by the process now suggested, and in the folding of the Aethwy mélange we have independent evidence that such a process actually took place.<ref>That the rocks on the Ithoscolyn Fold escaped, under these circumstances, from still higher metamorphism than that whirls they had already undergone, is probably due to that fold having by this time become incapable of any more movement. The Coedana granite was also absent there. The same explanation may apply to the less altered parts of the Nappe of Holyhead. The condition of the latter must be admitted, however, to be a difficulty—the only serious one that seems to remain in the way of this interpretation of the Complex. But see footnote to page 227.</ref> That folding, and with it the Pemnynydd metamorphism, are therefore to be regarded as later than any of the structures hitherto described.

Later structures

Transverse folds — The foregoing folds are all determinants of the dominant strike, hut on many tectonic horizons, especially in the Aethwy Region, they are crossed abruptly by still later folds.

These are usually sharp and sudden, but instead of pervading the whole rock, occur only at intervals of a yard or two (Figure 80). The movement is nearly always in the horizontal dimension, so that they appear in ground plan as cross-wrenches at angles of about 65° to the strike. The transverse folds impart a peculiar waviness to the general strike, and where combined with polyclinal folding, a confused "gnarling" to the whole system. They often pass into thrusts, along which there is a little deformation, and sometimes a slight development of nemablastic foliation in quartz that is traversed by them.

Final catamorphic movements — Even the latest of the many movements that have been described are in some degree anamorphic. But the Mona Complex is traversed by countless lines of crush along which no re-crystallisation has taken place. Large numbers of these are doubtless Post-Ordovician, and all might have been considered so, but for one piece of interesting and decisive evidence. The Gneisses, and also the Coedana granite, are cut by seams of pale-green mylonite (E9944) [SH 350 752] that resemble in every particular the mylonite of a North-West Highland thrust-plane, though the displacements are small and the seams not often more than one millimetre thick. They are better developed in these granitoid rocks, on account of the abundant felspars, but are to be seen in many others. Now large boulders of gneiss and granite are plentiful in the Ordovician conglomerates at the base of the zone of *Didymograptus extesus,* and some of them contain the seams of mylonite. But when traced outwards, these seams are found to end off sharply at the surface of the boulder, and not to pass out into the conglomerate. (Figure 102) *e* (p. 244) shows a four-foot boulder of basic gneiss with gneiss-granite sheared against it, but the shear-plane (though producing an ancient weathering-bay) does not pass outside the boulder. The conglomerate is cleaved, but the old shear-line lies at about 70° to the strike of the cleavage. These inylonites are therefore Pre-Ordovician, and are to be regarded as produced by the last movements of the Mona Complex. They have not been observed on the lowest tectonic horizons, and are first known on the Nappe of Holyhead.

Folial relations

Relations to bedding, folding, and thrusting

The relations of the foliation to bedding, folding, and thrusting are important. Most of the rocks are mono-planie, one structure only being visible at one time. In the New Harbour Beds at Holyhead, for example, the foliation seldom transgresses the banding, but will follow it round and round the most rapid folding, and that without showing the least trace of catamorphism. The crystalline dynamics of such a process are but imperfectly understood. There are, however, some notable bi-planic rocks, where a folded bedding is traversed by a steadily clipping foliation. Chief of these are the South Stack Series and the Holyhead Quartzite, but the Amlwch Beds have the same structure about Amlwch Port and Point Lynas. The South Stack Series afford by far the finest examples, and it can be studied in them to great advantage, both in relation- to major, minor, and minimum folding, to coarse beds and fine, and to varying states of crystallisation, especially at the great South Stack section.

The law seems to be that, in the coarse and massive beds, the foliation is parallel to the axial dip of major folds. Thus, at the South Stack, and throughout the Quartzite of Holyhead Mountain, where the major folds are at a high angle and some of them symmetrical about vertical axes, the foliation is vertical or nearly so (Plate 1), (Plate 16). There is, however, a slight fan-shaped arrangement with divergence upwards. both in very massive beds on maior folds and in the Quartzite considered as a whole. As the axial dip of the major folds lowers and they become isoclinal, the foliation-dip lowers with them (Plate 18). On the Llwyn-y-berth promontory, where the land is too low to show the whole sweep of the major folds, its dip is much lower than that of the long limbs; and may not be straight, but within each bed be disposed in sigmoidal curves (Figure 81), (Figure 82), a new series of sigmoids developing in each of such beds. But there are some long limbs to which it is nearly parallel (Figure 83). On the larger minor folds it also shows a tendency to fan-like divergence (Figure 84) at the apex of the fold. In the grits, therefore, it behaves very much like an ordinary cleavage, night indeed be called a cleavage-foliation; and as the great mass of the deposit is grit, this foliation determines the conspicuous features of the crags, especially In the Quartzite, over most of which no other structure is perceptible. But in the lepidoblastic bands we meet with a complete exception. Instead of passing directly through them (with perhaps a slight deflection) as does an ordinary cleavage through bands of shale, this structure stops at their margins (Plate 1), Frontispiece, and (Figure 37), begins again as usual in the next grit. and leaves them, to all appearance, completely unaffected. Their foliation, which is very fine, scents to be their own, and is violently folded in sharp isoclines, in which there is no sign whatever of the vertical foliation of the grits. The break, however, is not always complete. On the South Stack (Plate 24), the cleavage-foliation passes out into minute thrusts and slides that rupture the sharp corrugations of the fissile partings. Sometimes, again, as it approaches the lepidoblastic seam, the steep straight foliation of a grit will begin to bend, then to fold, sometimes quite sharply, until its ends appear, at the junction, to be in continuity with the contorted foliation of the fissile seam. (Figure 85), (Figure 86). This may possibly mean that the lepidoblastic foliation has been folded by a south-easterly thrust of the upper massive beds along the planes of bedding. But that does not seem to account for the relation shown in (Figure 87). In other cases ((Figure 86), *e* it bends over at the junction, and a faint cross-foliation at low angles may be discerned within the fissile beds.

Independently of junctions, little bends and folds appear in the steep foliation-planes of the grits, these grow sharper, and pass into small thrusts which drive it southward, as may be seen on the outer end of the South Stack (Figure 88). It may even be violently folded (Figure 89), the sharp old folds of the bedding being visible as they are carried round the fold of the foliation There is but little thrusting along the foliation itself, but sometimes the ends of the sigmoids open a little admitting thin wedges of lepidoblastic matter, which are driven in between them. The same kind of horizontal wrenching as is described on p. 200 affects this foliation, as may be seen on the Holyhead Quartzite in many places. It is a little difficult to realise that there is any connexion between the vertical foliation of the enormous packed mass of the quartzite that forms Holyhead Mountain, and the low-dipping, rapidly folded foliation of adjacent rocks, but both are undoubtedly parts of the same folial system.

Foliation in other parts of the Complex — Folial relations in other members of the Complex are as follows. In the New Harbour Beds on Holy Isle it follows everywhere the folded bedding, save where it develops along the minute strain-slips in the lepidoblastic seams as they pack into the cores of anticlines, and along the multitudinous minor thrusts that are ancillary to the Tre-Arddur primary thrust-plane. In the New Harbour Beds of the Western Region its development is, as shown, along the Valley thrust-planes; and as these same planes are continued into the Church Bay Tuffs, and from them into the Gwna mélange, there seems (when once we have passed above the Valley tectonic zone) to be no folial break in the whole region. The same is the case at the Fydlyn Inlier, but at the Garn and Corwas Inliers bedding-foliation seems to reappear in places. In the Coeden and Amlwch Beds of the North, it follows folded bedding (save at the places mentioned on p. 202, and at some strain-slips) and then develops along the minor thrusts of the western portion, as it does along the shear-planes of the Gwna mélange below the Caerau thrust-plane. At the passage between the Amlwch Beds and Skerries Grits in Bull Bay a steep foliation can be detected crossing bedding that is at a lower angle. This steep foliation is the only structure to be seen in the massive tuffs of Trwyn Bychan, save the thrust-planes (themselves foliated) that throw it into sigmoidal curves. Such slight foliation as is to be seen in the Gwna rocks of Gynfor coincides with that of the Trwyn Bychan rocks. The massive grits of The Skerries have also a steep foliation cut by lower thrusts, which may be taken to be the same as that of Trwyn Bychan. In the Middle Region (excluding the Gneisses), foliation is only known to follow folded bedding in the Bodafon anticline, where the roll-over of the massive quartzite probably compelled it. Almost everywhere else it is at high angles or vertical, and as the vertical planes of the Gwna mélange are foliation, though of a low order, and there is no break; that of the rest of the rocks, including the Penmynydd Zone and even the hornfels, must be developed along one and the same system of shearing. When folding is to be seen, the folded planes are doubtless the same shearing, thus foreshadowing the conditions of the Aethwy Region. The Pentraeth Inliers repeat the conditions of the Middle Region. In Aethwy, as we have seen, the foliation-planes are without doubt old shear-planes of the same system as those of the Gwna mélange, now rapidly folded. At one or two places about Llangaffo, the folded foliation of the glaucophane-schist is crossed by a second foliation (Figure 90) (see also (Figure 177), p. 369), but this is rare. In the Llanddwyn Wedge, the low grade of foliation that exists is generally vertical, but with violent folding locally. Its relation to that of Aethwy proper is not known. The foliation of the sernentine-suite in Holy Isle, produced during the major folding, is generally parallel to the major thrust-planes. The old foliation of the Coedana granite is not related to any known suite of planes, but its later one belongs to the vertical system of the Middle Region. The foliation of the Gneisses in all the regions is undoubtedly determined by ancient planes of movement, but belonging, apparently, to a system of their own, though locally forced into rude parallelism with later ones.

The chart in (Figure 101) (p. 239) shows the varying strike and general arrangement of the foliation in the several regions of the Complex.

Chronology of the foliation

We have seen that the foliation of Holy Isle is older than that of the Western Region, to which belongs, among others, the foliation of the Western Gwna mélange. Now, although Gwna mélange may not be of the same date everywhere, yet that on the Nappe of Bodorgan cannot be older and may be later than that on the Nappe of Holyhead. So, as the foliation of the Aethwy Region generally is later than the production of the mélange of the Nappe of Bodorgan, it must be a later foliation than that of the Western Region. Foliations of at any rate three different dates can therefore be discriminated: that of Holy Isle, that of the Western Region (with the Northern and part of the Middle Region), and that of the Aethwy Region. These are foliations a the Bedded Succession. But that of the Ancient Floor (pp. 165–9) (of which the Gneisses, moreover, appear to be a part) is undoubtedly older than all of them. Records of four successive metamorphic periods are therefore preserved in the Mona Complex.

Note — See Note on page 242, and Appendix 9.

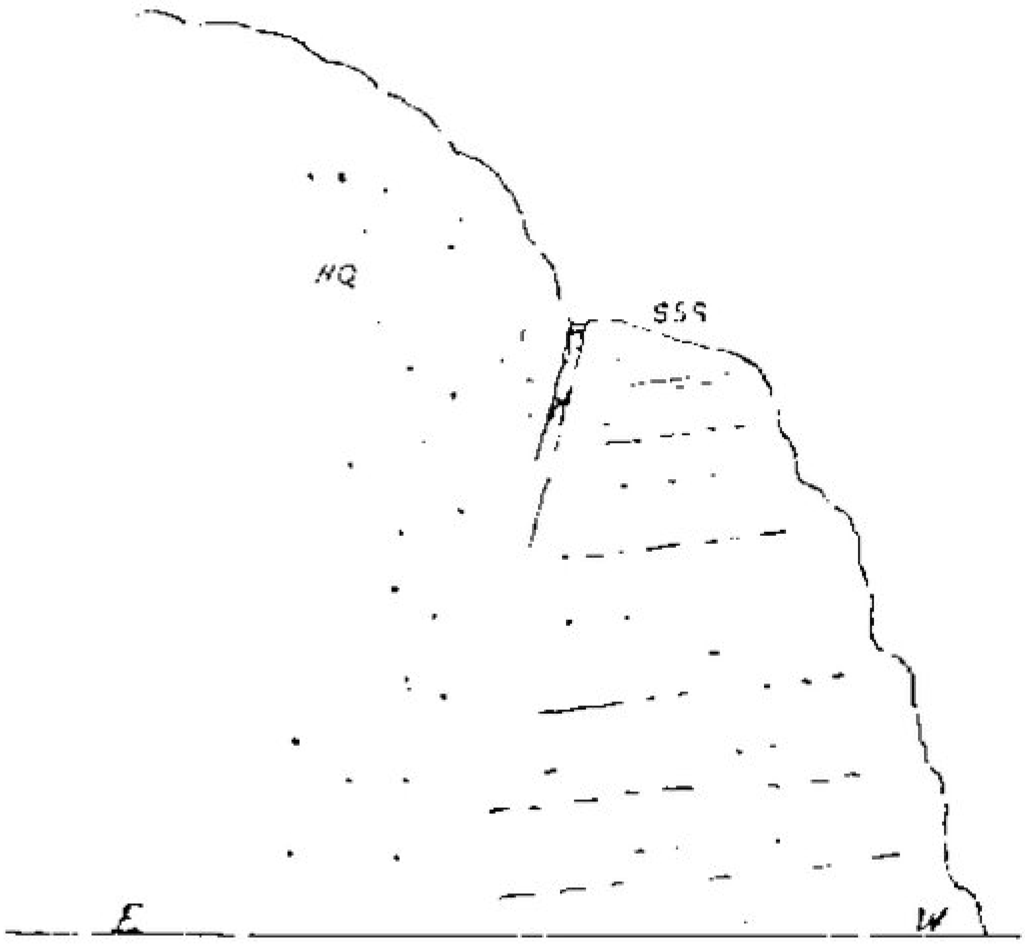


FIG. 33.

(Figure 33) The North Stack Fault, Seen from the Signal Station. Height, 400–500 feet. HQ = Holyhead Quartzite. SSS=South Stark Series.

(Plate 16) The North Stack and the sea-cliffs of the Holyhead Quartzite From the South Stack Moor. Height seen = 582 feet. ***Note****.—The feature determined by the North Stack fault runs on, from sea-cliff, up the mountain-side, below the sky-line.*

(Plate 17) The Namarch Fault. Porth Namarch.

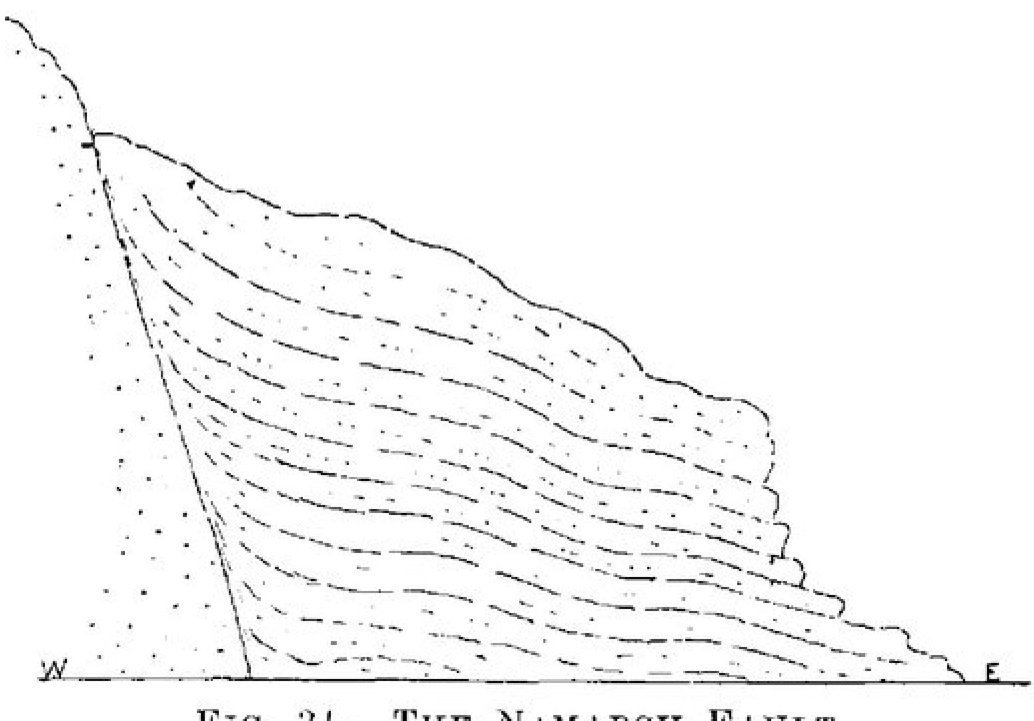


FIG. 31.—THE NAMARCH FAULT

(Figure 34) The Namarch Fault at Porth Namarch. Height about 50–60 feet. South Stack Series to the right: Quartaite to the left.

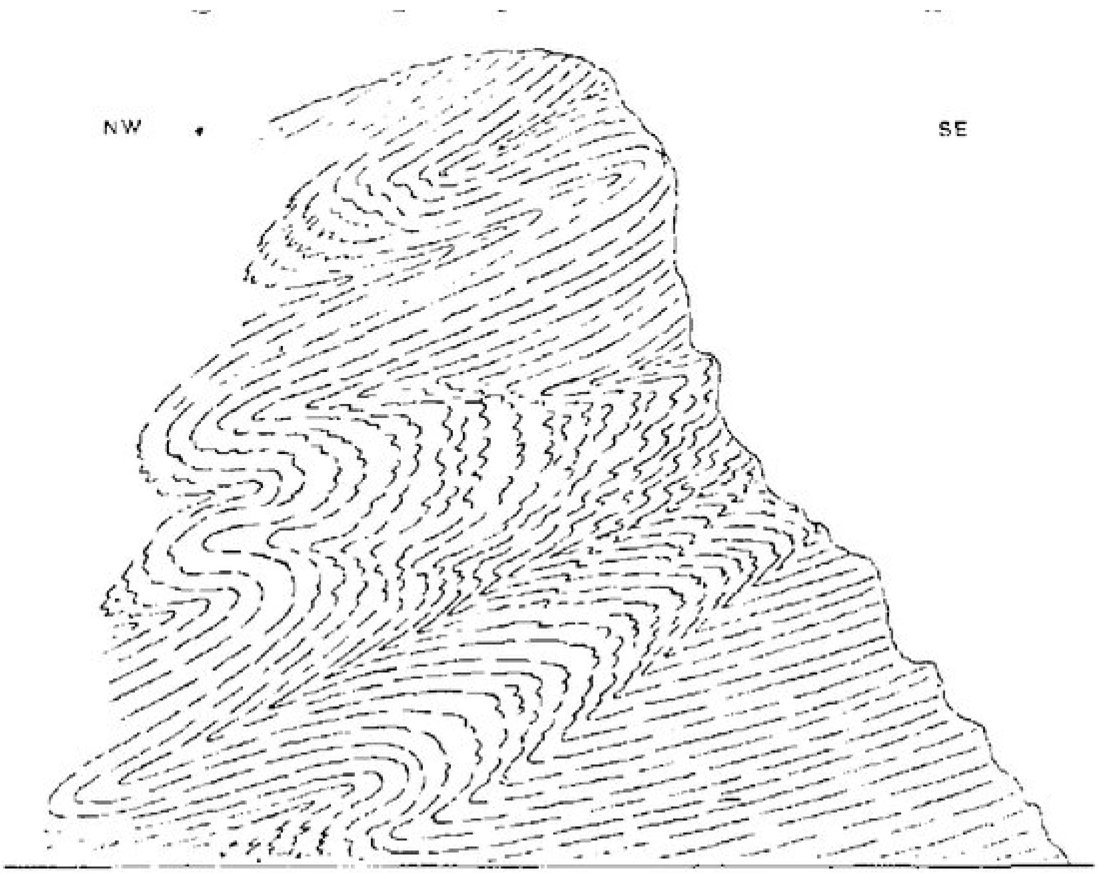


FIG. 47.—MINOR ISOCLINES IN C[illegible]
MYNYDD CELYN.

(Figure 47) Minor isoclines in Celyn Beds Mynydd Celyn. Height about one foot.

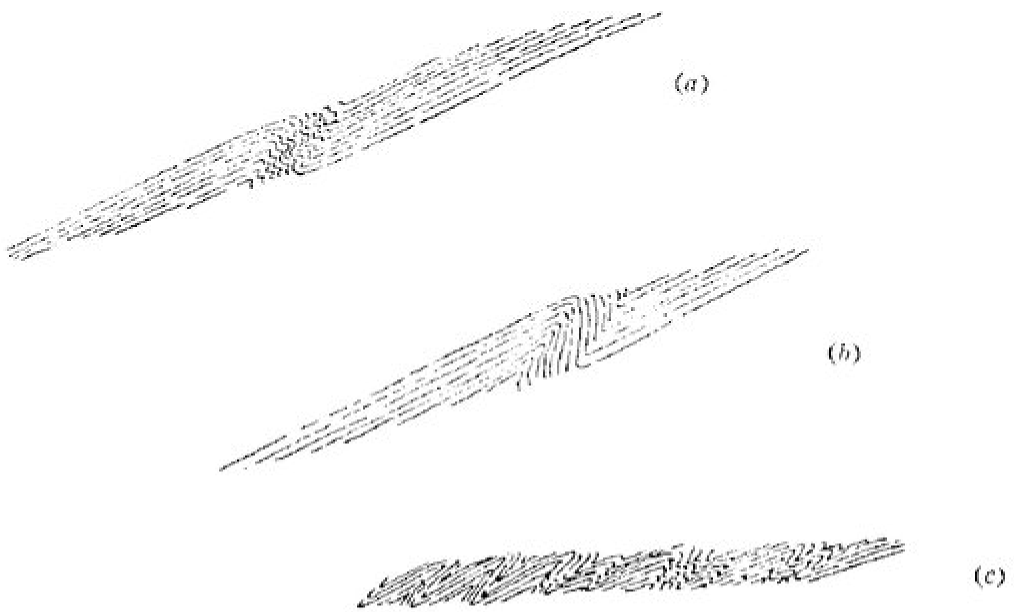


FIG. 52.—STRAIGHT-LIMBED ISOCLINES.

(Figure 52) Straight-limbed isoclines. Western Cliffs of Point Lynas. (a), (b) Limbs 30 to 40 feet in length. (c) Limbs three feet in length.

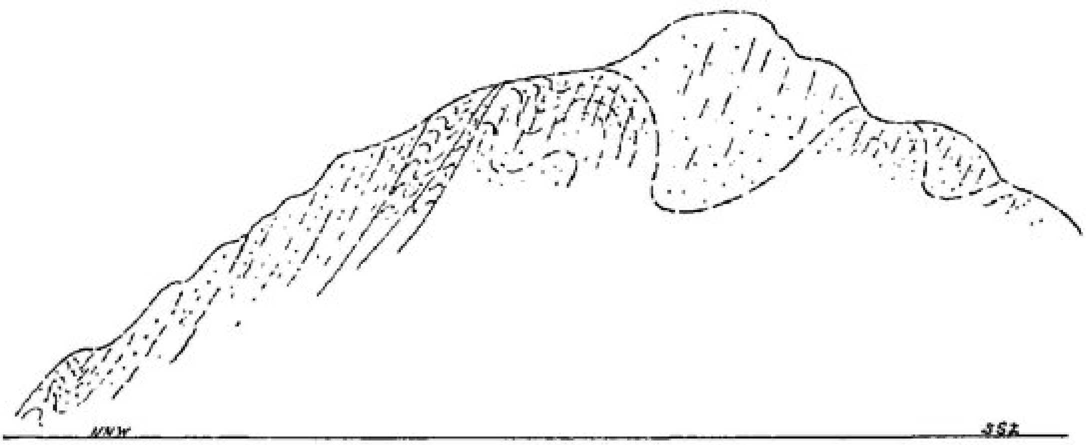
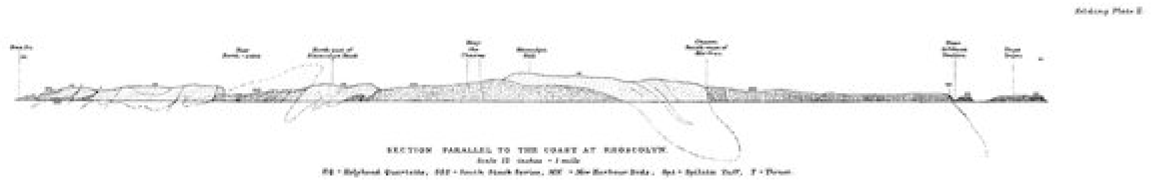
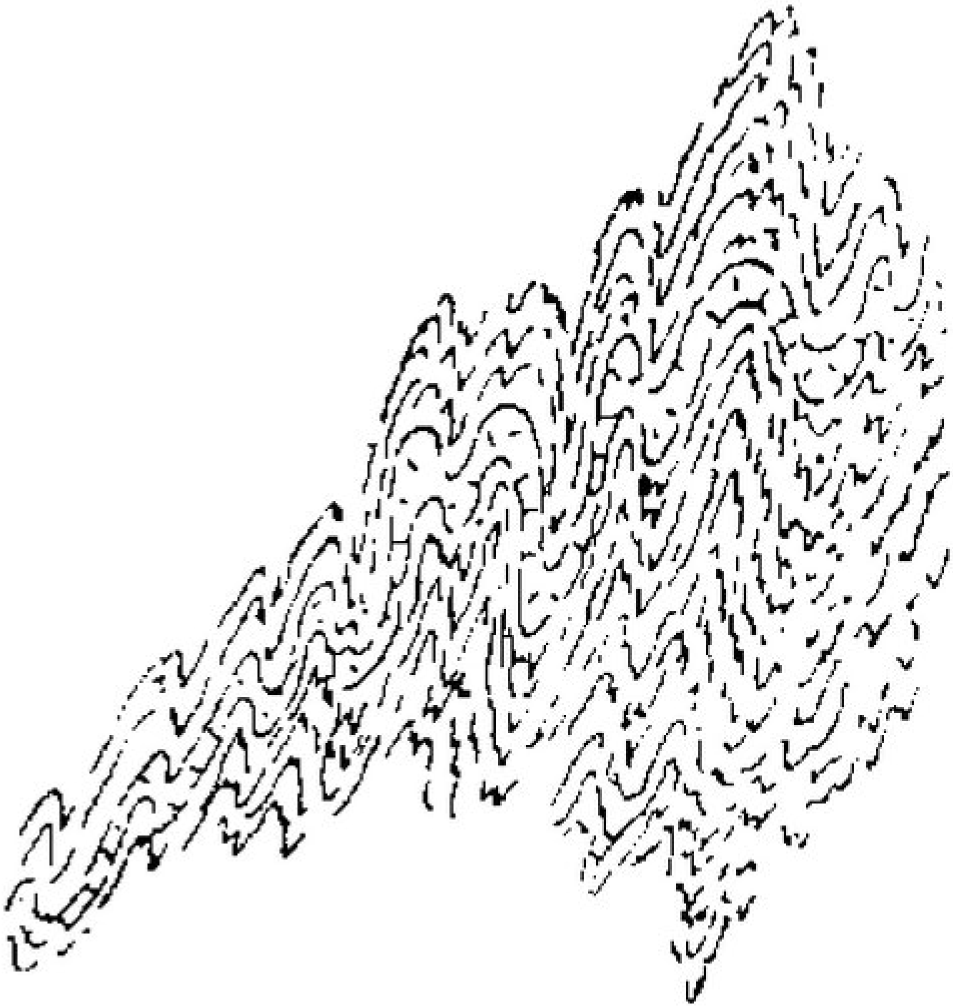


FIG. 28.—INFOLDED OUTLIER OF HOLYHEAD QUARTZITE ON THE SOUTH STACK MOOR.

(Figure 28) Infolded outlier of Holyhead Quartzite on the South Stack Moor. At the 500 foot contour. Height of section, 60 feet.



(Folding-Plate 2) Section parallel to the coast at Rhoscolyn. Scale 12 inches = 1 mile. HQ = Holyhead Quartzite, SSS A South, Stack Series, MN = New Harbour Beds , Sp.t Spilitic Tuff, T Thrust.



(Figure 43) Minor folding on vertical axes in tile Middle Region. Gwna Green-schist, 500 yards south-east by south from Pen-y-graig, of 600 yards north by east from Bryn-yr-odyn.

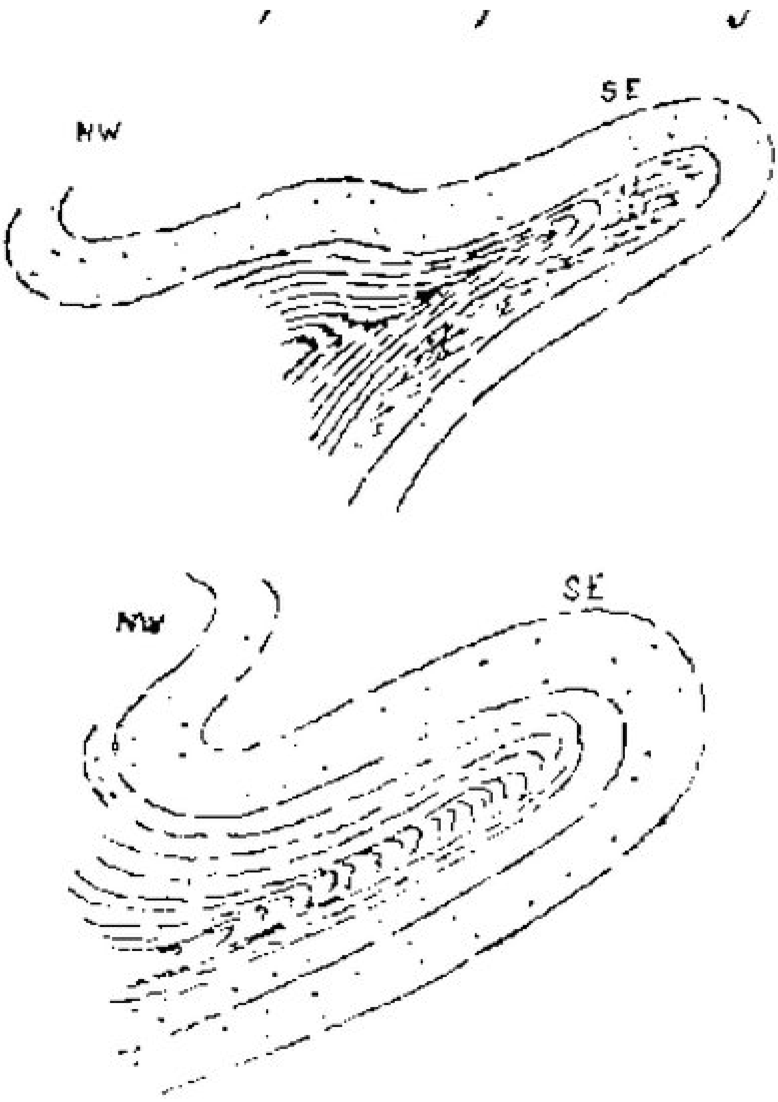
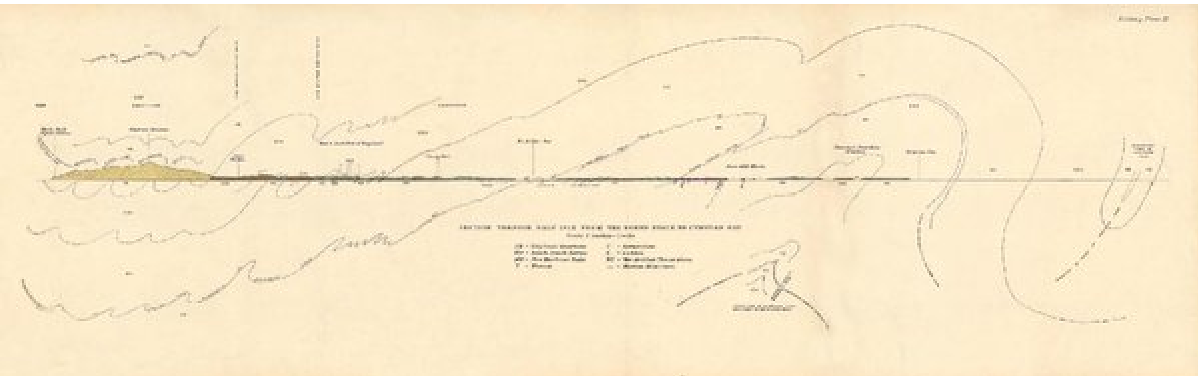


FIG. 44.

(Figure 44) Minor isoclines in Soldier's Point Beds, Tipper Road Cutting, Government House. Three and four inches in amplitude.



(Folding-Plate 3) Section through Holy Isle from the North Stack to Cymyran Bay. Scale 3 inches = 1 mile HQ = Holyhead Quartzite. SSS A South, Stack Series, MN = New Harbour Beds T = Thrust. U Serpentine. E Gabbro, TrT Tre-Arddur Thrust-plane [symbol Marine Alluvium.]

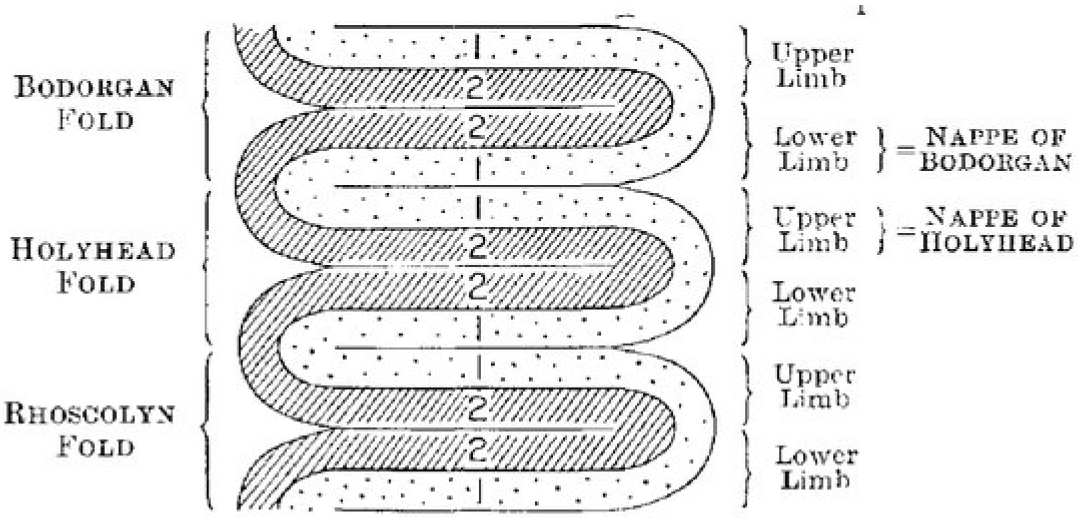
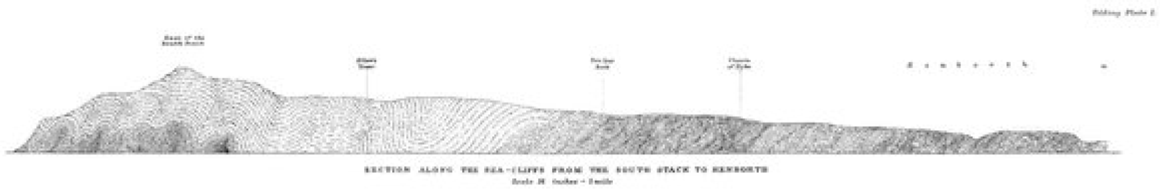
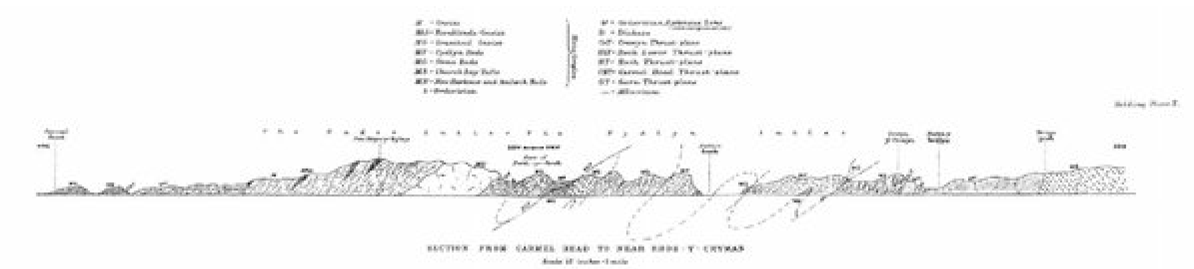


FIG. 35.

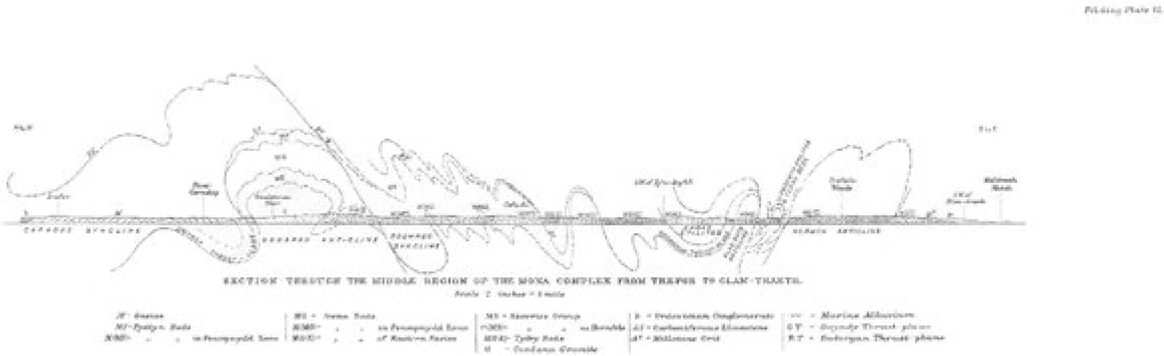
(Figure 35) Diagram of the recumbent folds of the Mona Complex.All thrusts omitted.



(Folding-Plate 1) Section along the sea-cliffs from the South Stack to Henborth. Scale 16 inches = 1 mile



(Folding-Plate 10) Section from Carmel Head to near Rhos-y-Cryman. Scale 12 inches = 1 mile.



(Folding-Plate 6) Section through the middle region of the Mona Complex from Trefor to Glan-traeth. Scale 2 inches = 1 mile

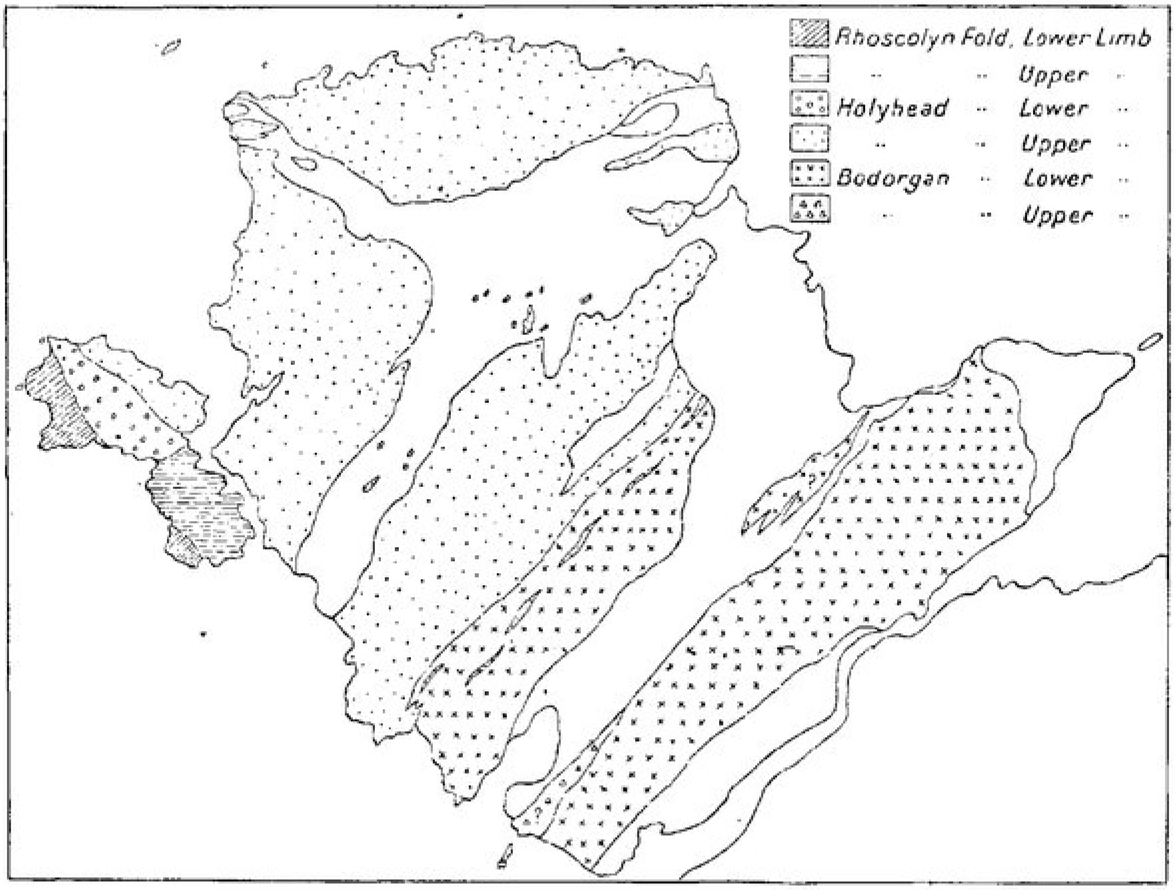


FIG. 100.—CHART SHOWING THE DISTRIBUTION OF THE TECTONIC HORIZONS OF THE MONA COMPLEX.
Scale: 1 inch = 6 miles.

(Figure 100) Chart showing the distribution of the tectonic horizons of the Mona Complex. Scale: 1 inch = 6 miles.

(Plate 1) The Folding of the Mona Complex, as viewed from the South Stack, Holyhead. Height seen: 445 feet. Frontispiece to Vol 1..

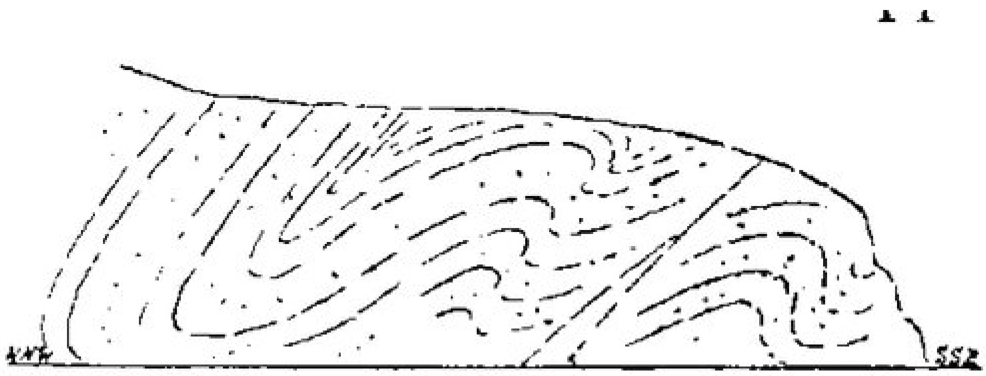
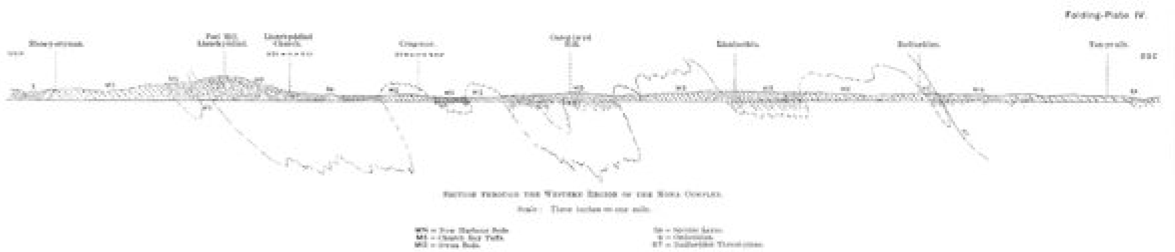
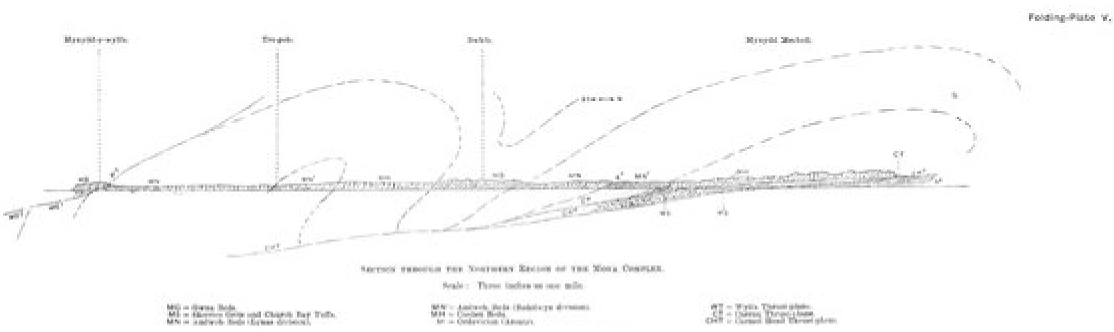


FIG. 36.

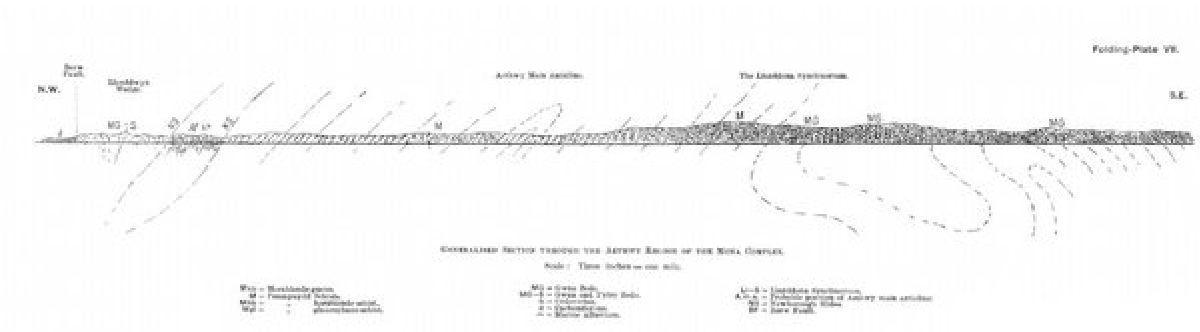
(Figure 36) Major isoclines in Llwyn Beds In the chasm of the dyke. North cliffs of Henborth. Height, about 200 feet.



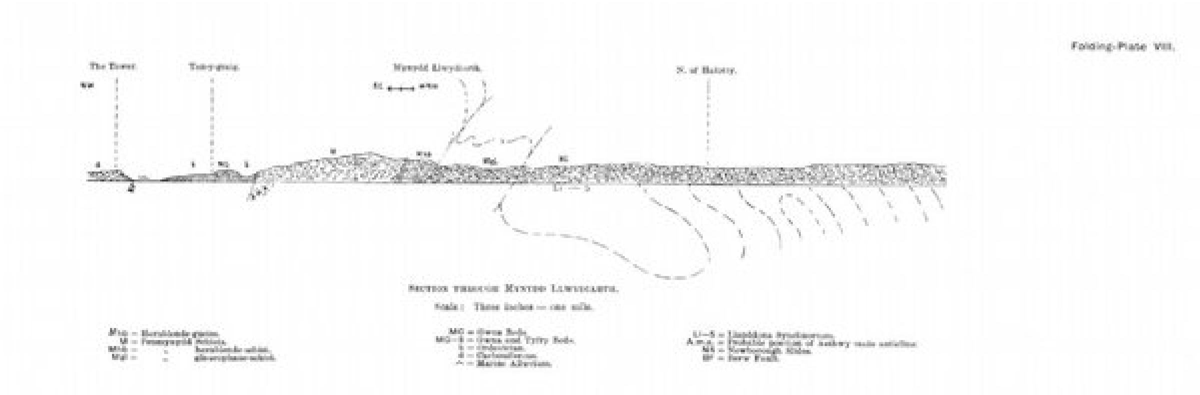
(Folding-Plate 4) Section through the western region of the Mona Complex. Scale: three inches = one mile. MN = New Harbour Beds. SP = Spilitic Lavas. MS = Church Bay Tuffs. B = Ordovician. MG = Gwna Beds. BT = Bodfardden Thrust-Plane.



(Folding-Plate 5) Section through the Northern Region of the Mona Complex. Scale: Three Inches = One Mile. MG = Gwna Beds. MN= Amlwch Beds (Bodelwyn Division). WT = Wylfa Thrust-Plane. MS = Skerries Grits and Church Bay Tuffs. MH = Coeden Beds. CT= Caerau Thrust-Plane. MN = Amlwch Beds (Lynas Division). BC = Ordovician (Arenie). CHT = Carmel Head Thrust-Plane.



(Folding-Plate 7) Generalized section through the Aethwy Region of the Mona Complex. Scale: Three inches = one mile



(Folding-Plate 8) Section through Mynydd Llwydiarth. Scale 3 inches = 1 mile.

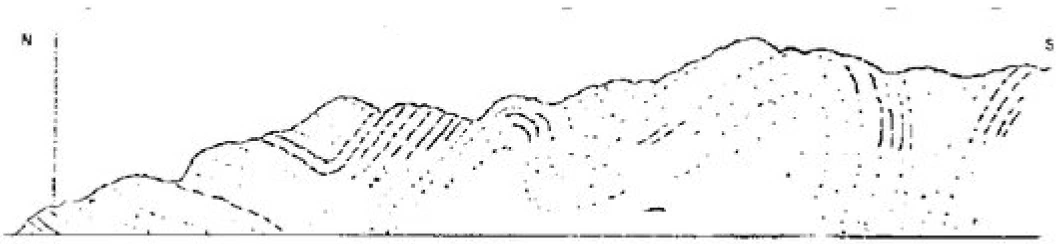


FIG. 91.—MAJOR FOLDS OF THE QUARTZITE ON THE GREAT SEA CLIFFS.

(Figure 91) Major folds of the quartzite on the great sea cliffs. Bedding obscure where lines are dotted. Height, about 500 feet.

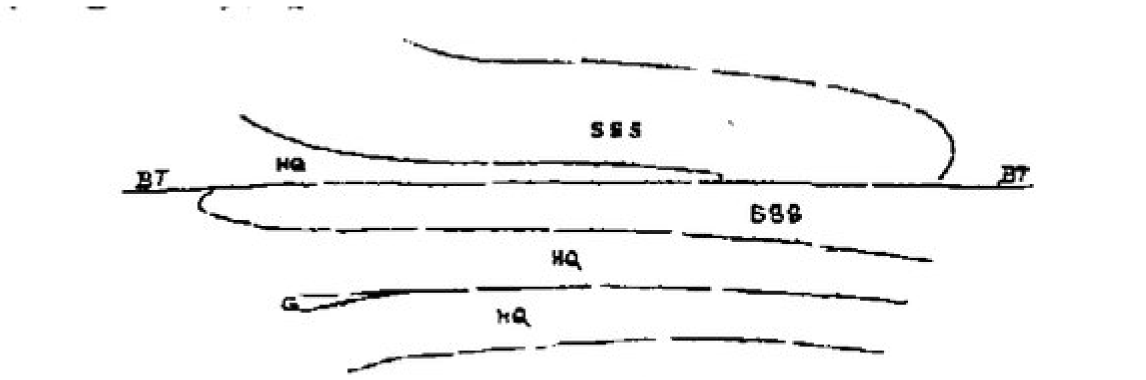


FIG. 92.

DIAGRAM OF RECUMBENT BREAKWATER FOLD.

(Figure 92) Diagram Breakwater Fold. HQ=Holyhead Quartzite. SSS=South Stack Series. BT=Breakwater Thrust-plane. G=Direction of gape of Holyhead Fold.

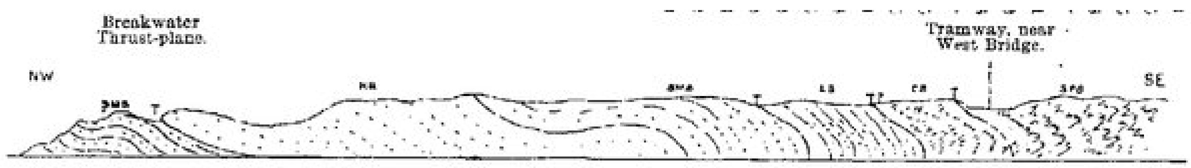


FIG. 93.—SECTION ACROSS THE BREAKWATER TRACT.

(Figure 93) Section across the Breakwater Tract. About three-eighths of a mile east of Porth Namarch. Scale 24 inches = one mile. HQ = Holyhead Quartzite. SMB = Stack Moor Beds. LB = Llwyn beds. CB = Celyn beds. SPB = Soldier's Point Beds. TT = Thrust

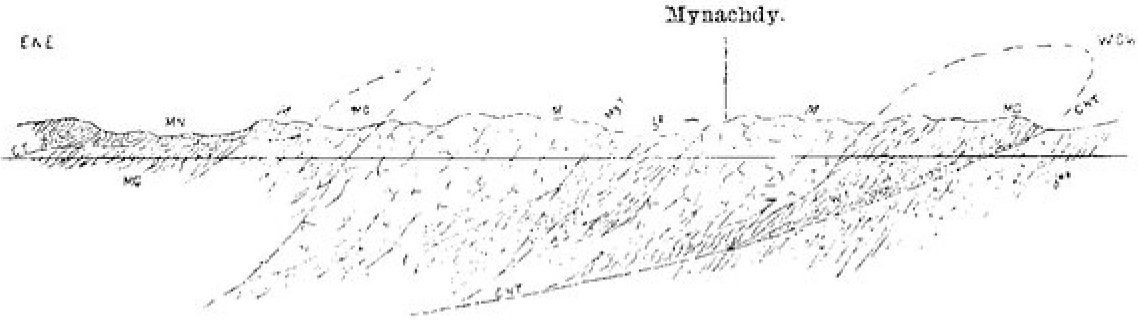


FIG. 94. SECTION AT MYNACHDY.

(Figure 94) Section at Mynachdy. Scale: Nine inches = one mile. MN = Amlwch Beds. MG = Gwna Beds. M = Gneiss. beb = Lower Ordovician Beds. be = Glenkiln Beds. CT = Caerau Thrust-plane. MyT Mynachdy Thrust-plane. WT = Wig Thrust-plane. CHT = Carmel Head Thrust-plane.

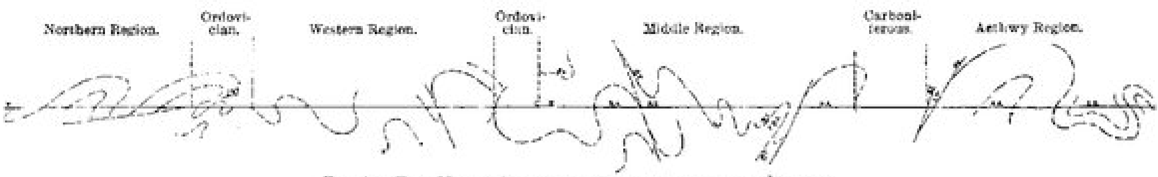


FIG. 99.—THE MAJOR SECONDARY FOLDS ON THE MAIN ISLAND.

(Figure 99) The major secondary folds on the main island. XX = Top of New Harbour Beds. CHT = Carmel Head Thrust-plane. CS = Caradog Syncline. BA = Bodafon Anticline. BS = Bodwrog Syncline. BT = Bodorgan Thrust-plane, BA = Plâs-bach Anticline. HA = Hermon Anticline. BF = Berw Fault. LW = Llanddwyn Wedge. NS = Newborough Slide. AA = Aethwy Anticline. LS = Llanddona Synclinorium.

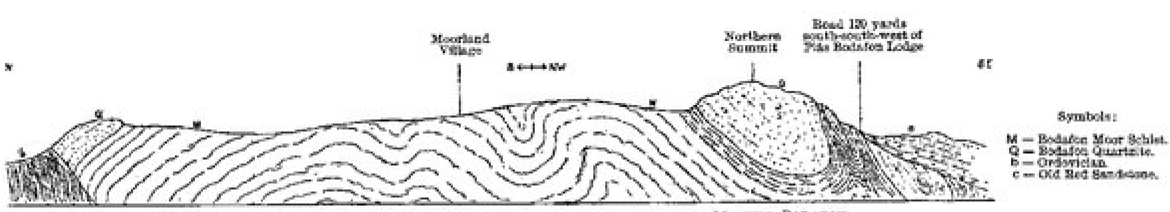


FIG. 156.—SECTION ACROSS BODAFON MOOR AND THE NORTHERN SUMMIT OF MYNYDD BODAFON.

(Figure 156) Section across Bodafon Moor and the northern .summit of Mynydd Bodafon. Scale: Eight inches = one mile. Symbols: M = Bodafon Moor Schist. Q = Bodafon Quartzite. b= Ordovician Shale. c = Old Red Sandstone.

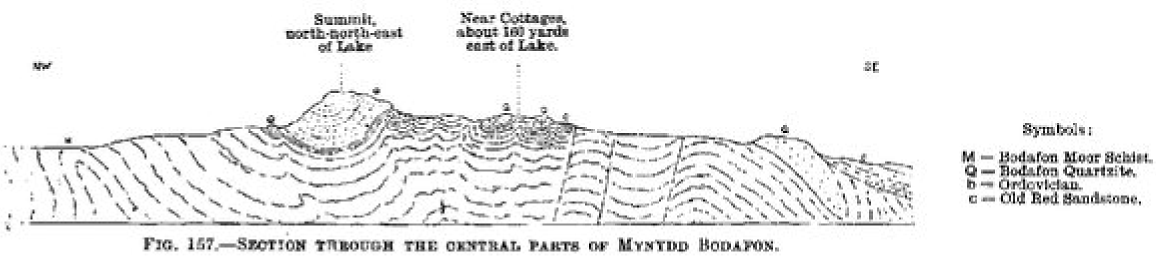


FIG. 157.—SECTION THROUGH THE CENTRAL PARTS OF MYNYDD BODAFON.

(Figure 157) Section through the central parts of Mynydd Bodafon. Scale: Eight inches = one mile. Symbols: M = Bodafon Moor Schist. Q = Bodafon Quartzite. b= Ordovician Shale. c = Old Red Sandstone.

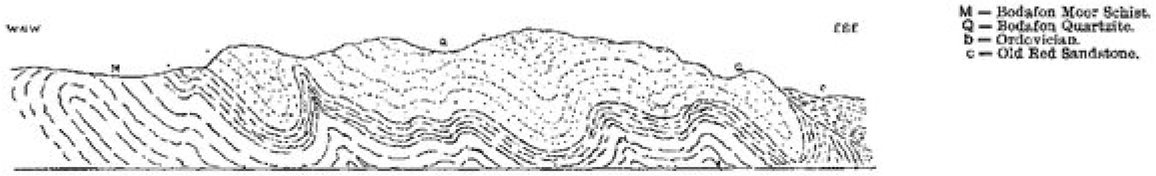


FIG. 158.—SECTION THROUGH THE SOUTHERN PARTS OF MYNYDD BODAFON.

(Figure 158).-Section through the southern parts of Mynydd Bodafon. Scale: Eight inches = one mile. Symbols: M = Bodafon Moor Schist. Q = Bodafon Quartzite. b= Ordovician Shale. c = Old Red Sandstone.

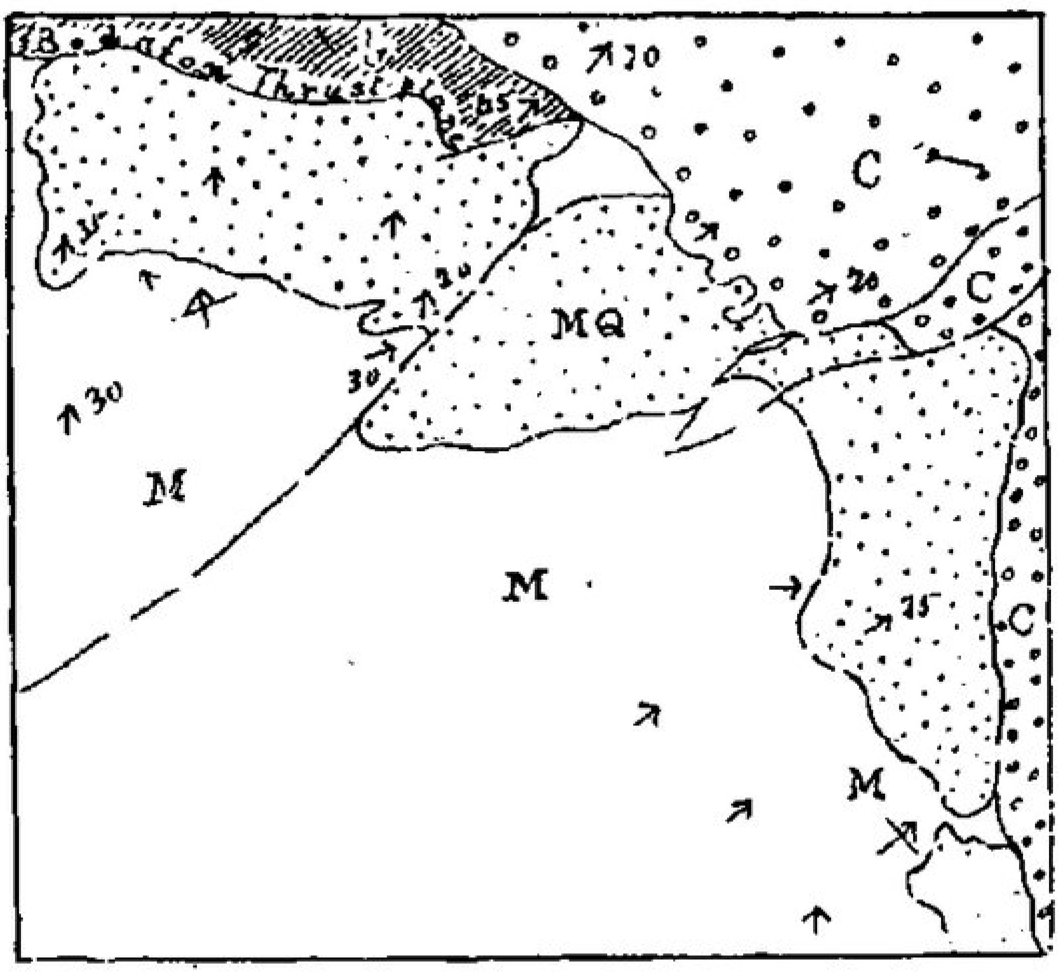


FIG. 154.

NORTHERN PARTS OF BODAFON MOOR.

(Figure 154) Northern parts of Bodafon Moor. From the six-inch maps. M = Bodafon Moor Schist. MQ = Bodafon Quartzite. b= Ordovician Shale. c = Old Red Sandstone.

FIG. 95.—THE THRUST-PLANES AT TRWYN BYCHAN.

(Figure 95) The thrust-planes at Trwyn Bychan. Sketched from a boat. Cliffs about 100 feet in height. MS = Church Bay Tuffs. MG = Gwna Melange. b = Nemagraptus Shales.

FIG. 37.

(Figure 37) Folds of the Llwyn Beds At one-eighth of a mile west of Porth Dafarch. Height, 80 feet.

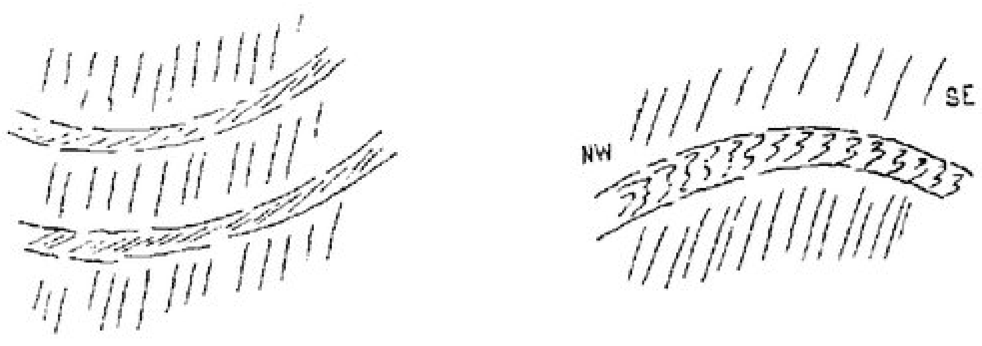


FIG. 38.—FOLIATION IN MASSIVE AND FISSILE BEDS.

(Figure 38) Foliation in massive and fissile beds. Cliff opposite the South Stack.

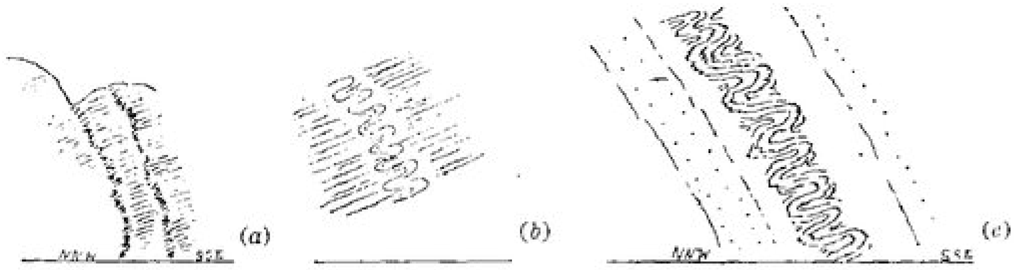


FIG. 39.—MINOR ISOCLINES WITH OVERDRIVE OPPOSITE TO THAT OF MAJOR FOLD. RHOSCOLYN MOUNTAIN (208-foot hill).

(Figure 39) Minor isoclines with overdrive opposite to that of major fold. Rhoscolyn Mountain (208-foot hill) (a) height of cliff, about 100 feet, junction of quartzite and south stack series. (b) detail, enlarged. (c) similar structures at the fissile seam in the quartzite.

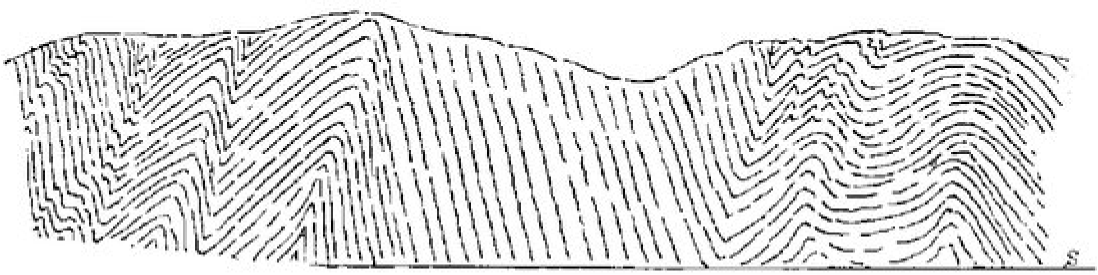


FIG. 40.—FOLDING IN AMLWCH BEDS.

(Figure 40) Folding in Amlwch Beds. Moor, top of Ednyfed Hill, Amlwch Port. Height, two feet. Isoclines becoming locally symmetrical.

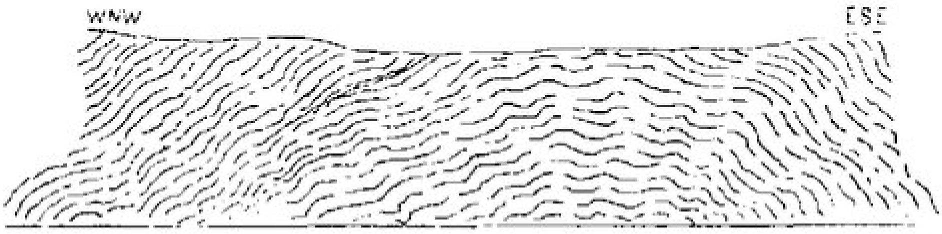
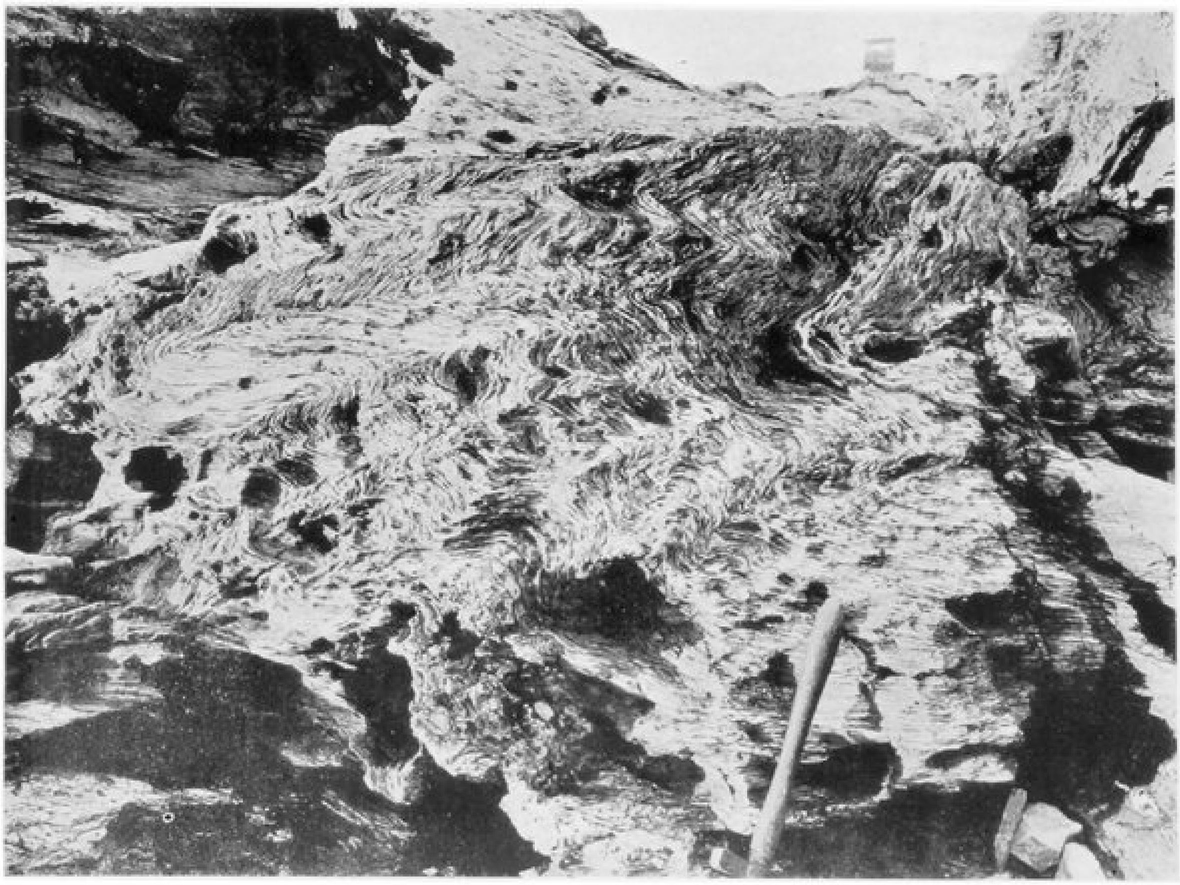


FIG. 41.—SECTION BETWEEN TUNNELS, BODORGAN.

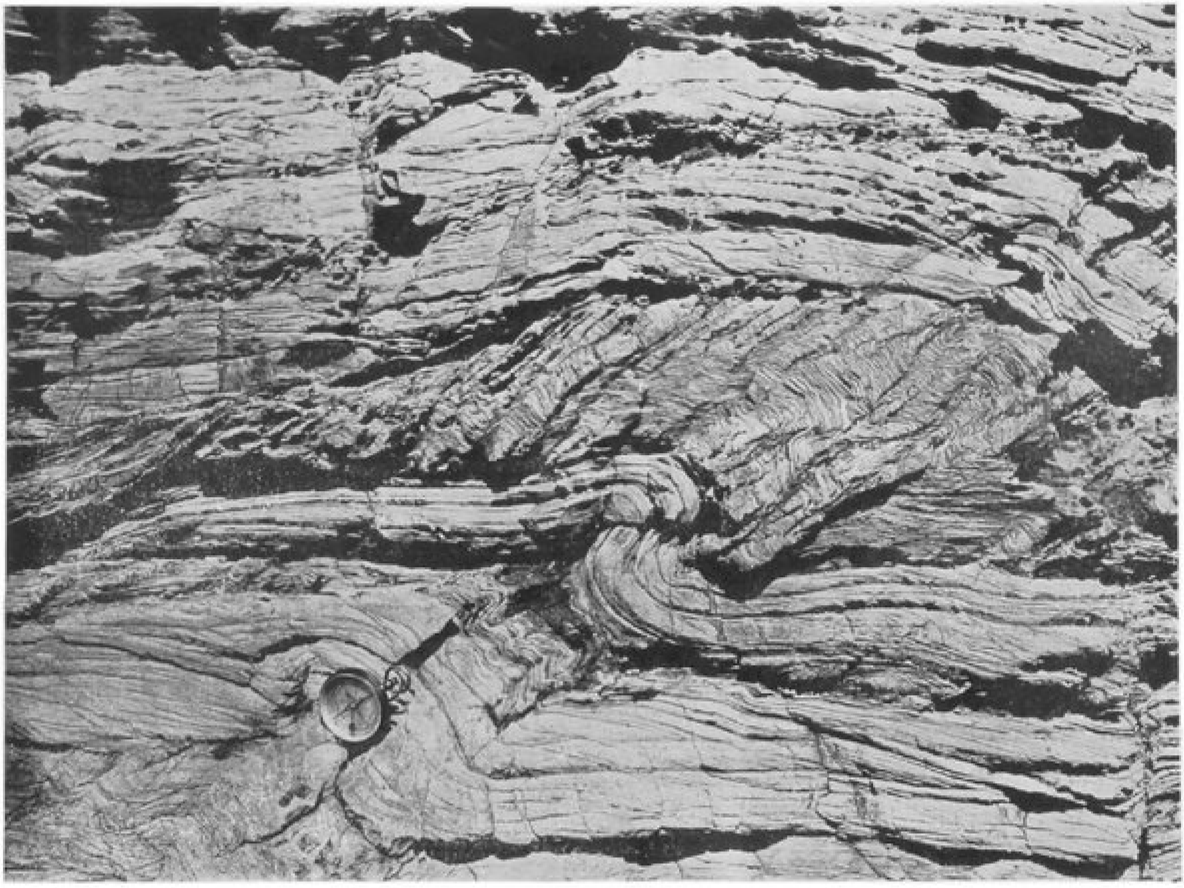
(Figure 41) Section between tunnels, Bodorgan. About 30 feet deep.

(Figure 42) Minor folding on vertical axes in the Middle Region. Gwna Green-schist, 500 yards south-east by south from Pen-y-graig, of 600 yards north by east from Bryn-yr-odyn.

(Plate 18) Minor isoclines in the South Stack Series. Near Porth Rhwydan, Holy Isle.



(Plate 19) Minor isoclinal folding in the New Harbour Beds. Holyhead Breakwater.



(Plate 20) Isoclinal folding with small-scale thrusting. Salt Island, Holyhead.

(Plate 11) Folded Penmynydd Mica-schist with quartz-augen. Graig-fawr, Holland Arms.

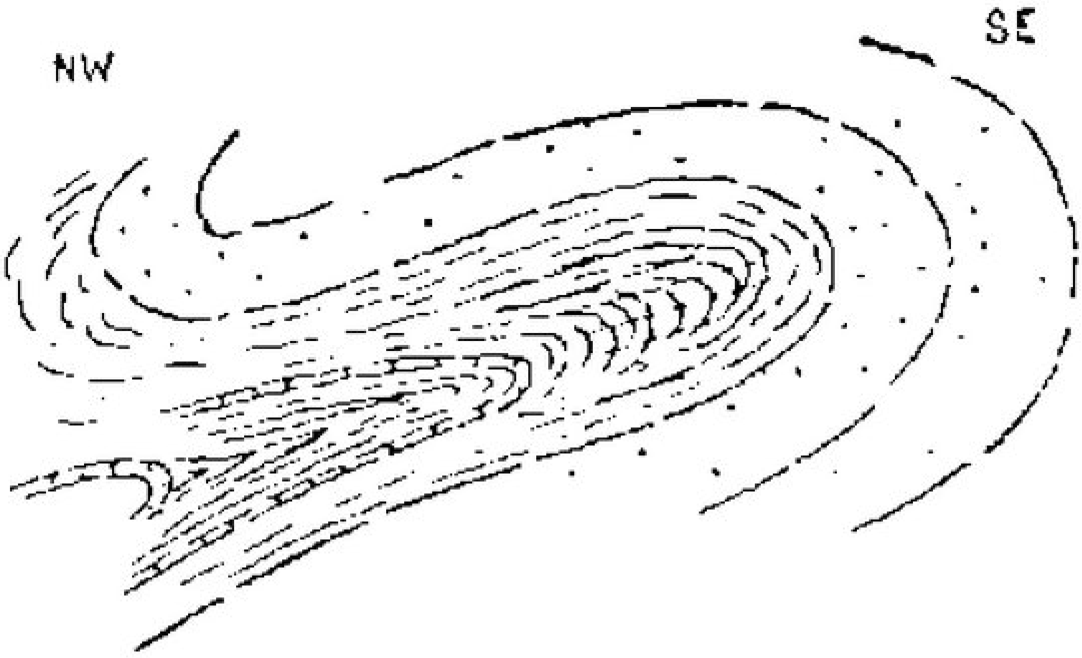


FIG. 45.

(Figure 45) Minor isoclines in Celyn Beds. Breakwater Cove. Amplitude three inches.

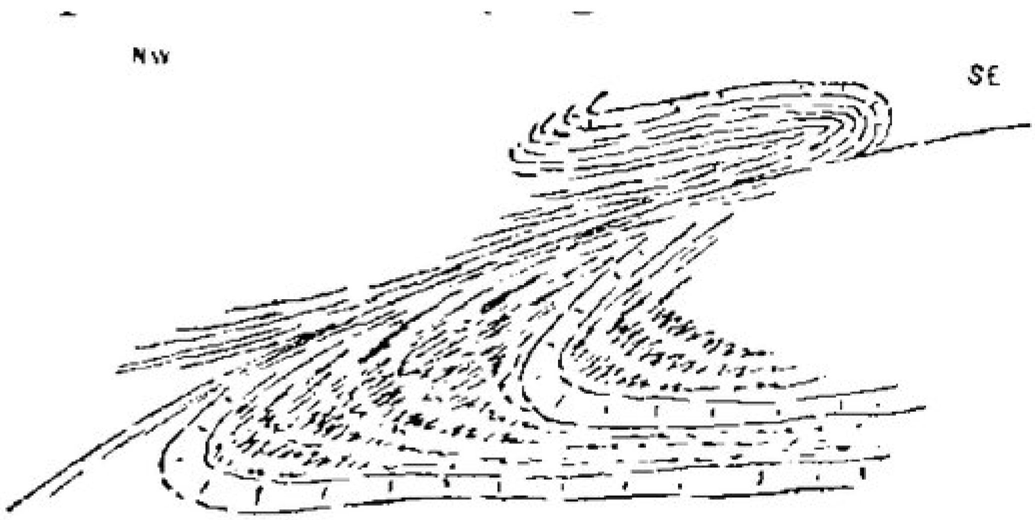


FIG. 46.

(Figure 46) Minor isoclines and thrust in Celyn Beds. Breakwater bosses. Length four inches.

FIG. 48.

(Figure 48) Minor isocline of a few feet amplitude. in Clwyn Beds. North-west of Gors-goch.

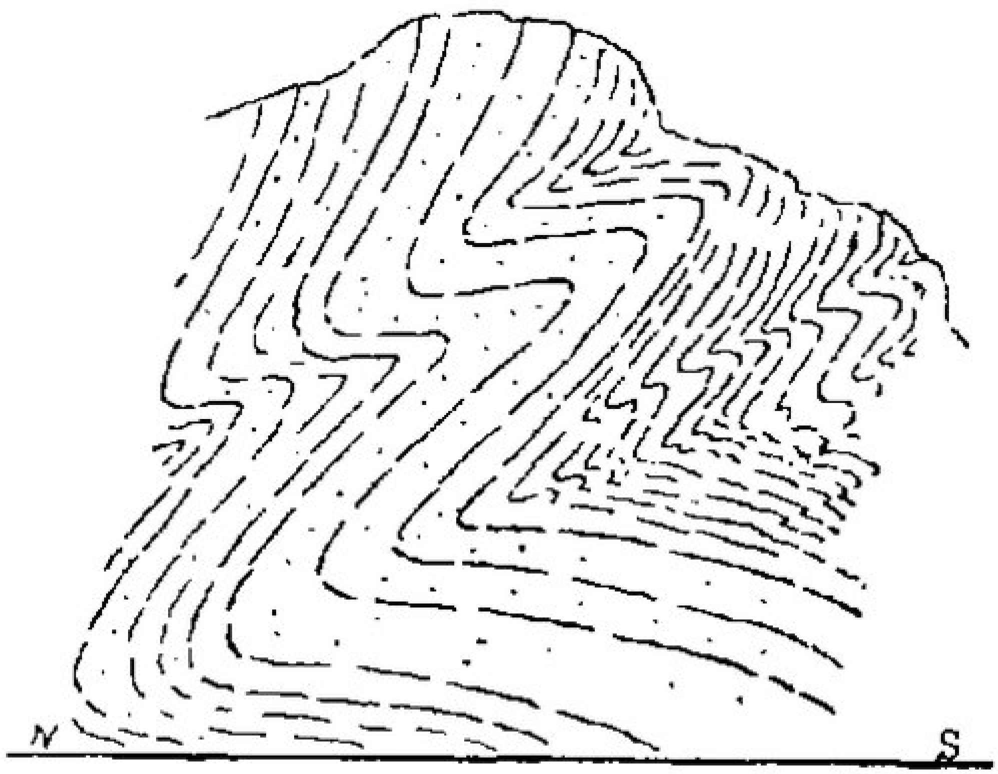


FIG. 49.

(Figure 49) Folding in Amlwch Beds. Half-a-mile west of Bryn-eilian. Height about two feet.

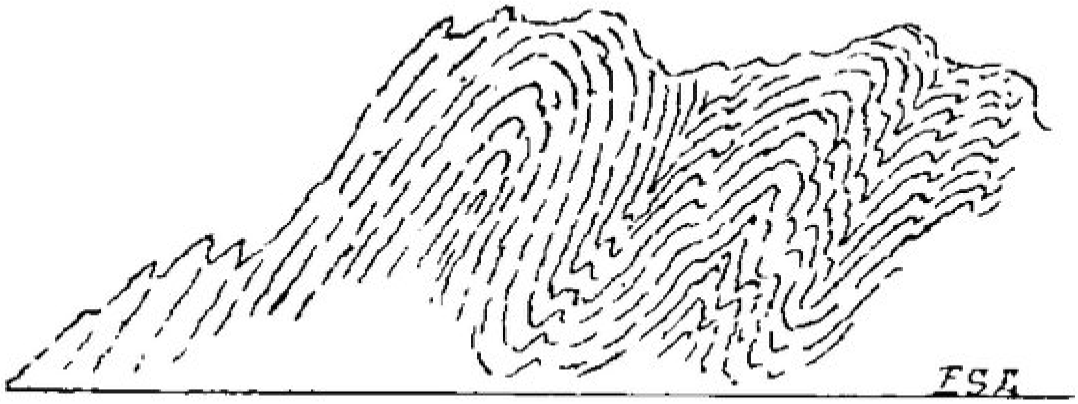


FIG 50.

(Figure 50) Minor isoclines of two feet amplitude in hornblende-schist. 566 yards north-west of Bryn-eryr, Aethwy Region.

FIG. 51.

(Figure 51) Sharp two-foot isocline in hornblende-schist. Gigfran, Mynydd Llwydiarth.

FIG. 53. -FLAT-LIMBED ISOCLINES.

(Figure 53) Flat-limbed isoclines. South of Porth-y-felin, Holyhead.

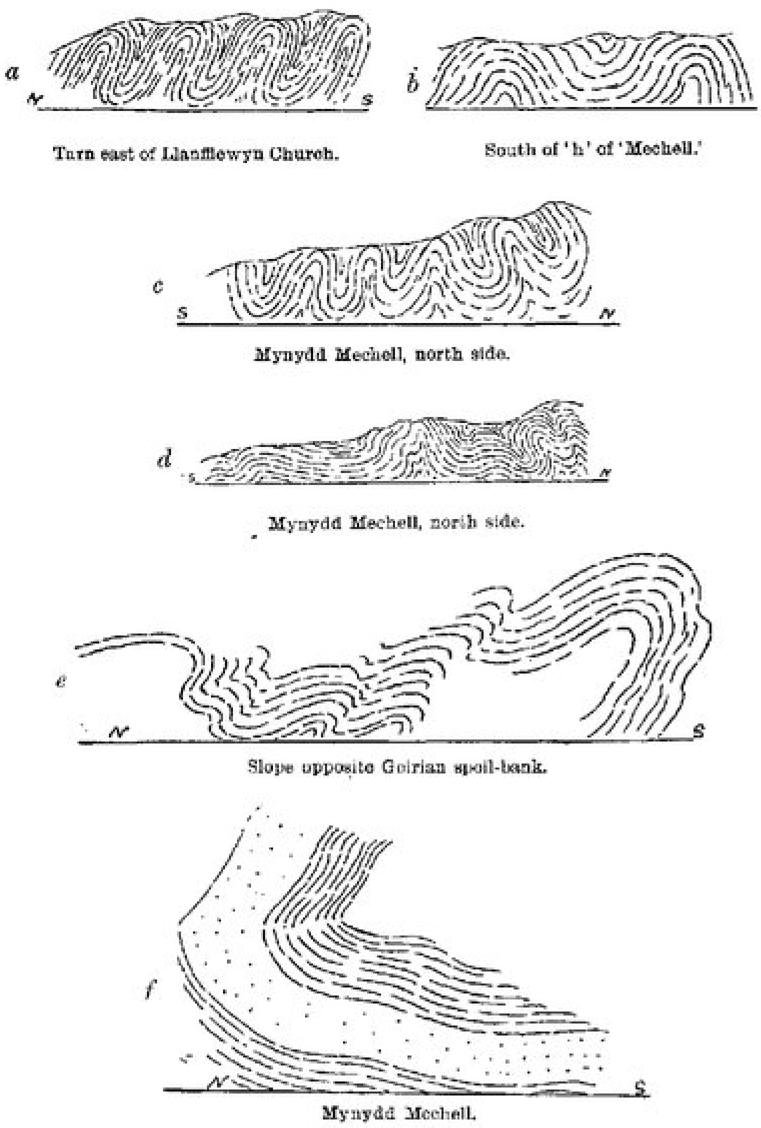


FIG. 132.—MINOR FOLDING IN COEDEN BEDS.

(Figure 132) minor folding in Coeden Beds. a. Tarn east of Llanfflewyn Church. b. South of 'h' of 'Mechell'. c. Mynydd Mechell, north side. d. Mynydd Mechell, north side. e. Slope opposite Geirian spoil-bank. f. Mynydd Mechell.

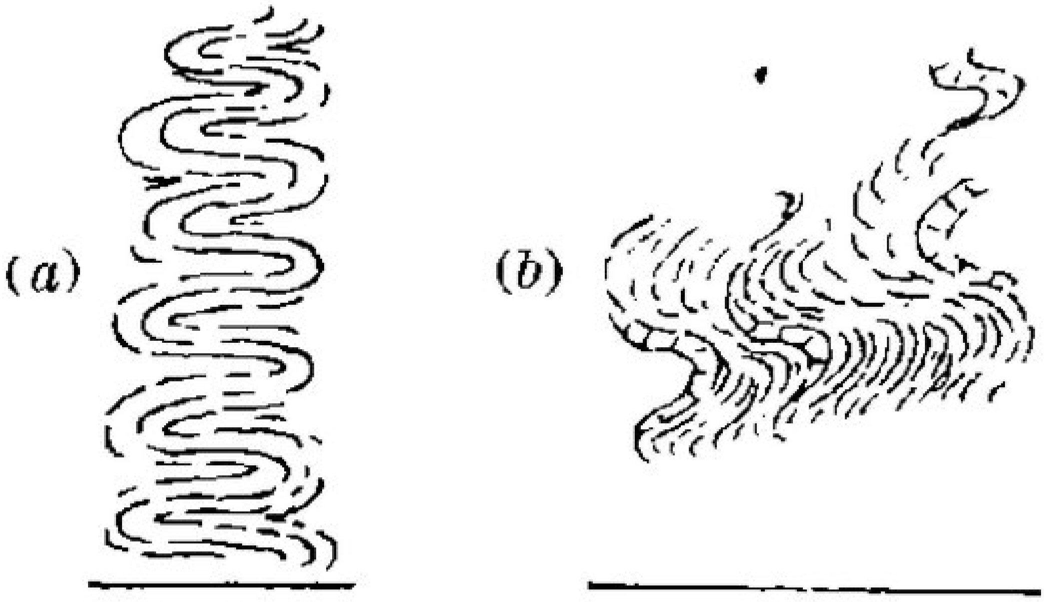


FIG. 54.
A-CLINAL MINOR FOLDING.

(Figure 54) A-clinal minor folding. (a) Diagrammatic. (b) Drawn from Nature. West side of slack, north-west of Ty'n-y-rnynydd-east, Mynydd Llwydiarth.

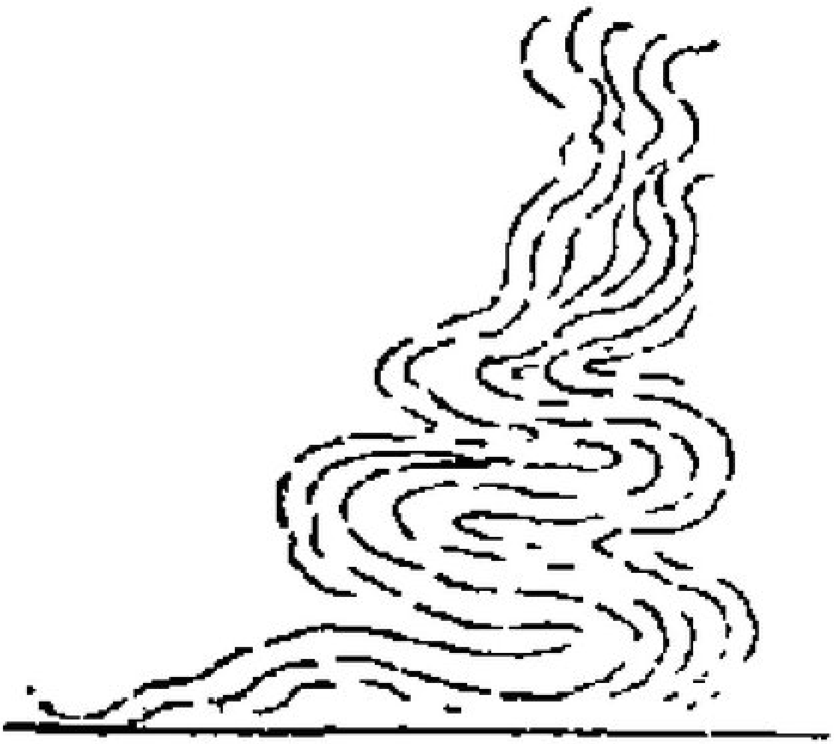


FIG. 55.—A-CLINAL MINOR FOLDING.

(Figure 55) A-clinal minor folding. A little north of Ty'n-y mynydd-east, Mynydd Llwydiarth.

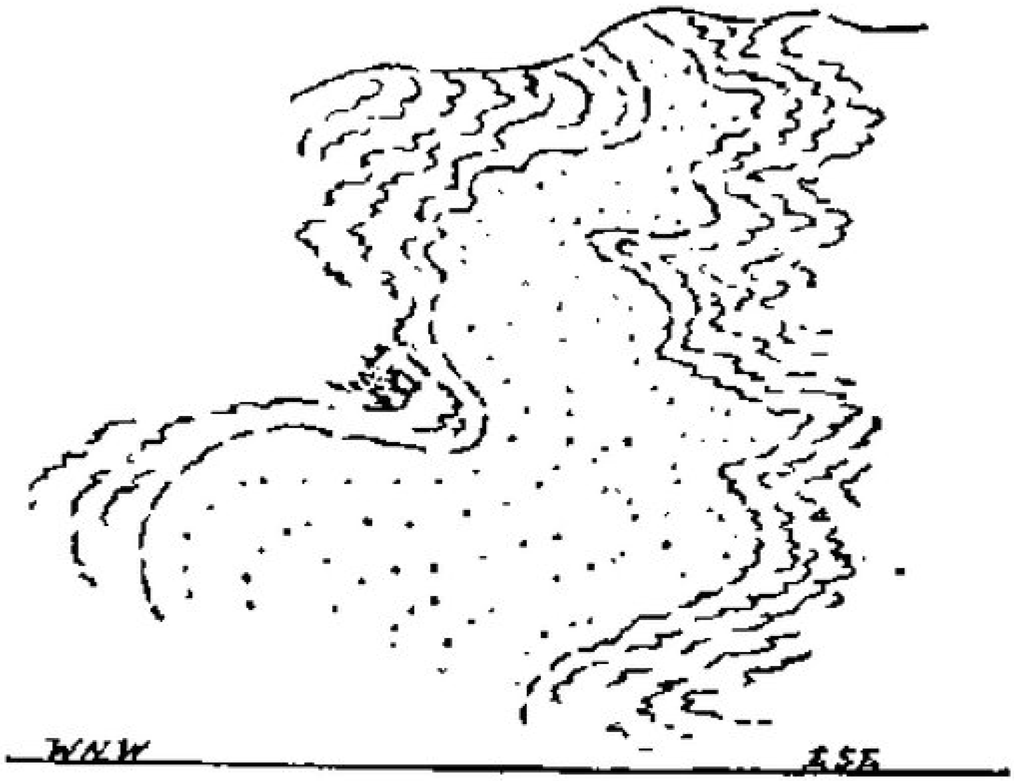


FIG. 56.—A-CLINAL FOLDING OF HORNBLENDE-SCHIST IN MICA-SCHIST.

(Figure 56) A-clinal folding of hornblende-schist in mica-schist. West shore of Elusendai alluvium. Penmynydd. Height one foot.

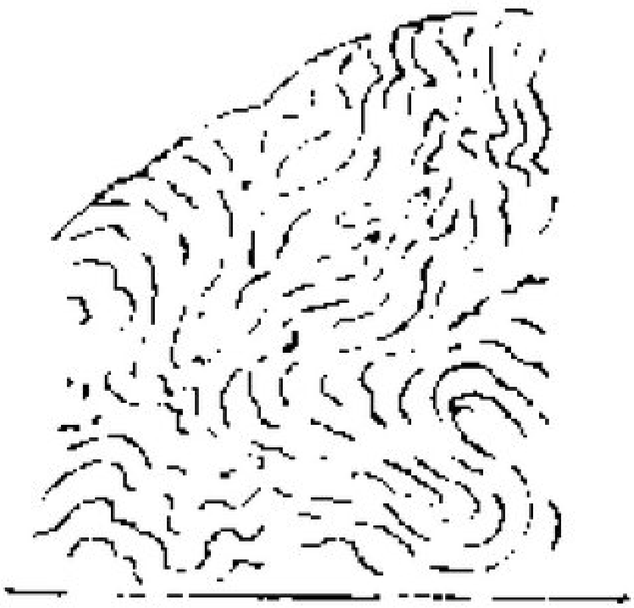


FIG. 57.—POLYCLINAL MINOR FOLDING.

(Figure 57) Polyclinal minor folding. 300 yards south-west of Ty'n-y-mynydd-east, Mynydd Llwydiarth. East side of slack. Height about two inches.

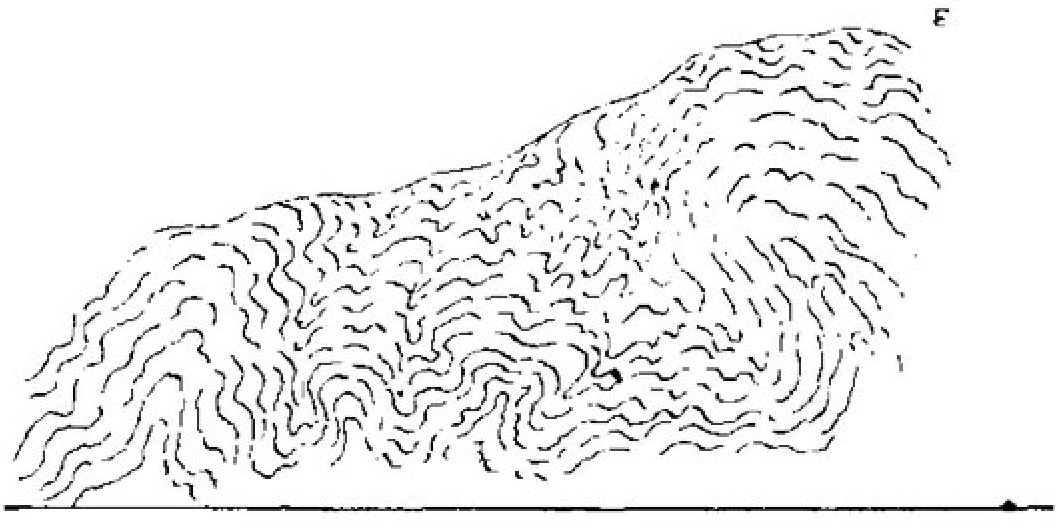


FIG. 58.—POLYCLINAL MINOR FOLDING.

(Figure 58) Polyclinal minor folding. 250 yards south by west from Ty'n-y-mynydd-east. Height one foot.

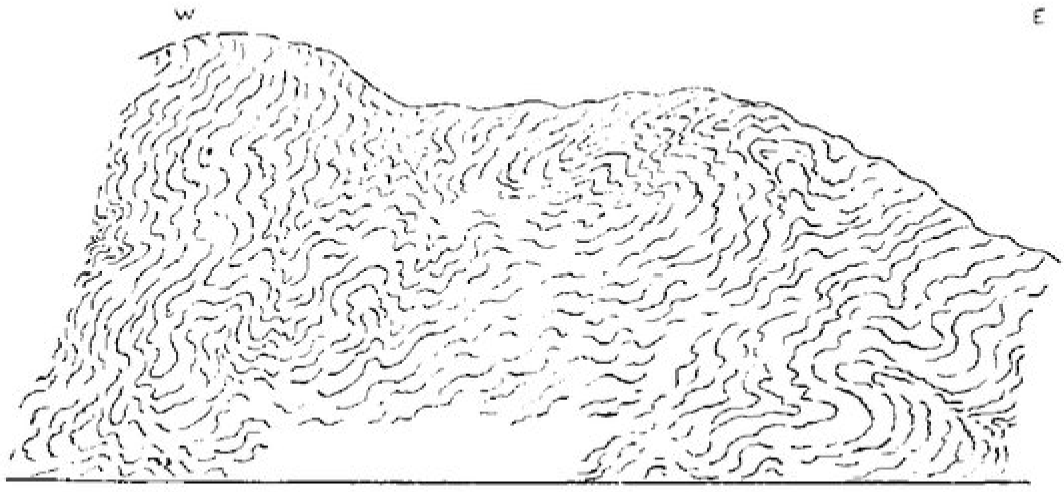


FIG. 59.—POLYCLINAL MINOR FOLDING.

(Figure 59) Polyclinal minor folding. 250 yards west of Ty'n-y-mynydd-east, south of dry pool. Height three feet.

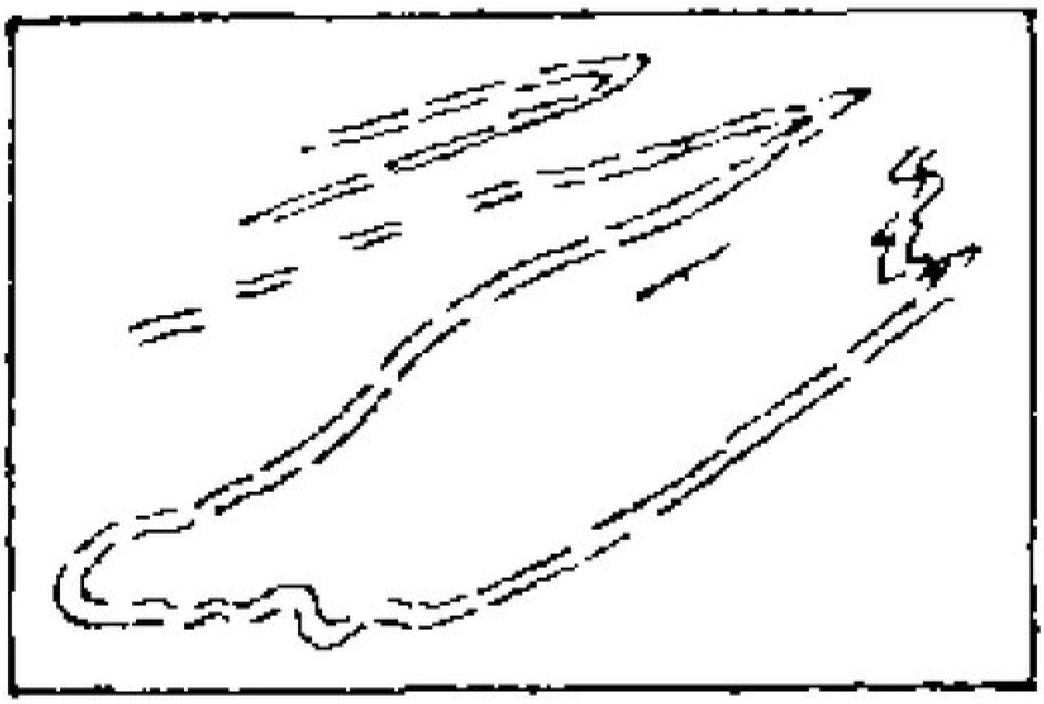


FIG. 61.

(Figure 61) Plan of five-foot folds in hornblende-schist. About 100 yards north-east of Gigfran, Mynydd Llwydiarth.

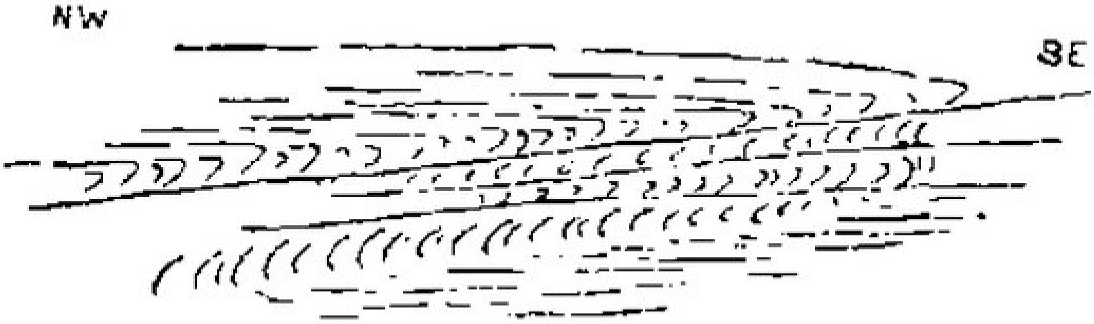


FIG. 62.

(Figure 62) Minor thrusts in the Tre-Arddur zone. Cliffs west of Castell.

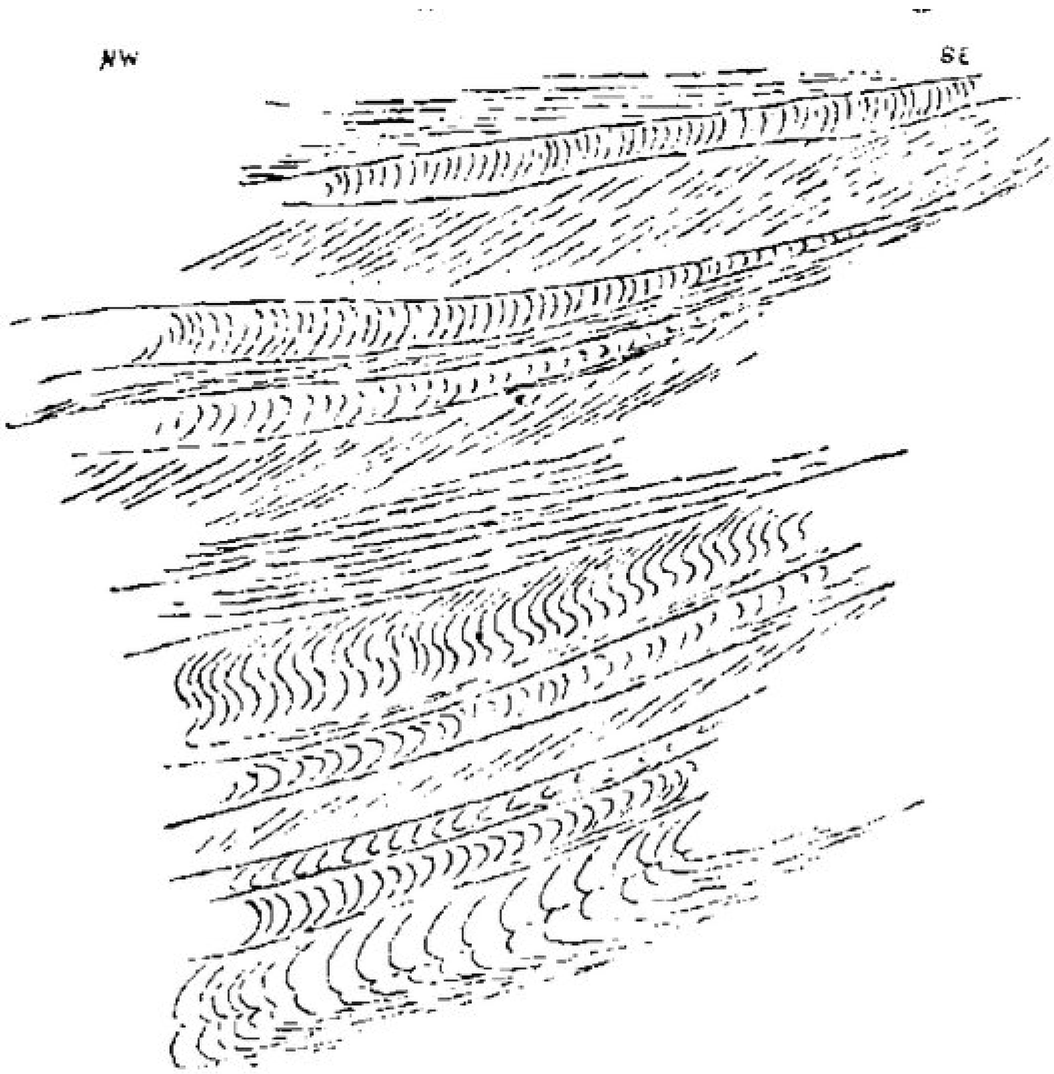


FIG. 63.

(Figure 63) Minor thrusts in the Tre-Ardour Zone. Foot of crag, south-east of Gareg-fawr. Height about nine inches.

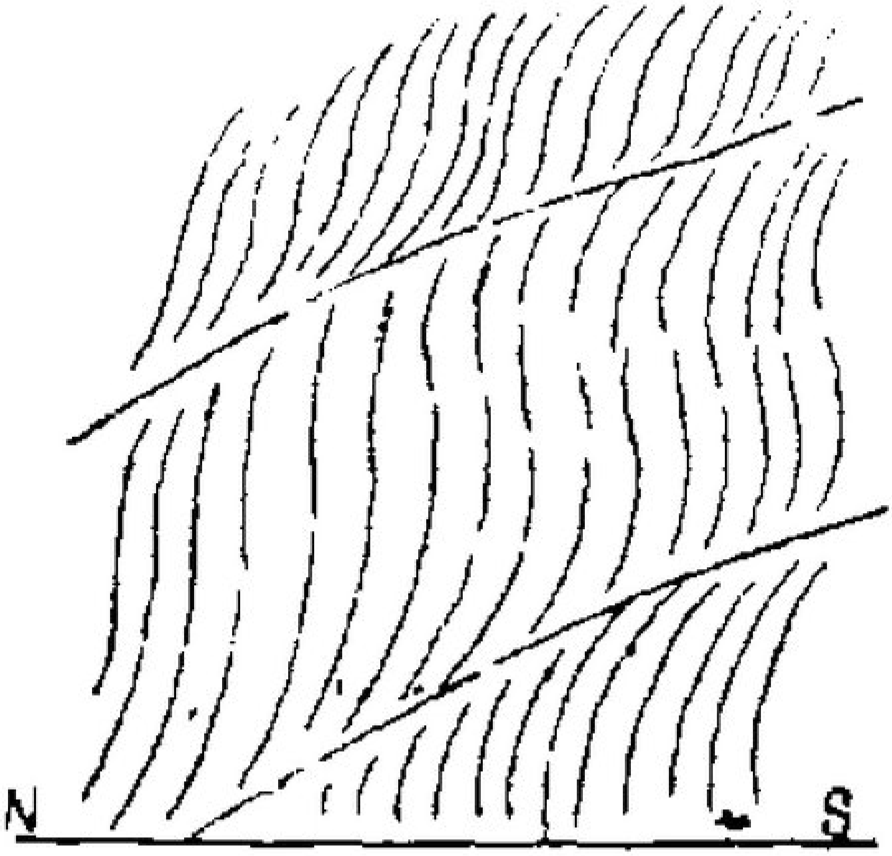


FIG. 64.

(Figure 64) Sigmoidal foliation with thrusts at one-foot intervals. East bluffs of Trwyn Bychan.

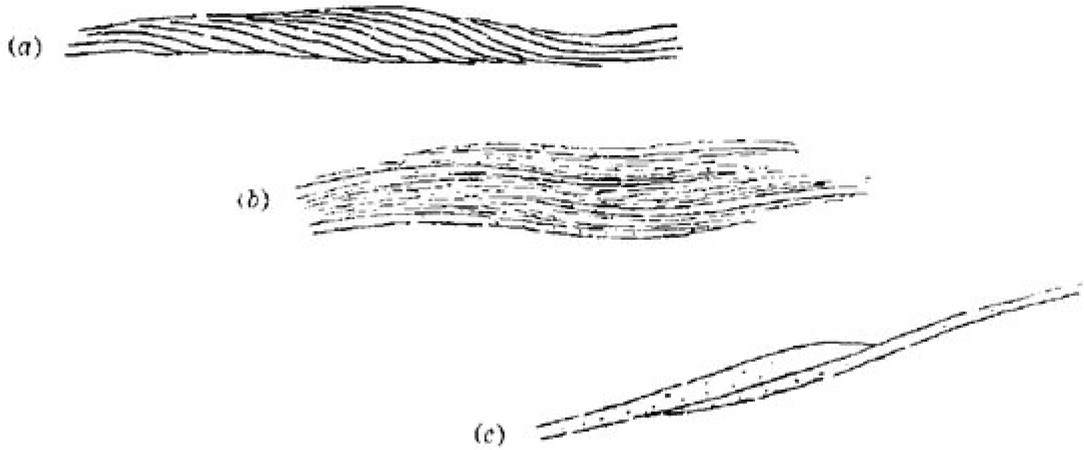


FIG. 65.--STRUCTURES IN THE AMLWCH BEDS.

(Figure 65) Structures in the Amlwch Beds. (a) West-south-west of Graig-ddu. (b) Porth-y-gwartheg. (c) About 250 yards west-north-west of 'Cave', Bull Bay.

FIG. 66.

(Figure 66) Structures the Amlwch Beds. Porth-y-gwartheg.

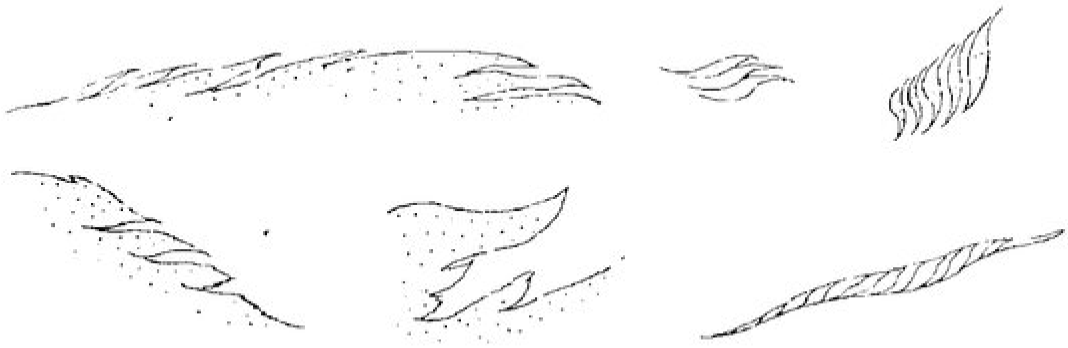


FIG. 67.—INCIPIENT LENTICULAR CUTTING.

(Figure 67) Incipient lenticular cutting. 170 yards north-east of Coast-guard path end, Analweh. Half natural size.

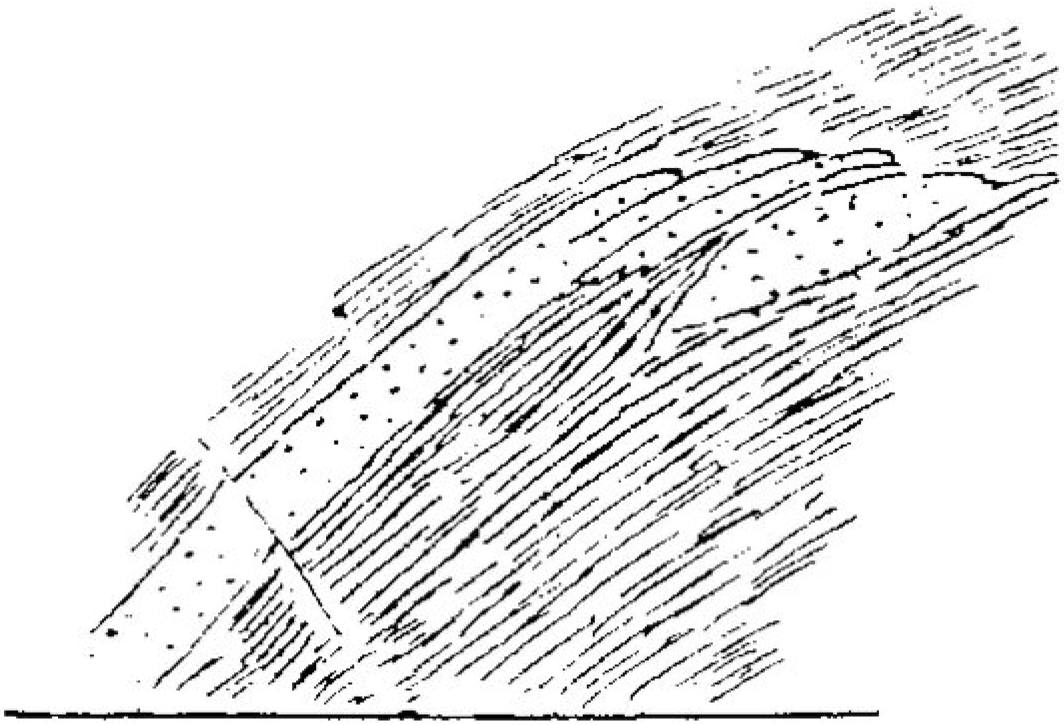


FIG. 68.

(Figure 68) Breaking down of Tyfry Beds. One-third natural size. 400 yards west by north from Tyfry.

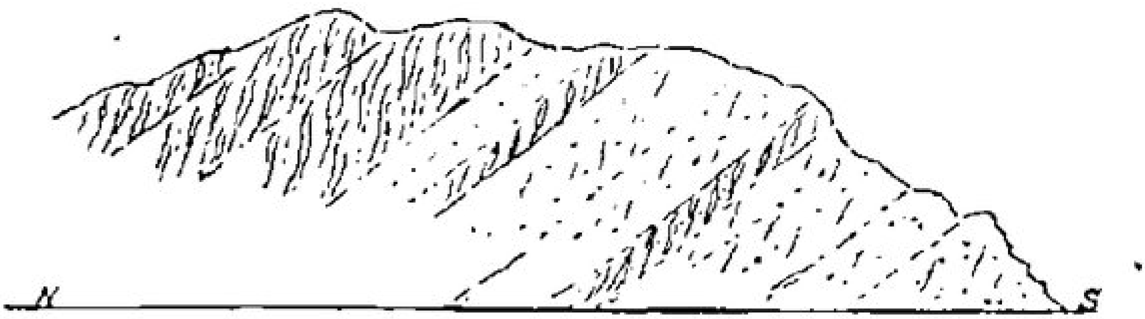


FIG. 32.

(Figure 32) Passage from Fydlyn to Gwna Beds. About 10 feet high. Brow of Fydlyn Cliff.

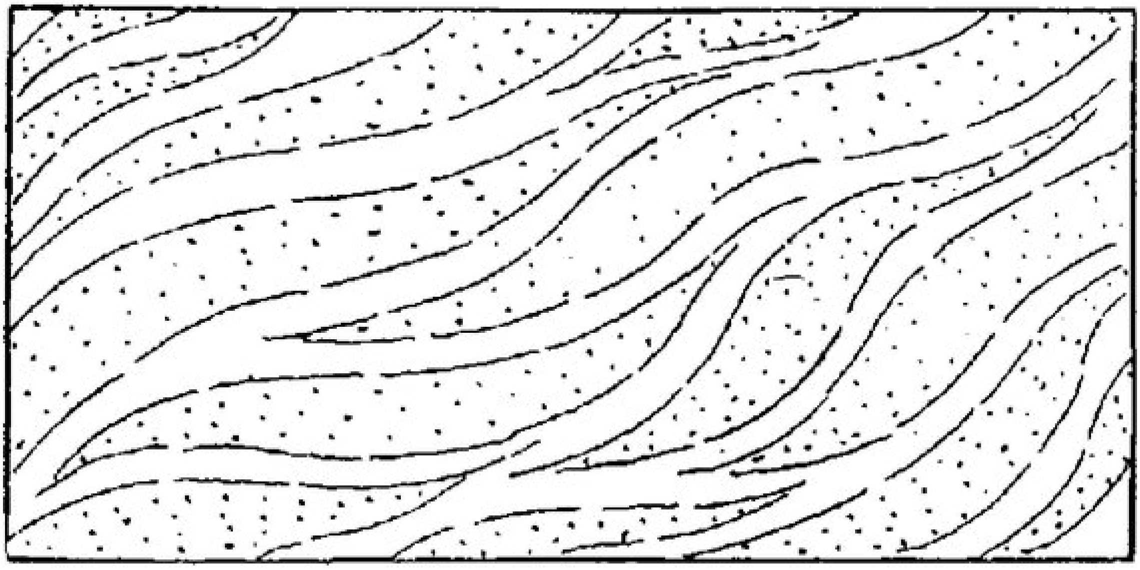


FIG. 69.—DIAGRAM OF AUTOCLASTIC MÉLANGE.

(Figure 69) Diagram of autoclastic melange.

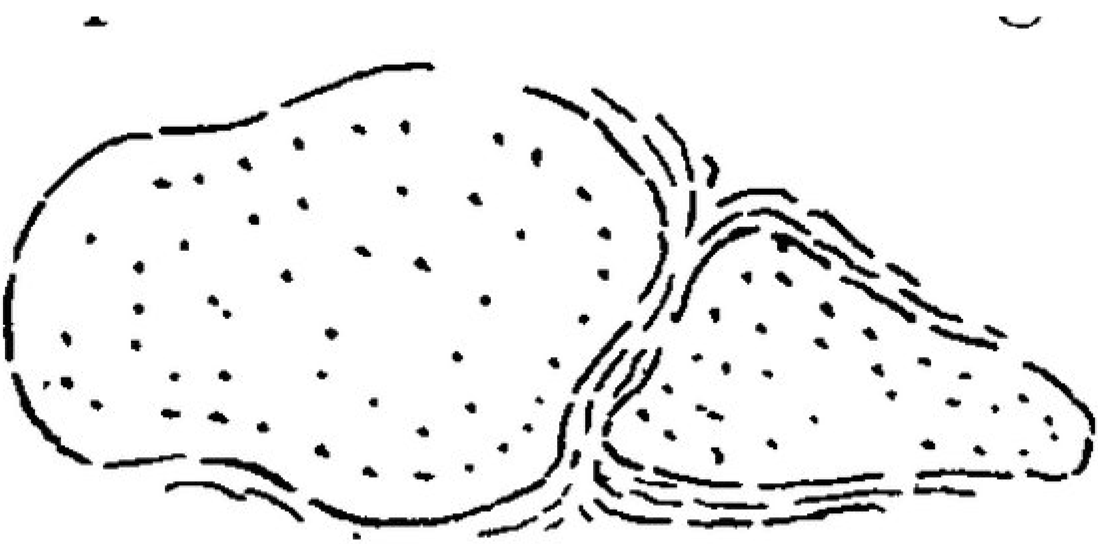


FIG. 1.

(Figure 1) Two-foot ellipsoids. Chapel, 500 yards north of Llanfwrog Church.

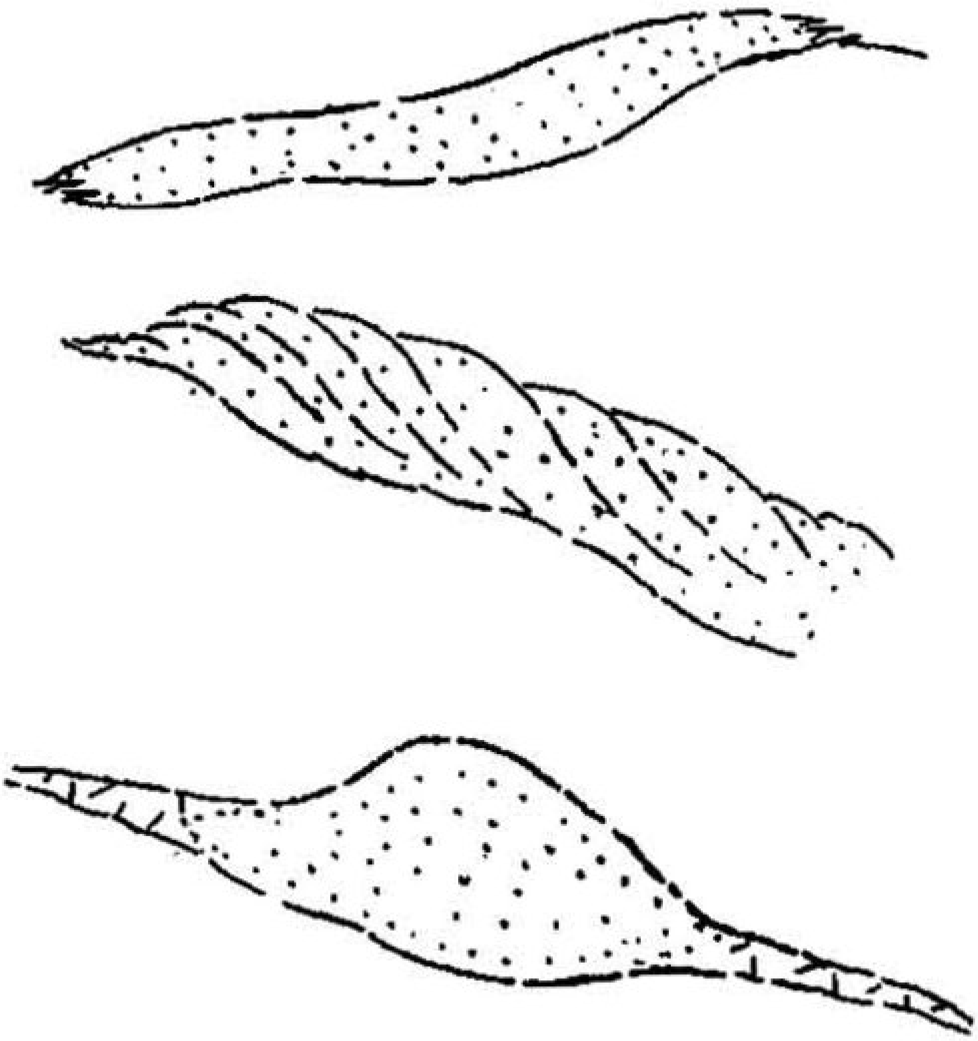


FIG. 5.

(Figure 5) Peacoids of grit in Gwna Mélange. North of Glyn-afon.

Fig. 165.
Base of Limestone.

(Figure 165) Base of limestone. South-west of Pen-y-parc, at Bath House, Menai Strait. Height: about 10 feet.

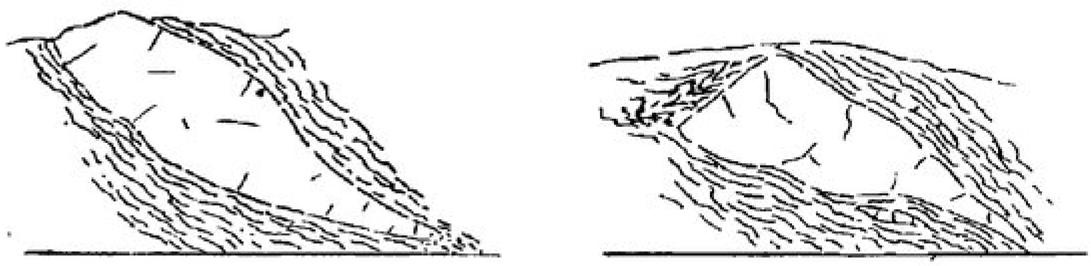


Fig. 166.—Limestones in Gwna Green-schist.

(Figure 166) Limestones in Gwna Green-schist. About four feet and three feet thick. Roadside, about 200 yards west of bathing house.

Fig. 169.—Lenticular Quartzite.

(Figure 169) Lenticular quartzite. Three and a half feet long. In Gwna Mélange, Llansadwrn.

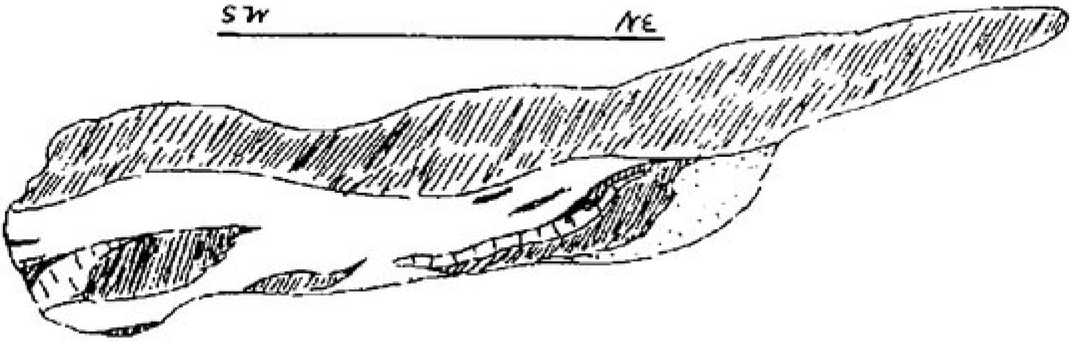
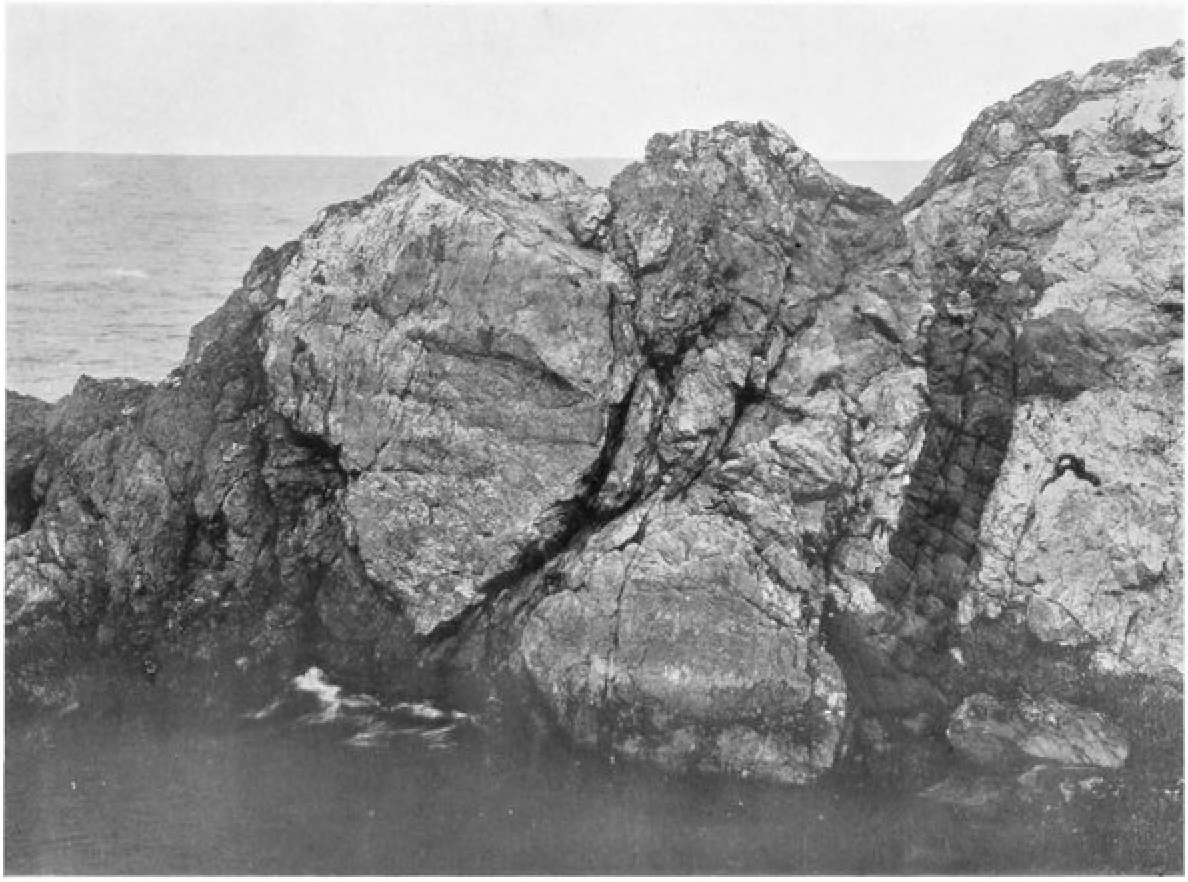


FIG. 188. -1/2500-PLAN OF BOSS AT CERIG-DUON, NEWBOROUGH.

(Figure 188) 1/2500-plan of boss at Cerio-duon, Newborough. Spilite-schist, limestone, quartzite, and Gwna Green-schist.

(Plate 7) Autoclastic Melange. Coast near Porth Cadwaladr, Bodorgan.



(Plate 22) Lenticular quartzites in Autoclastic Mélange, with late basic dyke. Porth Wnol.

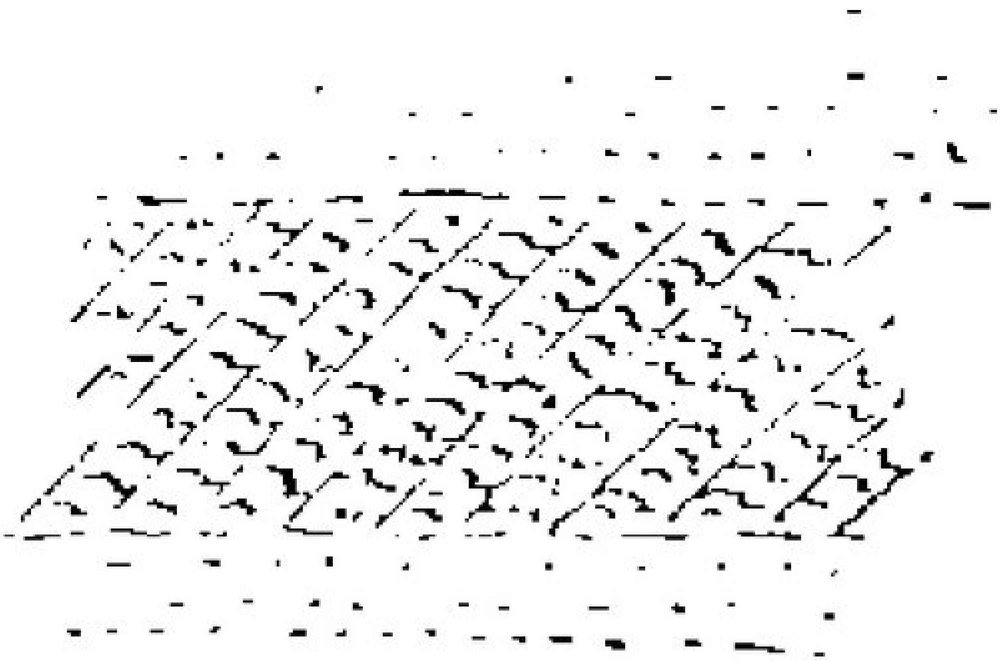
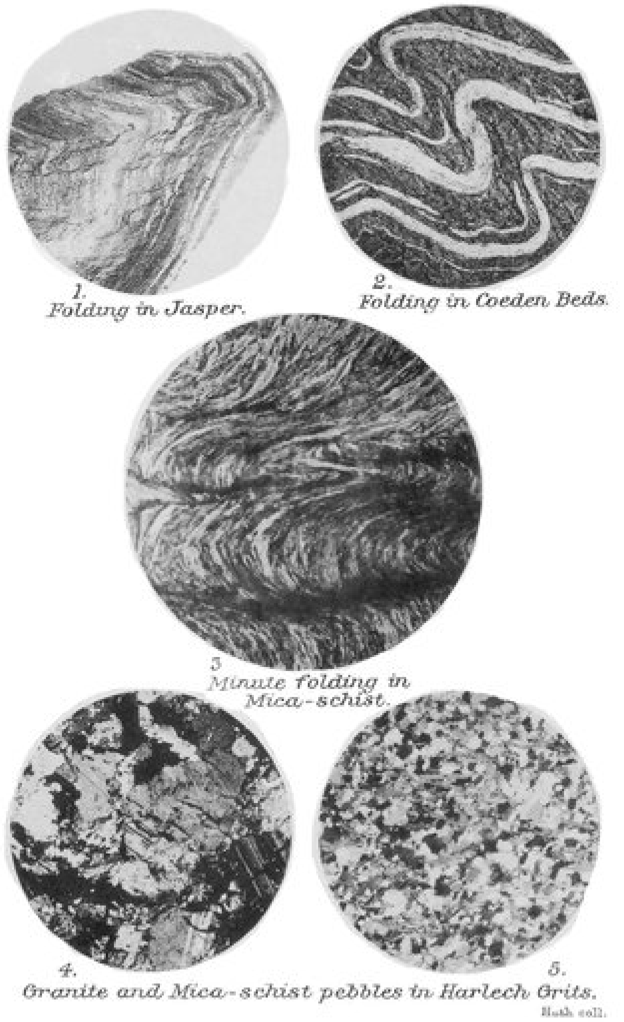


FIG. 70.—STRAIN SLIP.

(Figure 70) Strain slip. Quarter of a mile west of Minffordd Windmill

Plate XXI.



(Plate 21) Microphotographs of the Mona Complex. 1. Folding in Jasper. 2. Folding in Coeden Beds. 3. Minute Folding in Mica-schist. 4. Granite Pebble in the Harlech Grits. 5. Mica-schist Pebble in the Harlech Grits. See Appendix 3.

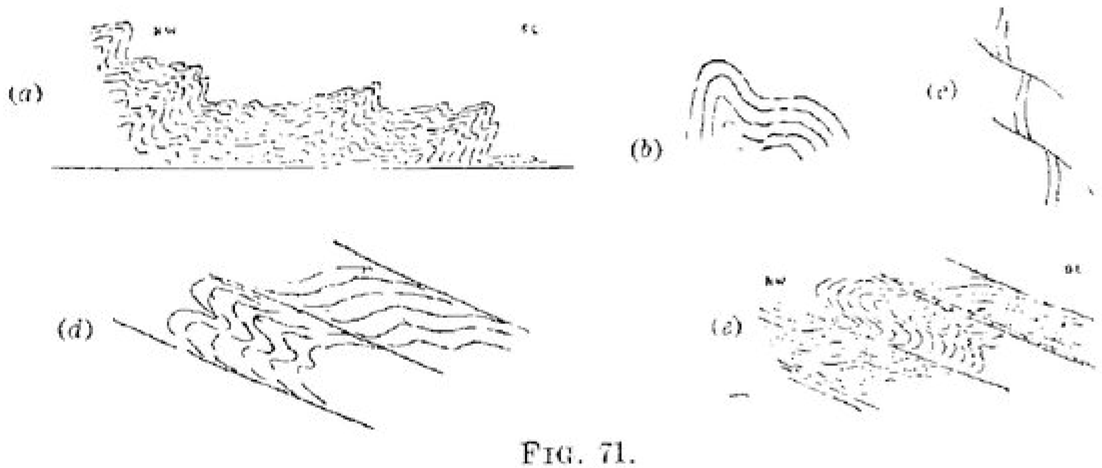


FIG. 71.

CHANGE OF STRUCTURE ALONG THE ESTUARY OF THE ALAW.

(Figure 71) Change of structure along the estuary of the Alaw. Amplitudes one foot or less. Nos. a to e in order eastwards, from Valley Foundry to Gored Footpath.

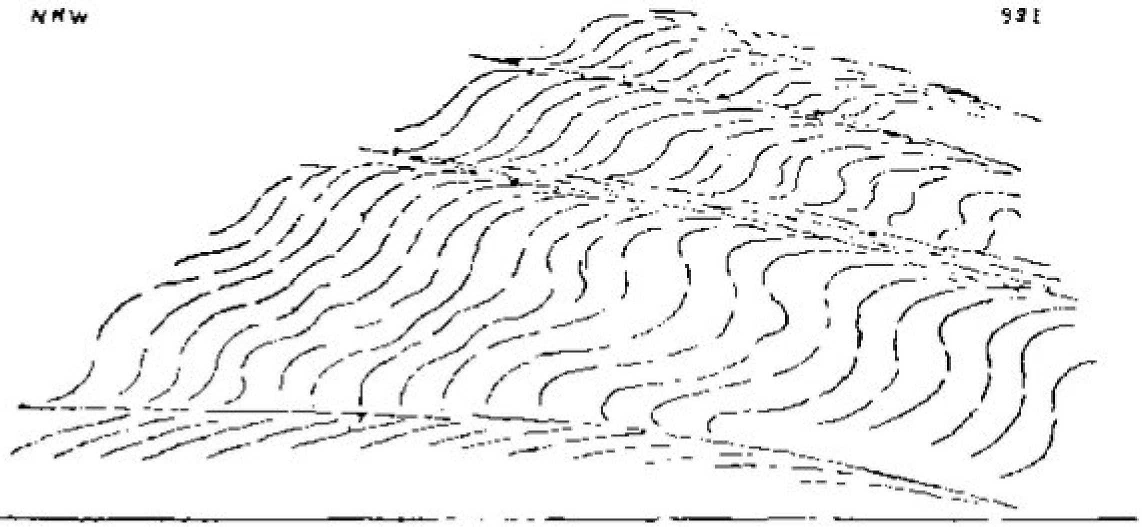


FIG. 72.—THE VALLEY THRUST-PLANES.

(Figure 72) The valley thrust-planes. Crags above the railway, east and south-east of Llanfair-yn-neubwll Church.

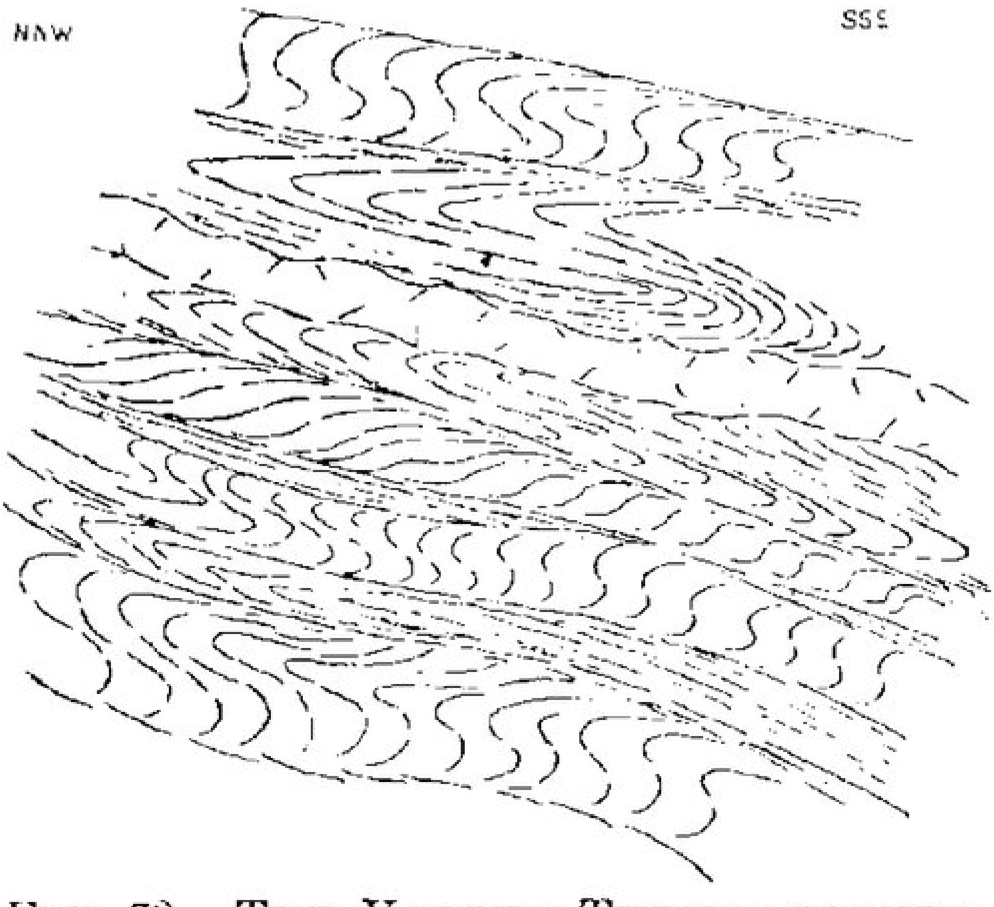


FIG. 73.—THE VALLEY THRUST-PLANES.

(Figure 73) The valley thrust-planes. Further stage, and with vein-quartz. Crags above the railway. east and south-east of the same Church.

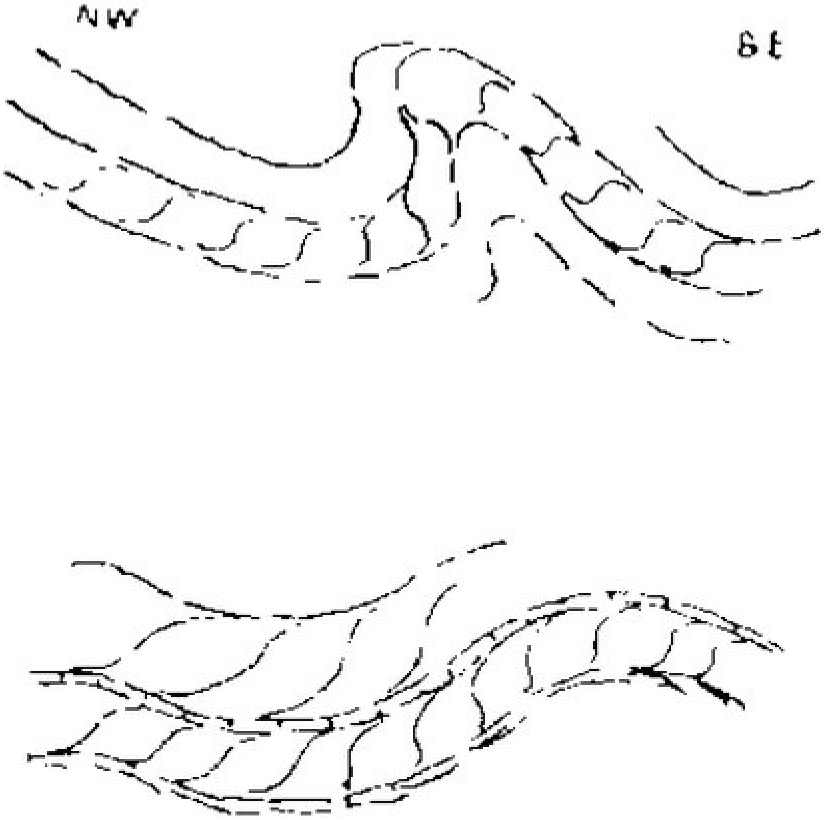


FIG. 74.—UNDULATIONS OF THE VALLEY THRUST-PLANES.

(Figure 74) Undulations o' the valley thrust-planes.

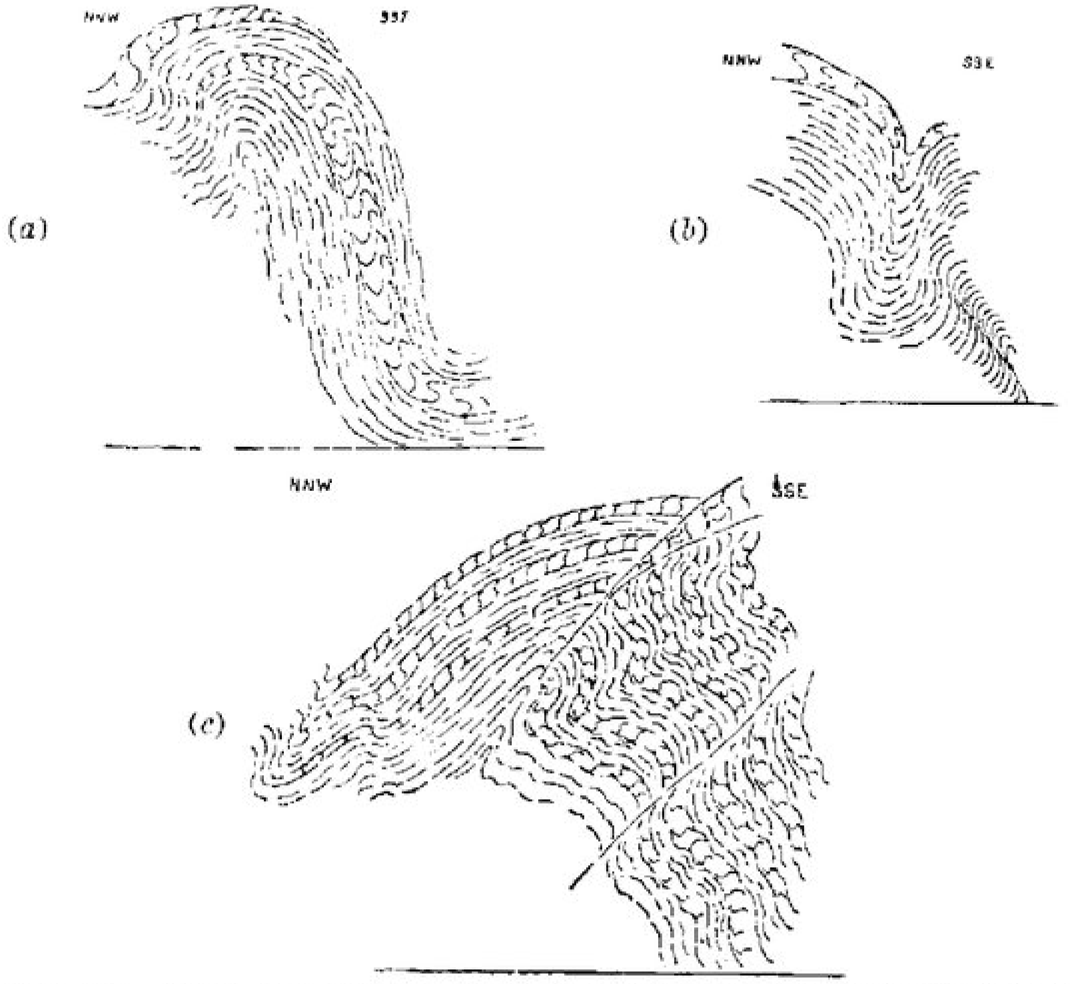


FIG. 75.—THE FOLDING AND THRUSTING OF THE VALLEY THRUST-PLANES.

(Figure 75) The folding and thrusting of the valley thrust-planes. Amplitudes up to four feet. Crags above the railway, north-east and east of the Church.

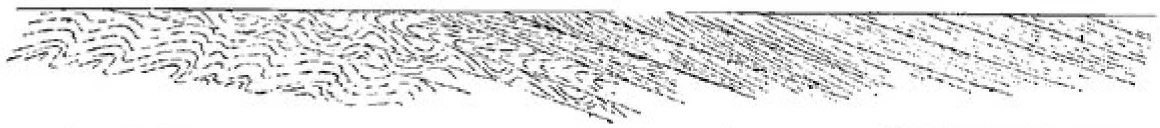
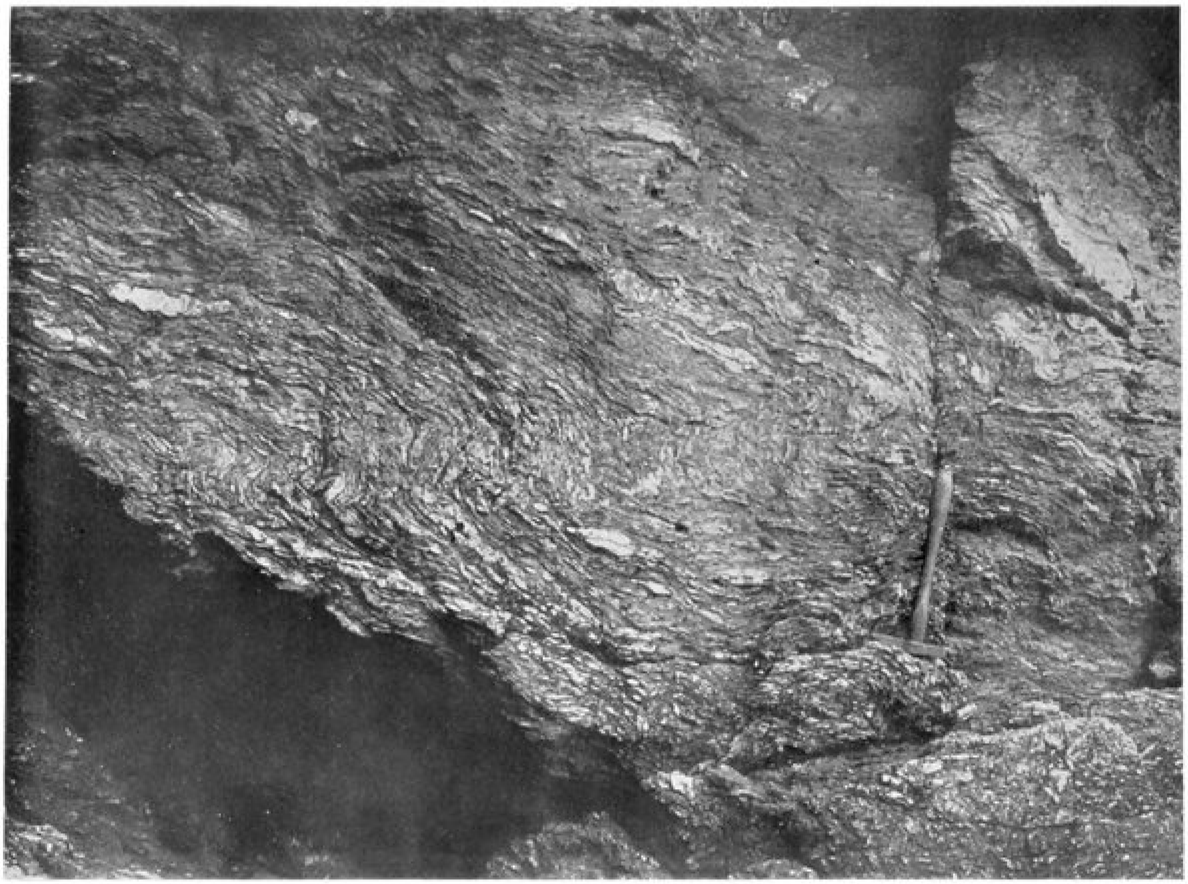


FIG. 76.—DIAGRAM TO ILLUSTRATE THE CHANGE FROM THE ISOCLINES OF HOLY ISLE INTO THE FOLIATION OF THE WESTERN REGION.

(Figure 76) Diagram to illustrate the change from isoclines of Holy Isle into the foliation of the Western Region.



(Plate 23) Folding of Autoclastic Melange. Menai Strait.

FIG. 77.—FOLDED PHACOIDS OF GRIT.

(Figure 77) Folded phacoids of grit. 300 yards east-north-east of Pedair-groeslon.

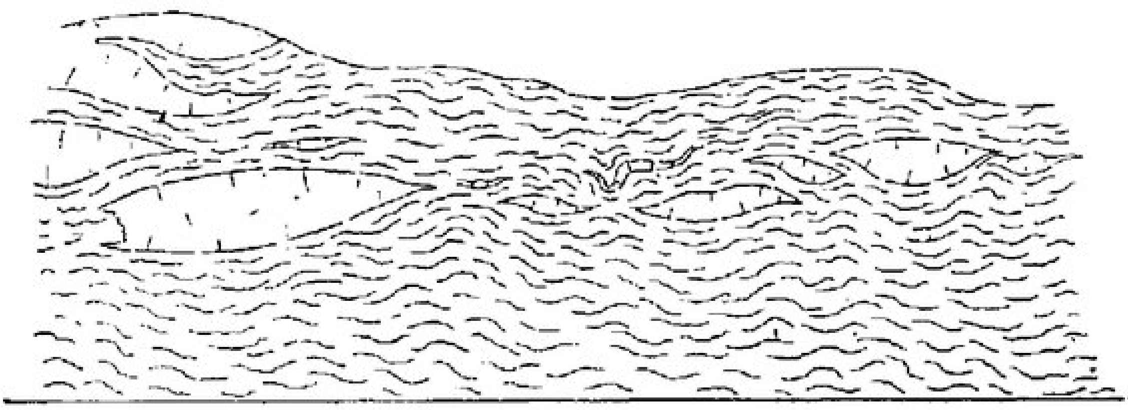


FIG. 78.—LIMESTONES IN GWNA GREEN-SCHIST.

(Figure 78) Limestones in Gwna Green-Schist. Baron Hill drive, at 'M' of 'Meurig'. Height about 15 feet.

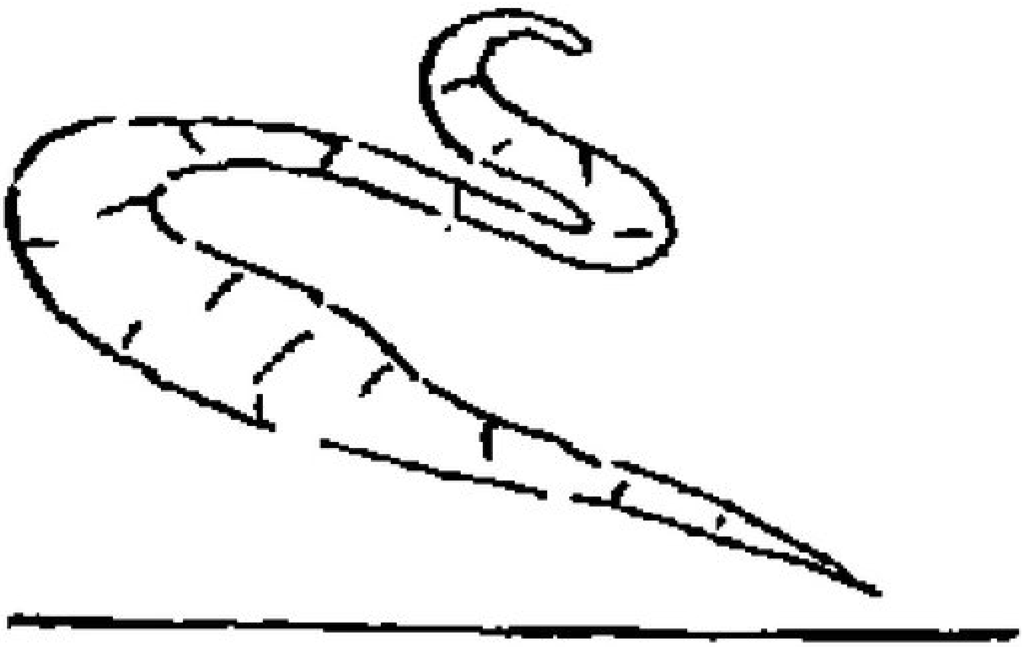


FIG. 79.

FOLDED PHACOID OF LIMESTONE IN FIG. 78.

(Figure 79) Folded phacoid of limestone in (Figure 78), Longest limb about two feet.

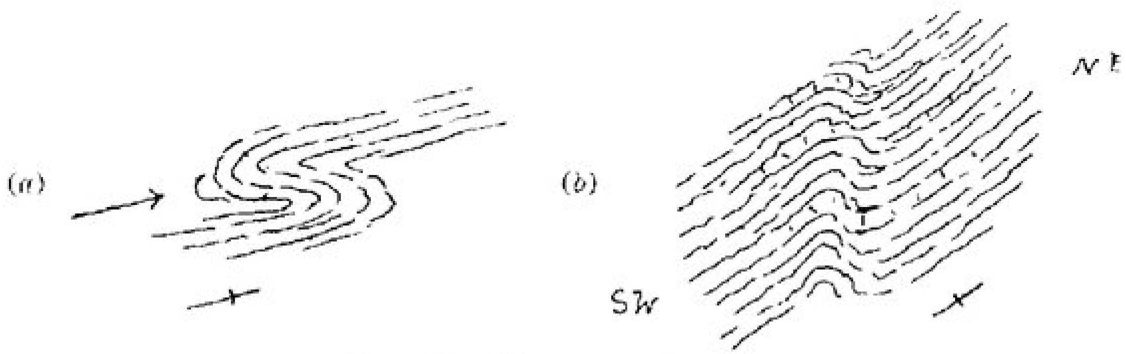


FIG. 80.—CROSS-WRENCHES.

(Figure 80) Cross-wrenches. (a) Bodewran. (b) North side of road 550 yards west of Garth Ferry Inn.

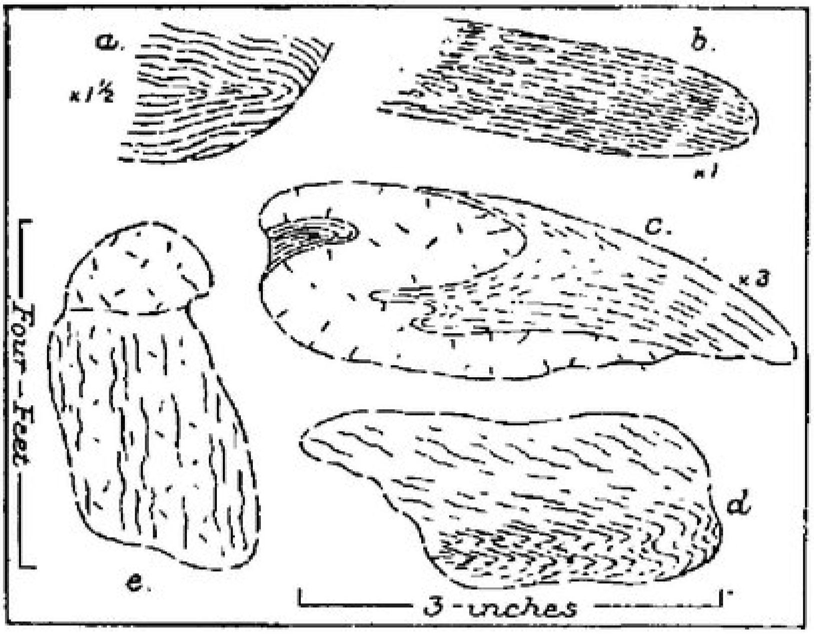


FIG. 102.

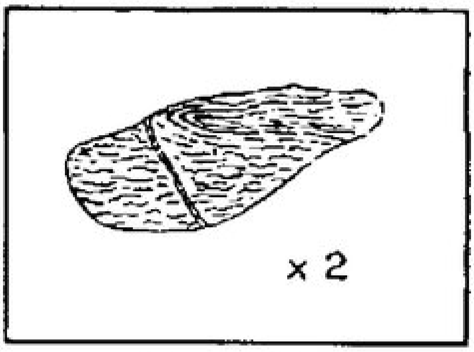


FIG. 102 B.

(Figure 102) Pebbles from the basal Arenig conglomerates Containing old folds and thrusts of the Mona Complex. 102 B. Pebble from Lower Cambrian Grits containing an old fold and vein of the Mona Complex.

FIG. 81.

FOLIATION IN A GRIT.

(Figure 81) Foliation in a grit. West of Forth Rutrydd. Height 30 feet.

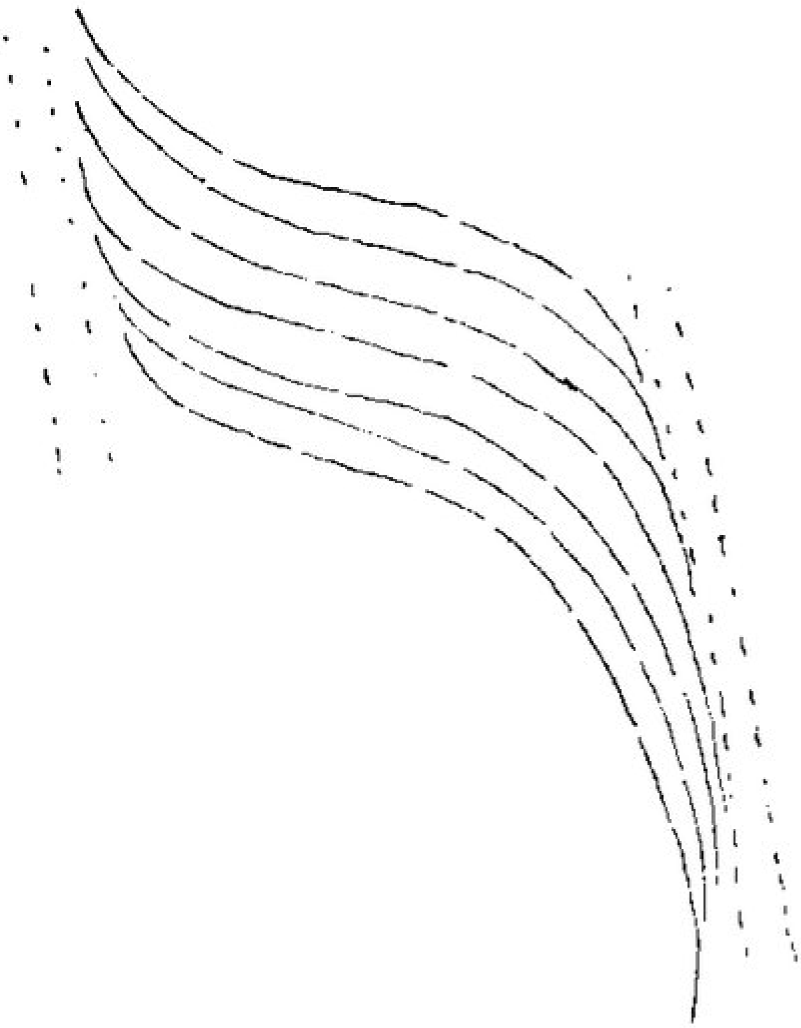


FIG. 82.—FOLIATION IN GRITS OF SOUTH STACK SERIES.

(Figure 82) Foliation in grits of South Stack Series. Quarry north of road. Kngsland. Holyhead.

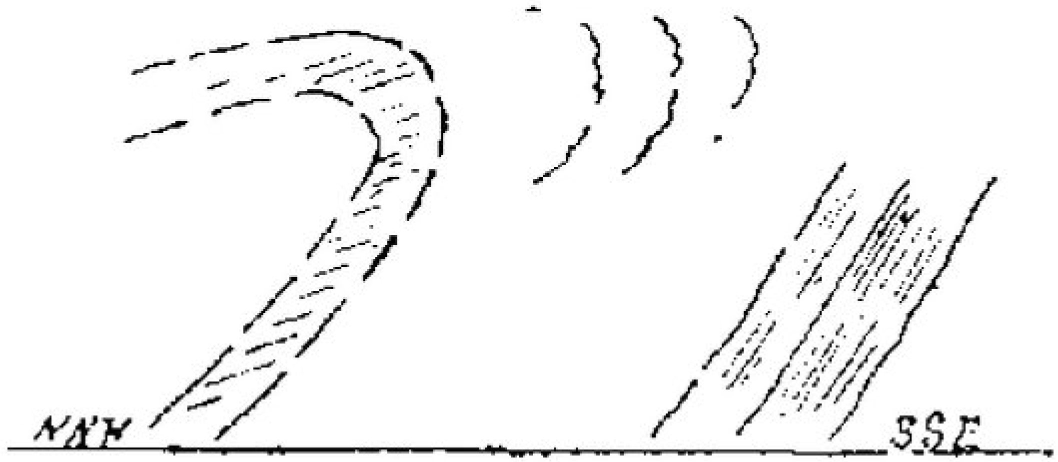


FIG. 83.
FOLIATION IN GRITS.

(Figure 83) foliation in grits. East of Porth Ruffydd.

FIG. 84.
DIVERGING
FOLIATION IN GRIT.

(Figure 84) Diverging foliation in grit. Amplitude about two feet. Headland west-south-west of Gors-goch,

(Plate 24) Bedding and foliation in the South Stack Series. Seaward end of the South Stack.

FIG. 85.
PORTH RUFFYDD.

(Figure 85) Porth Ruffydd Bending of foliation in fold of bedding.

FIG. 86.—FOLDING OF FOLIATION OF FISSILE BED AT JUNCTION WITH OVERLYING GRIT.

(Figure 86) Folding of foliation of fissile bed at junction with overlying grit. Cliff north·north·east of Maen·y·fran, Rhoscolyn.

FIG. 87.

FOLIATIONS IN A TWO-INCH ANTICLINE.

Rhoscolyn.

(Figure 87) Foliations in a two-inch anticline Rhoscolyn

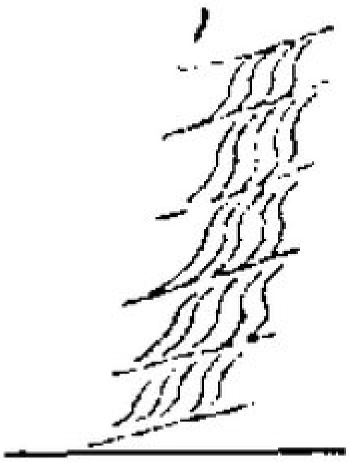


FIG. 88.

MINOR STRUCTURES AT THE END OF THE SOUTH STACK.

(Figure 88) Minor structures at the end of the South Stack

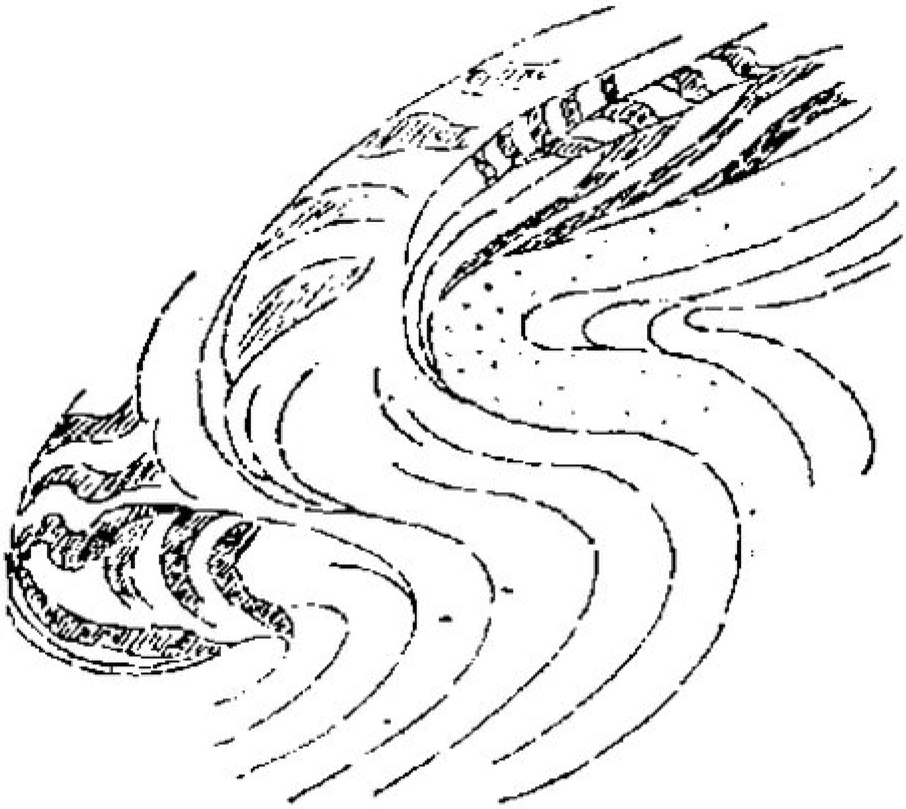


FIG. 89.

FOLDING OF FOLIATED MINOR THRUST-PLANES, WITH TRUNCATION OF BEDDING.

(Figure 89) Folding of foliated minor thrust-planes. With truncation of bedding. Headland three-sixteenths of a mile east of Clybyddiad. Height, about two feet.

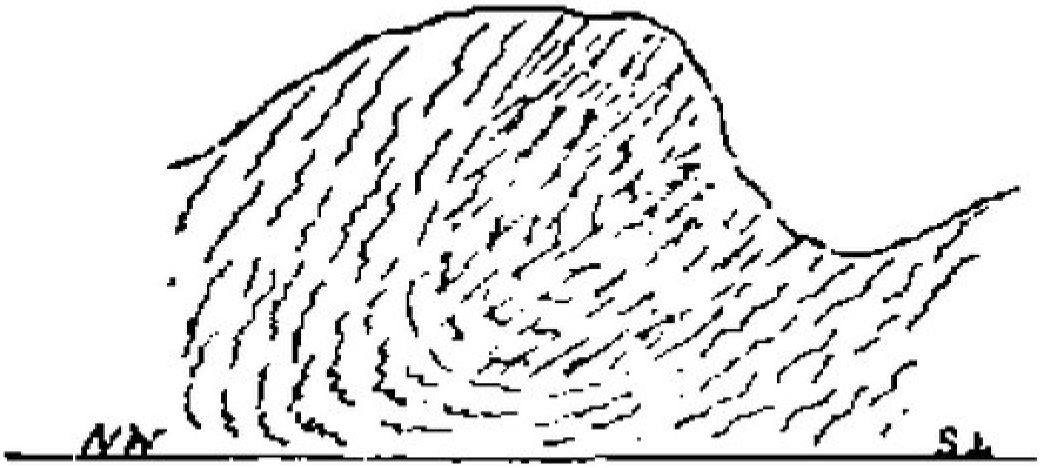


FIG. 90.

SECOND FOLIATION CROSSING THREE-FOOT ISOCLINE OF GLAUCOPHANE-SCHIST IN MICA-SCHIST.

(Figure 90) Second foliation crossing three foot isocline of glaucophane-schist in mica-schist Farm north-east of Tyddyn-fawd.

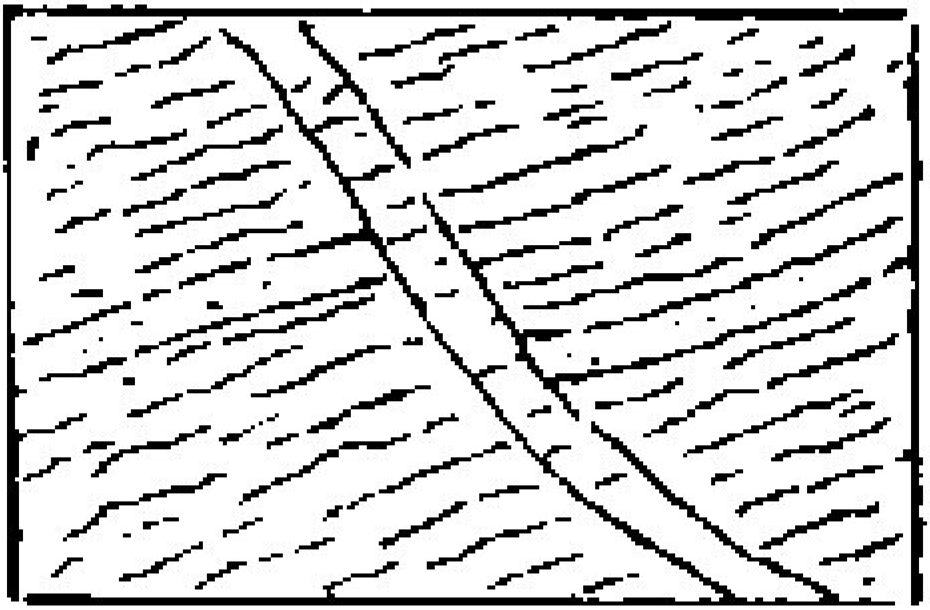
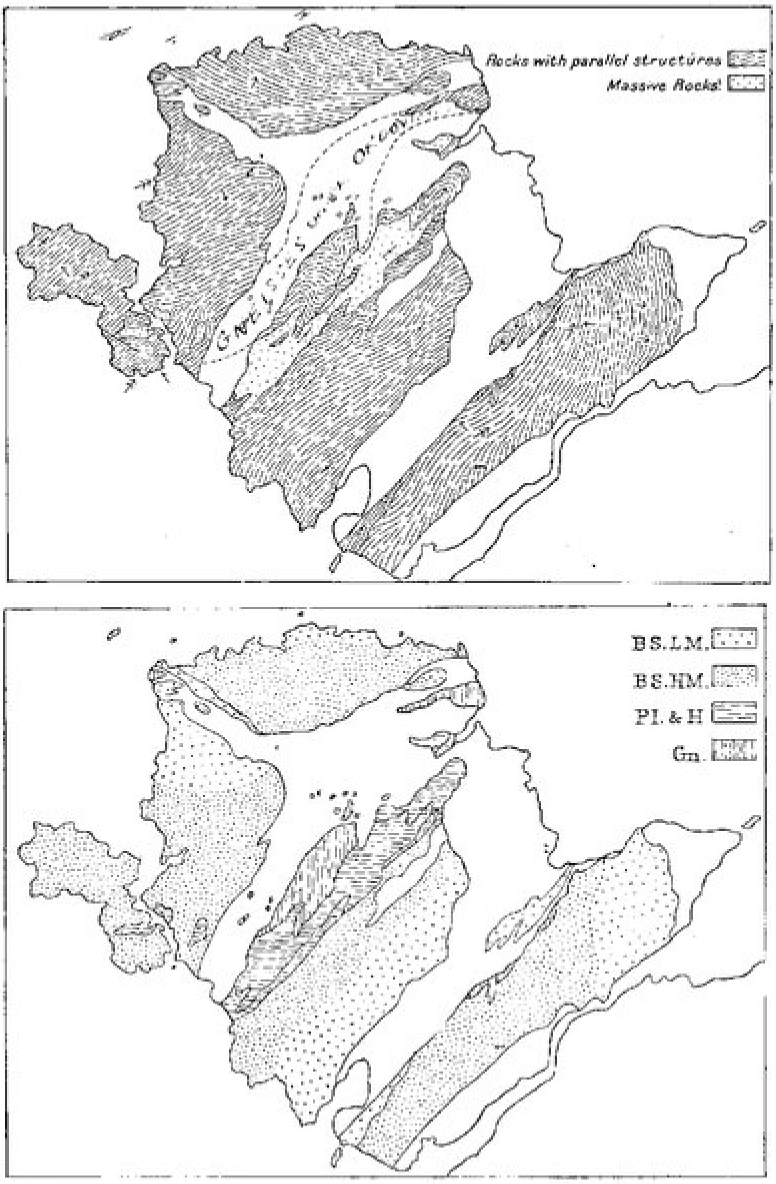


FIG. 177.

QUARTZ-VEIN

(Figure 177) Quartz-vein In fault, crossed by foliation of Glaucophane-schist. Farm north-east of Tyddyn-fawd.



(Figure 101) a. Chart showing the general directions of strike and other structures in the Mona Complex. Scale: 1 inch = 6 miles. 101B Chart showing the distribution of the metamorphism in the Mona Complex. Scale: 1 inch = 6 miles. BS. LM. = Bedded Succession, Low Metamorphism. BS. HM. = Bedded Succession. High Metamorphism. PI. & H. = Plutonic Intrusions and Hornfels. Gn. Gneisses. Note: To bring out the waxings and wanings. delicate gradations of stipple would be required that could not he applied to a small-scale chart. The chart here given ignores all gradation, and minor complications, but shows at a glance the general distribution of the metamorphism.