Chapter 41 Additional studies

This chapter is designed as a repository for a number of studies which, for one reason or another, could not be placed in the preceding parts of this book. Several of them (the Hereford Earthquake, for example) are isolated subjects. But most of them are expressions of ideas which have developed since the parts of the book' to which they belong have been printed off. Such addenda really form part of the natural course of the argument, and it is requested that they be read, not here, but at the places which have been already indicated on the Addenda-sheet near the beginning of the book, and are also given in footnotes to their titles. They are arranged in two groups, those on miscellaneous subjects being placed first, and those on the Mona Complex (which are for the most part more important) second. Especial attention is asked to the interpolations on the Age of the Mona Complex, on Folding and Metamorphism, and on the Reconciliation of the Metamorphic with the Tectonic Succession.

Miscellaneous studies

The Hereford Earthquake of December 17, 1896

The varying manifestations of this earthquake in Anglesey and along the Menai Strait showed that the impulse was considerably modified by the nature of the rocks and by the geological structure. From 40 reports collected in the district<ref>See Bibliography, p. 34, Dr. C. Davison and E. Greenly.</ref> it was found that the shock was felt most powerfully upon Carboniferous and Ordovician rocks, less so upon the volcanic rocks of Bangor, and least of all upon the Mona Complex<ref>The presence of Glacial drift seems to have made less difference than the nature of the underlying rock.</ref>; that is to say, in inverse ratio to the stability and elasticity of the rocks which form the surface. It had long been known, from experience of the Lisbon and other formidable earthquakes, that buildings standing upon gravel or alluvium are apt to be far more severely shattered than those standing upon solid rocks. The Anglesey results, therefore, extend the same principle to differences in degree of elasticity between the several solid rocks themselves.

No connexion could be found between the intensity of the shock and any of the local faults, whose behaviour was evidently quite passive. But intensity was greater in the neighbourhood of junctions, whether faults or not, and whether they were at high or at moderate angles to the horizon. This was found to be the case on the north-western slopes of the Malldraeth, towards Bodorgan, where the base of the Carboniferous series rests, at an angle of some 30°, upon the Mona Complex. The strike of these junctions, faulted or otherwise, is north-east and south-west, which is precisely at right angles to the general direction of propagation, the epicentre at Hereford being directly to the south-east. This connexion between junctions and intensity would appear to fall, moreover, under the law of inverse ratio just enunciated; for junctions between formations are planes of discontinuity, which would reduce the general stability and elasticity for some distance on either side of them. The unequal elasticity of the two formations, moreover, would also tend to set up reflection, or what may perhaps be called reverberation, at the junction-plane. The direction of propagation is reported as being from the southeast, except upon the Carboniferous rocks of the Straitside, where it varied considerably. Now, though the Dinorwic fault has the usual strike, the Carboniferous base in that tract runs nearly east and west, and rests partly on Ordovician rocks, partly on the Mona Complex. It would appear, therefore, that the local deflections may be ascribed to these exceptional conditions.

The Mona Complex being the foundational formation of North Wales, the vibrations that emerged in its Aethwy Region might be supposed to have had a long journey in the same Complex underground. Their journey, however, being from Hereford to Anglesey, was north-westwards, directly across the dominant strike of all the country traversed. Nov, the epicentre was 100 miles away, and Dr. Davison considers that the depth of the focus from which the principal vibrations proceeded cannot have been more than a few, and is unlikely to have been more than five miles. Consequently, the seismic impulse when reaching Anglesey must have been at a low angle, probably not more than 3°, to the horizon. But in its path were the Harlech anticline, in which the Sub-Cambrian floor must rise to within a moderate distance from the surface; and then the Snowdonian syncline, where that floor must descend to a depth of more than 17,000 feet. Protracting from the latter position to sea-level at the Menai Strait, the angle subtended is about 20°. The seismic impulse must therefore have entered and left a dome of the Mona Complex, and then have traversed. a deep mass of Palaeozoic rocks, before it was transmitted to that portion of the Complex which emerges in the Aethwy Region of Anglesey. Leaving that, it must have traversed Ordovician and Carboniferous rocks in the Malldraeth infold before it could be transmitted to the Middle Region of the Complex.

It appears, therefore, that the local intensity of a shock varies inversely as the stability and elasticity of the rocks; and that stability, even in highly elastic rocks, is low in the vicinity of junctions, points that may be of some importance in countries where formidable earthquakes are frequent. It further appears that a seismic impulse, when at a long distance from the epicentre, though still travelling upwards as well as onwards, may, in powerfully folded countries, be transmitted not only from lower to higher, but from higher to lower formations. Further investigation of the modifications of seismic impulses by geological structure would probably yield results of considerable interest.

The ice-worn slab in the dolmen of Henblâs

Geologically, the most interesting of the megalithic monuments<ref>See 'The Megalithic Remains of Anglesey', by E. Neil Baynes (*Trans. Hon. Soc. Oywntrodorion,* 1910–11, p. 3); also 'The Cromlechs of Anglesey and Carnarvon-shire', by J. Griffith. I have examined all but a few of those in Anglesey. They are (except, possibly, that of Llanddyfnan) composed of materials which could have been obtained on the spot, either from rock in *situ* or from ice-borne erratics.</ref> is the dolmen at, Henblâs, Llangristiolus, which is of rude and massive aspect. Two uprights are standing, very rough and irregular in shape, the larger one being about 15 feet high and nine feet thick. Resting against these, at an angle of about 20° from the horizontal, is the fallen top-stone, about 13 feet square and only three feet thick. All are of the local Gwna quartzites. The material appears to have been obtained on the spot, as there are some obscure exposures that seem to be *in situ.* Now the top-stone is rough, like the uprights, on its upper surface, but its under-side is ice-worn. Clearly, then (for it is certainly not a boulder), it has been turned upside down. Further, not only is it ice-worn, but the direction of the ice-movement can be made out, there being distinct onset-and-lee-sides to its finely striated bosses, and the lee-sides look to north-north-east. But the direction of glaciation in the district is to south-south-west. Therefore the stone has not only been turned upside down, but turned round as well. So the builders did not lift the stone by merely wedging up and up:' they dealt with it much more freely.

Land-surface and earth-movement

We have attempted to form physiographical pictures of certain old land-surfaces, but the part played by earth-movement in bringing on terrestrial conditions has not been dwelt upon.

The oldest surface of which any portions are still preserved appears (p. 783) to be of Pliocene age. But from all that is known, the Area seems to have been involved in the elevation and terrestrial conditions which were prevalent over most of the western British region<ref>The Tertiary anticline (p. 778), with which the late faults (p. 689) are doubtless connected, may be regarded as incidental to this general elevation.</ref>, throughout the greater part if not the whole of earlier Tertiary time. So prolonged an exposure must have involved severe erosion, but for the reason about to be given we are unable to form any estimate of it.

A plain of marine denudation was doubtless formed (p. 895) in Cretaceous times, but the next land-surface of which there are any indications must be assigned to the Carbonifero-Triassic interval. The Post-Carboniferous disturbances must have brought such a surface into being, for, the conditions of the Red Measures having been pene-terrestrial, there was no deep submergence to cancel, and the great Carboniferous anticlines must have risen above sea-level. That several thousand feet of rock have been swept from them is manifest, but, unfortunately, not a single Mesozoic outlier has been discovered, so that we are unable to say how much of Post-Carboniferous erosion is the work of Triassic, how much of early Tertiary time. The differential movement which followed the deposition of the Coal Measures was on a far smaller scale, but it effected the change from the physiographic and climatic conditions of the Coal Measures to those of the desert-basins of the Red Measures.

Turning to the principal inter-formational intervals of Palaeozoic time, we find high land-surfaces in existence at the opening of the Carboniferous, Old Red, and Ordovician periods. Each of these was preceded by an epoch of powerful earth-movement, the amplitude of whose folds exceeded in each case the greatest height we are able to assign to the land-surface. The amplitude of the Post-Silurian folding, indeed, is very greatly in excess of the relief of the land of Old Red Sandstone time, which, there is little doubt, is but a degraded wreck of part of a range which, with true mountain-structures, attained to true mountainous dimensions. The development of each of the high Palaeozoic lands may therefore be ascribed to the disturbances with which the preceding epoch terminated.

This brings us to the most interesting question of all. Can we discern signs of any Pre-Cambrian land-surface, and if so, can we find any genetical connexion between it and the great movements of the Mona Complex? Now, more than one writer has been struck by the remarkable development of the Cambrian series around the Harlech anticline, where not only has it a visible thickness of some 13,000 feet, but the base is at an unknown depth. Most of these deposits, being too coarse to have accumulated in any but shallow water near to shore, indicate the subsidence of a very lofty land, besides which, their mere bulk shows how vast was the mass that was destroyed by Cambrian denudation. Further, the nature of the pebbles indicates that, on some of the secondary anticlines, the Mona Complex was cut into as far down as the upper parts of the Nappe of Holyhead, which must have underlain an astonishing thickness of the tectonic succession. Accordingly the land could only have remained low. if elevation had been so slow that denudation was able to keep pace with it. This, in view both of the nature of the movements and of the resultant anamorphism, is obviously incredible. Finally, wherever disturbances of the same kind and on the same scale as those of the Mona Complex have taken place in Tertiary (and thus *comparatively* recent) times they have resulted in mountain-building. There seems, therefore, no room for doubt that the Mona Complex, in Pre-Cambrian times, was a part of a mountain-chain of not less than Alpine dimensions.

Records of an even more ancient land-surface are preserved to us in the fragments of metamorphic rocks which are (pp. 43, 61–3, 165–6, 169, &c.) contained in the pebbly beds of the Mona Complex. To put forward, on such scanty evidence<ref>Though the Gneisses are believed to be really a part of this old complex.</ref>, any propositions at all concerning the conditions of an epoch so inconceivably remote may well seem presumptuous. Nevertheless, just as in the preceding study, the great thickness of shallow-water deposits in the Bedded Mona Succession tells us of long continued subsidence concurrently with prodigious waste, while the nature of the fragments is conclusive as to powerful shearing stresses which induced the highest grades of dynamanamorphism, and at the same time as to an erosion which was able to lay bare the most deep-seated of these anamorphic products. Consequently, reasoning as in the case of the Mona Complex itself, we can but come (however generally and vaguely) to a similar conclusion.

Thus, throughout the whole record preserved in the Island, we find a rhythmical recurrence of the characteristic geological cycle, tangential disturbance building up structure and bringing in terrestrial conditions, terrestrial conditions resulting in erosion, and erosion in complementary accumulation 6–1 sediment within basins of vertical subsidence, thus providing material with which tangential disturbance is able to repeat the cycle.

The depth of Red Measure erosion <ref>To be read as an interpolation in Chapter 25, p. 670.</ref>

On p. 670 it was suggested that the pebbles of the Mona Complex contained in this formation might have been washed out of Palaeozoic conglomerates. Red Measure erosion, however, cut down to the Posidonomya zone in tracts where the Dibunophyllum limestones have nearly thinned out, and the pebbles of Ordovician grit show that it even cut down through the Carboniferous base in places. But, on both sides of the Malldraeth, quite close by, the Carboniferous oversteps from the Ordovician on to the Mona Complex, and rests directly thereupon. It is evident, therefore, that the Complex must have been, to some extent, exposed, and so the pebbles of Gwna quartzite, which could have come from the Middle Region, must be supposed to have been derived from those exposures.

The age of the Palaeozoic intrusions<ref>To be read as an interpolation in Chapter 16, pp. 510, 516.</ref>

On pp. 510, 516, the belief was expressed that these intrusions are of Post-Silurian date, but with reservations, on account of the nature of the Parys Mountain evidence. The unity of the cleavage ought to have been regarded as decisive. The hornblende-picrites, though late, are (p. 497) one with the rest of the intrusions. The picrites are later than the cleavage of the Harden shales, later even than the beginning of the thrusting. Now the cleavage in the Hartfell shales is one with that in the Llandovery shales. It follows that the intrusions are Post-Llandovery; and if so, then Post-Silurian, for no more than trifling local breaks are known in the Silurian rocks of Britain.

Since Chapter 16 was printed off, also, confirmation has come from other quarters. Mr. H. G. Smith, in an interesting paper<ref>*Geol. Mag.,* November, 1918.</ref>, has shown that the diabases of Gelli, Radnorshire, are intrusive into a limestone of Llandovery age. He also quotes a statement by Prof. Watts<ref>*Proc. Geol. Assoc.,* 1894, p. 342.</ref>, which had escaped my memory, that the basic intrusions of Shelve alter the Pentamerus limestones.

Palaeozoic and Tertiary vulcanism<ref>To be read as interpolations in Chapters 16, pp. 498, 516; 38, p. 169.</ref>

The Ordovician volcanic series which is developed on such a great scale in the adjacent mountain-land is absent from Anglesey. A few volcanic fragments appear (p. 405) to have been carried thither by southerly winds, but their scarcity is remarkable, and suggests that the prevalent winds were then from northerly directions. The Palaeozoic Intrusions, which are undoubtedly later than those eruptions, are closely' related to powerful tangential impulses, and among them, in true accord with the Harker-Bowen principle (p. 898), calcio-magnesian types are dominant. But their acid members are natrian, and even their basic ones are extensively albitised, so that, as in the volcanism of the Complex (p. 899), conformity is less complete than in geosynclinal depression. The Tertiary dykes are calcio-magnesian, and are but slightly albitised, but the local movements of that age are comparatively equable, so that the nature of the dykes can be discussed only in relation to British Tertiary vulcanism in general, which is outside the scope of this work.

A persistent petrological tendency

As the formations of Anglesey represent a large part of Palaeozoic and older time, it will be interesting to enquire whether any common characters can be discerned among them. The Mona Complex we have already found (p. 14–9) to be characterised at once by a high sodium- and a high titanium content. Its volcanic rocks are alkaline and highly natrian; its sediments extraordinarily rich in albite, and sometimes in titanium; while even its Plutonic Intrusions (except the peridotites and pyroxenites) are more or less natrian and titaniferous<ref>In this case, as in those of all the rocks connected with tangential stress, the characters. here noted are duly modified in accordance with the Harker-Bowen principle (pp. 898–9).</ref>. The Palozoic sediments (especially the Cambrian and Ordovician) contain (pp. 246–52, 390, 394, 399, 404–5, 440, 462, 578, 602, 660–61, 669–70) prodigious quantities of albite, with pebbles of spilites, titaniferous albite-gneisses and other albitic rocks, chiefly but not exclusively from the Mona Complex. The felsite of Bwlch-gwyn (p. 399) is an albite-rock. The Palaeozoic Intrusions we have found (pp. 497–8) also to possess a high sodio-titanium content, though with a waning as compared to the Mona Complex. In the Later Dykes (pp. 684–5) a heavy drop of both elements is at once apparent, yet albitisation is not unknown, besides which the felspar of the segregation-veins is wholly albite.

Now the rocks of what we have called the Ancient Floor (p. 169) are sodio-titaniferous in a high degree. The sediments of the Island are the children of those rocks, the older ones being in the first generation of descent, and even the later ones, owing to the frequent unconformities and overlaps, to some degree in the first, though chiefly in the second and third generations, 'through the medium of the older ones. The igneous rocks, having come from magmas which cannot be supposed to be foreign to the region, we are compelled to regard as descended in some way from the ultimate source of all the sedimentary rocks.

Thus, running through the whole geological record of Anglesey, we can discern a persistent recurrence of considerable sodium- and titanium-content, which may perhaps be spoken of as a primitive hereditary strain of the petrological province, becoming slowly attenuated in generation after generation.

The age of the Careg-Onen Beds<ref>To be read as an interpolation in Chapter 12, pp. 397–9.</ref>

The Careg-onen Beds and the Trefdraeth Conglomerate both contain pebbles of old quartz-felsites, pebbles which are extremely abundant in the Cambrian conglomerates of Carnarvonshire. On Mynydd Llwydiarth, they rest upon the Nappe of Bodorgan, and contain fragments of its Penmynydd rocks. The Trefdraeth Conglomerate rests upon the Nappe of Bodorgan at the Hermon anticline, but contains fragments of granitoid rocks. Whether these be derived from the Coedana Granite or the Gneisses is not yet known, but in either case they seem to indicate that erosion had already cut down to the upper part of the Nappe of Holyhead. As that is the tectonic horizon to which Cambrian erosion seems to have cut down, it is unlikely that these rocks can be so much older than the Harlech or the St. Ann's Grits as to be separated from either by any serious unconformity. Adding these considerations to those given on pp. 397–9, the balance of evidence appears now to be in favour of regarding the Careg-onen Beds and Trefdraeth Conglomerate as of Cambrian age.

The determination and development of the coast-line

This question has been dealt with in one way or another on pp. 780, 786, 791–6, 799–801, 802–3, 807–9, 810; but as the coast was first determined and developed in Pre-Glacial, and then re-developed in Post-Glacial times, there was no logical place in Chapter 34 for the subject as a whole.

We have seen (p. 780) that the surviving part of the Menaian Platform, composed of the Mona Complex and Palaeozoic rocks, must once have been a mere nucleus, enclosed within a vastly wider periphery composed of much softer rocks, most of which were Mesozoic; and that the present confines of Anglesey coincide roughly with the limits of this old hard nucleus. When, and how, were those limits first determined? Well, there is evidence that the nucleus itself is really (p. 778) the core, several times planed-off, of an Early Tertiary anticline. So its position and general outline-form were determined by the position and form of the flanks of the anticline.

Returning to the Menaian Platform, it is not difficult to see (p. 810) that the erosive forces under whose power the softer periphery gradually wasted away, must have received a sharp check when they had cut back to the margin of the hard nucleus. So that margin (probably sketched out for us by the fringe of outer isles, which curves round from Puffin, by Dulas and the three Mouse islets, to The Skerries) would have been the Pre-Glacial outline of a land which we mar, for the first time, call by the name of 'Anglesey'. Thence, but much more slowly, ensued a retreat to a second Pre-Glacial outline, whose position coincided very nearly with that of the present coast, in so far as that coast is composed of solid rock, and whose forms were essentially those which have been analysed on pp. 799–801.

The Glacial episode, however, once more considerably extended the land by enclosing the second old coast in a periphery, this time of boulder-clay. The present line has been developed by a second erosion of soft material, which has in its turn met with a check at a hard-rock limit, which is the line of the last Pre-Glacial coast aforesaid. Accordingly, that coast has been to a great extent restored. But it has not been reached everywhere, considerable tracts of boulder-clay still remaining to be cut away from the mouths of the Pre-Glacial valleys. The Forest-bed submergence has accelerated the destruction of the boulder-clay periphery, and has, also enabled the sea to attack the hard cliffs once more along considerable stretches from which it was, for a while, excluded, so that it has now broken slightly through the old limit of Pre-Glacial retreat, and is cutting still further into the solid nucleus. The same submergence has given us the beachless cliffs, with the two straits of Holy Isle and of the Menai.

Of the three open-sea coasts, about one-sixth is determined by, the present stage of retreat of the Glacial Drifts. The remaining five-sixths are essentially a. restoration (with very slight retreat) of the last limit of Pre-Glacial erosion, which in its turn is a line of retreat (varying from a trifling minimum to a maximum of two, miles at the Skerries) within the margins of the old hard nucleus of the Menaian Platform. But if, neglecting minor changes, we consider general position, form and proportions, we can see that the open-sea coasts of Anglesey were pre-determined by the differential movements which gave rise to the Early Tertiary anticline.

The comparative heights of Anglesey and of the mountain-land

While avoiding, of course, any attempt to deal with the physical history of Wales in general, it is nevertheless impossible to refrain from asking the question— 'Why is the mountain-land so much loftier than Anglesey?'

Looked at from anywhere a few miles out in the Island, the outline of the long array of mountains, though attaining a height of 3,571 feet, assumes the aspect of an exceedingly flattened dome, 50 miles across from side to side. There can be no doubt that this Welsh Highland is an ancient plain of denudation, somewhat modified, and of course very deeply eroded. Probably it has (p. 784) been base-levelled more than once—very likely in Carboniferous and Early Mesozoic times—but what is the date of its last base-levelling?

Now we have seen (pp. 777–8) strong reason to believe that chalk-with-flints is present *in situ* not more than some 20 miles from its northern bastions; and if we may rely on this evidence, it would seem very unlikely that any part of the tract under consideration can have escaped the great chalk-submergence. Its last base-levelling may, consequently, be assigned with some confidence to the Cretaceous period.

If that be so, its elevation must be ascribed to the differential movements of Early Tertiary time; and we should be justified in regarding the gentle, 50-mile aerial curve which just touches the summits of the mountains of Carnarvonshire as the profile of the Sub-Cretaceous plane of marine denudation, raised into a broad anticline of Tertiary age.

But we have also seen (p. 778) that Anglesey itself may be regarded as the site of an anticline of the same age, wherein the Cretaceous base must rise to at least 700 or 800 feet above present sea-level. This may therefore be looked upon as a subordinate lobe, on the north-western margin of a vastly greater anticline, whereof the mountain-land is the denuded core. At first glance it might seem as though the rise must be too steep for this to be probable. But it is really very slight, the angle of dip necessary to carry the Cretaceous base from its lowest admigsible level at the Menai Strait over the level of the summit of Snowdon being only 3°. At right angles to this, the south-westward inclination of the visible dome-profile is only 1°.

It is true that the rise from the Tregarth Shelf to the mountain-summits is 8° or 9°, to the foothill summits as much as 18° or 20^0; but this may be ascribed, first, to cutting back in Early Tertiary time, facilitated by the softness of the uncleaved Ordovician shales under the lee of the Padarn ridge; and then to the cutting-out of the Pliocene platforms. A concave profile of excavation would thus be substituted for a convex one of differential elevation. Further: the Island itself has been base-levelled several times, and is now considerably lower than any position which can be postulated -for the Cretaceous base within its area.

We seem, therefore, justified in ascribing the great difference of height between Anglesey and the adjacent mountain-land to the difference between the amplitude of a principal Tertiary anticline and the amplitude of a lobe on its north-western flank. In such case, the difference due to tectonic agency would have been added to by the dcnudations which have cut Anglesey down to the level of the Menaian. Platform. Finally: the suddenness with which the mountains rise may reasonably be regarded as an effect of successive Tertiary erosions, which have cut some way back into the flank of the principal anticline.

Additional studies on the Mona Complex

Though some of these are upon points of mainly local importance, others are upon chronological, volcanic, a,nd tectono-metamorphic problems of general interest.

The Mona Complex Outside Anglesey

Strictly speaking, this question is outside the scope of a work on the Geology of Anglesey, but a brief summary of what seems to be known may be of service. The kinship of the Gneisses (pp. 133, 142–3) to those of certain parts of Scotland is suggestive (pp. 162–3, 167–9) of more than mere petrological accident. But suggestion is, of course, the utmost that can be put forward at present. As to the Bedded Succession, it is manifest that so great a stratified series must extend far outside the limits of the Island. Yet, so far, only two places are known where we can venture on anything like a correlation. These places are the Lleyn country and Howth Hill by. Dublin, where there is little doubt that we can.

recognise the Gwna Beds. Of the other possible tracts in Southern Britain, all that can yet be said is that several of them contain rocks which resemble certain members of the Succession. Turning north-westward, we find that quartz-schist, graphitic schist, and limestone are common to the Lewisian, the Dalradian, and the Mona Complexes, while peculiar green-schists<ref>Geikie, 'Ancient Volcanoes of Great Britain', p. 129.</ref> appear to be common to the two latter. Thus there is good ground for hope that correlation may some day be achieved. But the perplexities arising from lack of fossils, with changes of metamorphic state and especially of facies<ref>In the Torridon Sandstone, we have a great Pre-Cambrian formation which is quite unaltered and. also an obviously very special facies. It may therefore be expected to reappear elsewhere in some totally different guise.</ref>, grave even within the limits of a single complex (p. 152), become of course vastly graver when we attempt to overpass its limits. Possibly, too, the Mona facies, which are so highly volcanic, may not prove to be the best on which to found any system or systems that may be eventually established.

Vulcanism in the Mona Complex<ref>Interpolate in Chapter VIII, p. 233, before 'Facies and Physiography'.</ref>

In view of the great antiquity of these volcanic outbreaks, a concise recapitulation of their nature and relations may he of interest. Whether, among the original sedimentary rocks that seem (pp. 138–9) to be the basis of the Gneisses, there were any true contemporaneous volcanic products, can (for the present) only be conjectured, though the conjecture is (pp. 138, 325, 328) far from being unreasonable. The period of the Bedded Succession, however, opens with a great volcanic episode, whose products, which include both lavas and pyroclastic rocks, are thoroughly acid, highly alkaline, and for the most part natrian in composition. The Fydlyn vulcanism seems to have died out rather suddenly, and then came a period of quiescence. When, in Gwna times, activity was resumed, it was again alkaline, but of the spilitic type. The first eruptions, which were the largest, appear to have been effusive only, but the second include a few beds of spilite-tuff, while spilitic dust appears to have been widely disseminated in small quantity during the deposition of the Gwna sediments. Many small sills of albite-diabase were also injected. After another pause, activity was resumed on a great scale, but it was almost wholly explosive. Such lavas as are known are still spilitic, but they are very few and very thin; whereas the dust-accumulations of-the Church Bay Tuffs are some 2,000 feet in thickness. The composition of these dusts raises rather curious questions. The northern or Skerries facies of their upper beds is mainly composed of quartz liberated by the explosion of sodio-felsitic lavas, with a dusty matrix of the Church Bay type, and large blocks of albitic felsites and granites occur in them locally. Their Church Bay facies appears (pp. 56–8) to be derived from the explosion, partly of spilitic, partly of rhyolitic lavas, and yet it is wonderfully homogeneous. Now tuffs of hybrid composition are by no means unknown<ref>Harker, 'Petrology for Students', p. 270, and 'Tertiary Igneous Rocks of Skye', p. 59; Sir A. Geikie, 'Ancient Volcanoes of Great Britain', vol. i, pp. 148–51, 214, 234, 279–80, 322.</ref>, but most of those which have been described appear to be comparatively coarse. It is not easy to understand how dust from distinct explosions. or derived in part from explosion, in part from trituration, could mingle so thoroughly, especially on so great a scale. The whole Skerries Group, in fact, presents -an interesting problem in vulcanology. After another pause, came another outpouring of lavas, again of exclusively spilitic type, and rarely accompanied by true tuffs, though almost the whole of the sediments of the New Harbour Group appear to be tinged with a sprinkling of spilitic dust. Finally, just as that epoch was coming to a close, there was a brief explosive outbreak, to which we owe the thin green tuff, with its one local stream of spilitic lava, that lies immediately below the base of the South Stack Series. With it, and somewhat abruptly, this long volcanic history terminates.

The character of the products is pronounced, natrio-felsitic eruptions taking place on two, while spilitic recur on no less than five horizons, the spilites being, considered as a whole, the later. We cannot but be struck with their marked alkalinity, and with the dominance of sodium. All, save perhaps the great homogeneous mass, of the Church Bay Tuffs, appear to have been marine; and the total thickness of volcanic material seems to be between 7,000 and 8,000 feet. No trace of a vent has been discovered, the only intrusions that can be contemporaneous being the albite-diabases of the Llanddwyn suite, with (possibly) the acid rocks which are known only as boulders in the Skerries Grits. Now, throughout the whole of the Bedded Succession, whose deposits do not appear to be less than 20,000 feet in thickness, only one stratigraphical break, and that merely local, has been detected. In spite, therefore, of the marvellous disturbances to which they were subsequently subjected, these rocks were laid down in a region of profound but gentle and tolerably steady subsidence. The vulcanism of the Bedded Succession thus exemplifies in a striking manner the principle recently enunciated by Dr. Harker<ref>Pres. Address Geological Society, *Quart. Journ. Geol. Soc.,* 1918, pp. lxvii—xcvi. An extension, really, of the proposition of Messrs. Dewey and Flett that spilitic eruptions are characteristic of subsiding volcanic areas.</ref> (and connected by him with the researches of Bowen), that alkaline, and especially natrian, types are closely connected with the subsidence of geo-synclinal depressions.

Turning to the deep-seated intrusions; the oldest in the Island, so far as can be made out (p. 903), is the unmodified portion of the basic gneiss, which is a highly titaniferous albite-diorite. Next in age are the acid permeation-components of the Gneisses, which are albite-granites. In places they contain oligoclase, but the possibility that this may be of xenolithic origin is not to be forgotten. Parted from these ancient rocks by an immense interval of time is the suite which we have called the Plutonic Intrusions, which comprise dunites, pyrolenic peridotites, pyroxenites, gabbros, dolerites, diorites, and granites. The original felspar of the gabbros has disappeared, and the felspathic portion of their saussurite is now albite. The dolerites were labradorite-rocks, but are now partly albitised. The diorites are as yet imperfectly known, but one group is found, though highly zoisitised, to contain some albite. The Coedana granites vary considerably, but may be summarised as orthoclase-albite-biotite-muscovite-rocks, poor in the micas.

Now, little as we know of the Gneiss-building movements, it is certain that their nature was that of heavy shearing stress; that the appearance of the basic-gneiss magma took place either before they began or at an early stage of them; and that the granitisation came on towards their close. The Plutonic Intrusion-suite has been shown to belong to the period of the great disturbances to which the constitution of the Mona Complex itself is due, appearing during an interval between the recumbent and the major secondary folding. Thus, all the deep-seated igneous rocks of the Complex are intimately connected with intense lateral thrust. Accordingly, calcio-magnesian types are conspicuous. But conformity to the Harker-Bowen principle is not so complete as in the case of the volcanic products, for, except the peridotites and pyroxenites, all these rocks are more or less natrian, the oldest being very highly so. We may expect to be able to explain this exception when we know more of the position of the intrusions in regard to the tracts of regional disturbance and metamorphism; with their relations, possibly to one another, in any case to the primitive provincial magma.

Another analysis of the Holyhead Quartzite<ref>To be interpolated in Chapter 1V, on p. 41.</ref>

The following analysis, made since Chapter IV of the present work was printed off, has been kindly supplied by the Geological Survey. It was made for, and will appear in Vol. VI of the 'Special Reports on the Mineral Resources of Great Britain', which are in course of publication.

SiO_2	97.78
TiO_2	0.33
ZrO_2	0.09
Al_2O_3	0.68
Fe_2O_3	0.44
MnO	0.05
(CoNi)O	nt. fd.
CaO	0.11
MgO	0.03
K_2O	0.37
Na_2O	0.01
Li_2O	trace
H_2O	at 105° C. 0.05
H_2O	above 105° C. 0.10
P_2O_5	nt. fd.
FeS_2	nt. fd.
C	trace
CO_2	0.05
Total	100.09
	Breakwater Quarries, Holyhead. (E11636) [SH 227 833]
	Anal. E. G. Radley.

This variety, which contains 1.78 per cent. more SiO_2 than No. I, must be quite as siliceous as (E10127) [SH 220 832], the massive rock of the southern escarpment. In the present analysis nine more elements are estimated than in Nos. I, II, III, but all of them are doubtless present in those rocks.

Some improvements in nomenclature

The Green-Mica-Schists<ref>Substitute in Chapter 4, on p. 46.</ref>

It would have been better if the stratigraphical term 'New Harbour Beds' had been substituted for this as a heading (also on pp. 50, 52, 55, 79, 109, 146–7, 157–8, 262, 265–6, 269, 272, 278, 286–7, &c.), as it is used in the scheme of the General Succession on p. 164. Green-mica-schist' is really a special metamorphic state of some of the New Harbour Beds.

The thrust-planes at Porth-yr-hwch<ref>Substitute in Chapter 8, on pp. 214, 291–4, (Figure 130), (Plate 25), (Folding-Plate 10), also pp. 464–5.</ref>

The 'Hwch Lower Thrust-plane' might with advantage be referred to simply as 'The Hwch Thrust-plane', and 'The Hwch Thrust-plane' as 'The Gader Thrust-plane', since the Gader Gneisses ride upon it.

The Bodafon Moor Flags<ref>Interpolate in Chapter 10, on p. 336.</ref>

It ought to have been stated more explicitly that these beds are correlated (p. 221) with the Gwna grit and phyllite. They have been given the Gwna colour and symbol on the one-inch map, though they are in an unusual anamorphic state, somewhat intermediate between that of the hornfels and that of the Penmynydd Zone.

The Plas Newydd Boring<ref> Interpolate in Chapter 10, pp. 367–8.</ref>

In the park, 800 yards south of Llanfair Station (p. 658), Penmynydd mica-schist was reached at a depth of 133 feet, and pierced for a further depth of 110 feet. There is no glaucophane-schist in the cores. On the Sub-Carboniferous floor, therefore, we may infer that the glaucophane-schist is either wedging-out or has risen on the pitch, probably the latter.

The age of the North Stack and Namarch Faults<ref>Interpolate in Chapter 7, on p. 201, after paragraph on 'Final Catamorphic Movements'.</ref>

These, two master-faults (pp. 171–2, 256, 260), though of great magnitude, have singularly sharp local curves. Also, while the North Stack fault produces 12 feet of breccia, the Namarch fault (Plate 17) has no fissure at all, but is compressive, and even induces a slight schistosity on the downthrow side. The other may have resembled it originally, and have been converted into a brecciating fissure by recurrent movement. Being parallel ruptures with the same direction of hade, we cannot but regard them as a pair of twins, originating in essentially the same period and from the same causes. Now there is definite evidence as to the age of the Namarch fault. The great dyke of Holyhead, of whose Palaeozoic date there can (pp. 508–14) be no doubt, passes, without the least deflection, across it, cutting it at an angle of 43°. The fault, therefore, must be Pre-Ordovician.

It happens that we know of others of similar date, such as the Treban fault (p. 333), which fails to displace the base of the Arenig Beds at Bryngwran; and an inspection even of the one-inch but still more of the six-inch maps will show that. the Mona Complex is cut by great numbers of such, which strike at the Ordovician rocks without passing into them<ref>There is no ground for assigning them to the Cambro-Ordovician interval, whose movements, at any rate over the site of Anglesey (p. 401), show no sign of having been on such a scale or of such a type.</ref>. Yet those that can be shown upon the maps are few compared with the multitudes that are met with on the ground, even hand-specimens often containing one or more. Most of them, like the two great faults of Holy Isle, pass abruptly, often at 90°, across the folding- and foliation-strike, and unlike the small mylonising thrusts (p. 201), they are found on all tectonic horizons.

The recumbent folding of the Complex must have brought about remarkable redistributions of load, involving (*cf.* p. 557) great readjustments in the vertical dimension. The North Stack, Namarch, and other faults of this class may therefore be assigned with considerable confidence to the period of readjustment and settlement with which the great movements of the Mona Complex were finally concluded.

The Penmynydd Zone<ref>Interpolate in Chapter 10, p. 386, and Chapter 8, p. 223, line 14.</ref>

When setting forth the horizons at which the Zone develops, a sentence ought to have been added, on the *tectonic* horizons to which it rises. Near the Coedana granite, we may doubt whether it rises to the Nappe of Bodorgan. At its inliers in the Middle Region its top very nearly coincides with the base of that nappe. It is not, however, limited by the Bodorgan thrust-plane, for it rises a few yards above it, the thrust being, now (pp. 179, 345), merely one of many foliation-planes in a belt of passage. In the Aethwy Region it rises far up into the Nappe of Bodorgan. These oscillations are effects of the secondary folding (pp. 227, 909–10), combined with the varying stratigraphical horizon of the base of the nappe.

The quasi-stratigraphical behaviour of the Zone at the Plâs-back and other anticlines (Folding-Plate VI) calls for a brief discussion. The rocks involved in it function locally as the sole to the Bodorgan thrust-plane, and in accordance with the law of depth, would undergo higher anamorphisrn than those riding on that thrust. The major anticlines represent the limit of the buckling to which that part of the Nappe of Holyhead was subjected. But since they and the anamorphism were products of one and the same process (pp. 907–10), the development of both would be contemporaneous. Consequently, as the rocks on the Nappe of Holyhead were being driven up into the core of the anticline, they would also be taking on the Penrnynydd anamorphism, which, ever waning upwards, no matter to what degree it might attain, would thus come to behave in a quasi-stratigraphical manner. This principle can be consistently combined with that which has been put forward on p. 222. For, in the large western emergence of the Zone, anamorphism is intensified, not only by compression against the Coedana-Caradog obstacle, but by rise of still lower tectonic horizons than those which rise at Plâs-bath<ref>That the (inverted) stratigraphical horizons, are higher is of no account; for the real index of depth is not stratigraphical but tectonic horizon.</ref>. Compression alone would, of course, be inefficient; depth is needed as well.

The foliation must not be pictured as rolling over on the anticlines. In the Middle Region it is (though often corrugated) persistently at high angles or even vertical, parallel to the axes of the major folding to which it owes its existence. Similarly, the dips in the foliation-anticline of Aethwy (pp. 228–31) are determined by the axial inclinations of the major facing anticlines of the Llanddona synclinorium, but are even more corrugated.

Folded mono-planic schists<ref>Interpolate in Chapter 7, on p. 201, last line, after ' understood'.</ref>

According to the dynamical theory of metamorphism, there is no difficulty in understanding how a massive rock should furnish a mono-planic, and a folded sedimentary series a bi-planic schist (in which, of course, mono-planism is admissible along limited lengths of the limbs). But how can a rapidly folded sedimentary series furnish a schist which is persistently mono-planic for miles together? Yet we find this in the Gwna Mélange, over large parts of the Northern Region, and especially (pp. 201, 204) in the New Harbour Beds of Holy Isle. In the Gwna Mélange, while it is true that the major folding survives, the minor folding has (at the first stage) been almost entirely replaced by thrusting (pp. 193–5), setting the lenticular autoclasts free to glide, no matter from what portion of a fold they may have been torn. As their maximum tenacity would be in the direction of stratification, their major axes would tend to be parallel to that; and as, further, those axes would tend to set themselves in the direction of shearing-flow, a general coincidence between bedding and foliation would become established. The eastern parts of the Northern Region (pp. 202, 301–2) are bi-planic, and the close approach to mono-pianism in its western parts can be explained by development of foliation along the type of thrusting that is illustrated in (Figure 65)–(Figure 66). With regard to the New Harbour Beds, especially the Soldiers' Point beds, of Holy Isle, the problem has been suggested on p. 201. How can foliation so persistently follow bedding round and round such rapid isoclinal folding? But is the bedding as unbroken as it seems? If the grits be watched, they may be seen to wedge-out much more rapidly than might be expected in so flaggy a series (as may be seen to some extent even in (Plate 20)) from which we may suspect that they are, after all, being cut out by thrusting, and that our attention is diverted from this by the wonderful beauty of the folding. Let us suppose that we are dealing with a large major fold, one of whose limbs is unusually long and straight, and keeps nearly parallel to the fold-axis for an unusual distance. Suppose that thrusting such as that in (Figure 65) develops on this limb, at an extremely low angle to the bedding, that these thrusts are then thrown into rapid minor isoclines, foliation developing concurrently (p.

48)<ref>The foliation along minor thrust-planes is another indication that it was developing contemporaneously with the minor folding. There is little doubt, indeed, that when anamorphism is once set up in a band which is undergoing folding, the foliation-crystals, such as the micas and amphiboles, are able to go on growing along planes tangential to the curve of the fold.</ref> with the successive stages of the movements. We should then obtain a folded crystalline schist which would appear to be completely mono-planic, and would, indeed, be very nearly such. But this suggestion (though abundantly supported by specimens) is made without an opportunity of re-examining the ground, and the whole subject requires further study in the field.

The age of the Gneisses<ref>Interpolate in Chapter 6, on p. 167.</ref>

The following point, though implicit, might with advantage have been made explicit. Where, as in the Nebo and Gader lnliers, orthoclase-granites are unknown, hornfels-metamorphism is also unknown<ref>The felspars of the Deri Inlier need to be examined much more extensively than they have been, before the absence of orthoclase can be asserted.</ref>. But gneissic anamorphism is quite as high as in the Middle Region. Where orthoclase-granites are found, hornfels-metamorphism invariably accompanies them. Further, orthoclase is the leading felspar, not merely of the Coedana granite itself, but of its hornfelses; whereas albite is the leading felspar, not merely of the granitoid, but of the foliated component of the Gneisses. Thus, in the Mona Complex, the two kinds of alteration are each associated with a special felspar, both in the granitoid and in the resultant metamorphic rocks.

The mutual relations of the basic and acid gneisses<ref>Interpolate in Chapter 6, on p. 163, at the end of paragraph on Position of the Gneisses'.</ref>

The basic gneisses occur as lenticular sills among the presumably sedimentary types 'A. B. C'. (pp. 138–9), into which, therefore, their primitive diorites must be regarded as intrusive. These basic intrusions, having been far more reconstructed under deformation than any of the granites, must have been long anterior to the granitisation. Are, however, any of the albite-pegmatites of the basic to be identified with the albite-granites of the acid gneiss? That they are closely allied in composition is evident, and doubtless, could we trace out their whole history, we should find that both were products of one and the same original magmatic source. Nevertheless, where we now find them, the relations of at any rate some of its albite-pegmatites to the basic gneiss point (pp. 130–3) to differentiation *in situ,* not merely at the close of, but before, and during, the process of dynamic metamorphism. Whereas the behaviour of the albite-granites is that of extraneous or at least quasi-extraneous matter, inducing thermal metamorphism upon sedimentary rocks that seem to have previously acquired a dynamic foliation. On the other hand, it is difficult to suppose that the basic gneisses should have been able to repel the granitic invasions. The subject calls for further research. In the meantime, we can begin to discern the outlines of a chronology within the Gneisses. The oldest component seems to be sedimentary. Into this were injected a number of dioritic sills, after which ensued segregation, compression, and dynamic metamorphism. Finally, while all still remained at a high temperature, came intense granitic permeation, which completed the gneissoid complex as it has come down to us.

The occurrence of Soldier's Point Beds to the west of the Namarch Fault<ref>Interpolate in Chapter 10, on p. 384, line 10 of text, after '(p. 263)'.</ref>

On pp. 174, 208, it was remarked that, if the theory put forward as to the recumbent folding were correct, Soldier's Point beds might be expected to occur about the middle parts of Holy Isle; and on p. 263 some places were mentioned where they were believed to have been found, while others were indicated where they might be looked for. After those pages had been printed-off an opportunity occurred, in October, 1917, to revisit the country about Four Mile Bridge, and re-examine some spots where flaggy beds were noted on the six-inch maps. The results were very satisfactory, beds of undoubted Soldier's Point type being identified at about a dozen places between Cae'r-sais and the Tre-Arddur gap. The best was at the 13-foot level north of Cae'r-sais, where grits three-quarters of an inch thick, and tolerably coarse, are folded in sweeping isoclines as at Soldier's Point; while their passage by alternations into the Celyn beds was visible about 150 yards farther north. Other good sections may be seen by the Wesleyan Chapel at the 23-foot level, also to the north and southwest thereof, and along a farm-lane east of the 37-foot level. Now, as these rocks everywhere adjoin the Celyn beds, into which they can be seen to pass by alternation, their discovery at so many places adds confirmation to the evidence (p. 384) for the scheme of the succession given on p. 164. Further, as Soldier's Point beds had not been recognised in the central parts of Holy Isle at the time of the surveying, the expectation of them being wholly a consequence of tectonical theory, their discovery may reasonably be regarded as a confirmation of that theory.

The Fydlyn-Gwna Junction<ref>Interpolate in Chapter VI, on p. 161.</ref>

This was revisited in October, 1917, at Fydlyn beach and cliff. At the south end of the beach (p. 289), lenticular green bands occur in the white Fydlyn rocks for some feet below the thrust. At the inner isle Gwna grits graduate by loss of chlorite and gain of felspar into the white felsitic rock. On the brow of the high cliff (Figure 32) the same thing happens, the first grits lying within the felsitic rock, in which felspar then wanes, quartz and chlorite waxing, while jasper occurs immediately above. Thus the passage by alternation is fully confirmed.

The Gwna-Skerries Junction<ref>Interpolate in Chapter VI, on pp. 159–60.</ref>

This important horizon was revisited at seven places (Caerau, Mynachdy, Clegyr-mawr, Porth-yr-hwch, the Garn Inlier, Porth Swtan, and Llangristiolus) in October, 1917, in order to ascertain whether any stratigraphical break had been overlooked; but no sign of such a break was detected. On the heights north of Caerau (p. 295) some of the Church Bay Tuff is quite massive, with wandering delessite veinlets, and yet the Gwna Beds graduate into it. The same is the case (p. 295) on clear sections west of Mynachdy. At Porth-yr-hwch (p. 159) there is much ashy matter in the closely adjacent Gwna Beds, though elsewhere in that inlier they are poor in it. At the Garn (pp. 159–60, 288), the tuff is typical close to the junction, but where the grits begin to appear, the matrix begins to grow more siliceous, as in Gwna Green-schist. At the junction south-east of the high craggy summits of Clegyr-ma wr, where, near the sea, the Gwna Beds were stated on p. 283 to be quite distinct from the Church Bay Tuffs, re-examination showed that for some yards they contain the peculiar pale-green and creamy matter of the Tuffs, alternating with grit; while conversely there are sheared gritty bands in the adjoining Tuffs which would certainly pass for Gwna Beds if found among those rocks. The passage from the Gwna to the Tyfry Beds (p. 160) was fully confirmed. At Porth Swtan, where the cliff-section is larger than elsewhere and absolutely clear, the description given on p. 159 did not call for the least qualification. Signs of some boundary-thrust separating the two groups were carefully sought for, but in vain. Even at a place where a sudden plunge of dip was observed, no rupture could be found. Both the Church Bay Tuffs (which, even in the cliff, are sufficiently well preserved for their little delessite veinlets to survive) and the Gwna Beds are unmistakable, and alternate with each other for some yards, Gwna Beds that are otherwise typical containing many layers of the tuff.

The whole of the zone of passage, 30–50 feet in thickness, is laid bare in a vertical cliff, and is one unbroken belt of rock. Reexamination of these seven sections thus confirms the view that there is a perfectly gradual passage from the Gwna to the Skerries Group. It is suggested, accordingly, that the fragments of Gwna rocks in the Skerries Grits do not imply an unconformity, but that they may be explained on the principle of contemporaneous erosion, acting in places where the Tuffs were thin, and perhaps also raised locally a little in the way that is known to take place in connexion with volcanic eruptions, though uninterrupted accumulation may be proceeding only a few miles away.

The age of the Mona Complex<ref>Interpolate in Chapter 9, on p. 253, at the end of the Review of the Evidence'.</ref>

A crucial point in connexion with this question is that if, in defiance of the evidence given in Chapter 9, on pp. 425–6, and in the preceding paragraph of this chapter, we attempt to divide the Complex at the Gwna-Skerries junction, and assign the upper portion to the Cambrian, stratigraphical difficulties will emerge within the Cambrian itself. The only possible correlations between any members of the Complex and the rocks of the mainland would be to identify the Bangor Volcanic Series<ref>Which series, it ought to be remarked in passing, we should have to place in the Cambrian system. But its age is still unknown, and is, indeed, matter of considerable controversy.</ref> with the Church Bay Tuffs and Tyfry Beds of the Skerries Group, and the Harlech with the Skerries Grits. We should then have to choose one or other of the two subjoined arrangements.

	Holyhead Quartzite		Skerries Group
'Cambrian'	South Stack Series	'Cambrian'	New Harbour Group
	New Harbour Group		South Stack Series
	Skerries Group		Holyhead Quartzite
	Gwna Group		Gwna Group
Pre-Cambrian	Fydlyn Group	Pre-Cambrian	Fydlyn Group
	Gneisses		Gneisses

The following dilemma will immediately appear. If we place the Holyhead Quartzite at the top of our newly erected group, as in the left-hand column, we shall have placed it thousands of feet up in the Cambrian, thousands of feet above the Bangor Volcanic Series or the Harlech Grits, an horizon on which it certainly does not exist<ref>If (in defiance of yet more of the evidence, especially that of the pebbles) we make the *whole* Bedded Succession Cambrian and place the Gwna Quartzite in the Olenellus Zone, the same absurdity emerges.</ref>. If, as in the right-hand column, we place that quartzite at the bottom of our Cambrian', we shall find, first, that we have violated the succession (with gradual passage) across the Gwna-Skerries junction, a succession supported not only by the mapping itself, but by uncounted sections, of which some 18 are quoted on pp. 159–161, while seven of them have been recently re-examined (see above) with this particular question in view, thus leaving its validity, and its nature, beyond any manner of doubt. In the second place, we shall be confronted by the fact that the member of our new 'Cambrian' which we have placed at the bottom and made to rest upon our 'Pre-Cambrian' is never found to rest thereon; whereas the member which, in point of fact, invariably is found to rest thereon, is the Skerries Group, which we have had perforce to place at the very top of the column!

Folding and metamorphism<ref>Interpolate on p. 205, at close of Chapter 7</ref>

In a footnote on p. 242 (combined with the Addenda-sheet) the reader was referred to this chapter for evidence as to the respective parts that were played by the recumbent and the post-recumbent movements in the production of the regional anamorphism of the Bedded. Succession.<ref>The Gneissic anamorphism, it will be remembered, is regarded as older even than the deposition of the Bedded Succession itself.</ref>

We have seen (p. 167) that the Plutonic Intrusions must be referred to an interval in the great movements. They are older than the Major Secondary Folding, for they are all traversed by planes of deformation connected with that folding, and (pp. 208, 277) the strikes and dips thereby produced are deflected around them. But we have also seen that they are later than the Maximum Recumbent Folding, for they rise From lower tectonic horizons into higher ones. The Coedana granite passes across (p. 221) the Gwyndy thrust-plane; while the diorites, which in the Middle Region are in the Nappe of Holyhead, have risen in Aethwy to the Nappe of Bodorgan, and as those of the Caradog river are associates of the Coedana granite, they confirm the tectonic transgression of that rock. These cases, it is true, might not be conclusive in themselves; but the behaviour of the peridotites and gabbros is unmistakable, £r (p. 211) in less than a quarter of a mile (horizontally) they rise from the upper limb of the Rhoscolyn to the upper limb of the Holyhead Recumbent fold.

Now all these intrusions induce thermal alteration of hornfels type, from whose nature it is clear that the general foliation of the several regions had not been developed at the time of the intrusions. It is certain (pp. 109, 273–7, 320–21) that the regional metamorphism of Holy Isle, of the Western and the Northern Regions, is later than the peridotites, pyroxenites, gabbros and dolerites. It is equally certain that the corresponding metamorphism of the Middle Region, which culminates in the Penmynydd Zone, is (p. 127) later than the Coedana granite, and that of Aethwy (pp. 121, 370–71, 372) later than an adinolisation which is dependent on the diorites. The regional anamorphism of the whole Bedded Succession is therefore subsequent to the recumbent folding.

Yet we have seen (pp. 98, 108–9, 320–21, 331) that the intrusions did find the rocks already affected by some degree of dynamic modification. What was its intensity? Nowhere (*loc. cit.* do we find any more than little shear-lines, and a fine foliation with minute micas, hardly exceeding that which is often developed along ordinary cleavage; while original structures, especially thin parallel bedding, that have been destroyed elsewhere, survive within these aureoles<ref>That hornfels aureoles are endowed with exceptional powers of resistance to dynamic metamorphism has been pointed out by Mr. Barrow, and also in the Memoir of the Geological Survey on the Ben Wyvis country.- In the Mona Complex, this power is well illustrated by the survival, not only of bedding and other original structures, but of the unfoliated thermal minerals themselves, as well as by the protection afforded to the igneous rocks within the aureole. This last effect is wonderfully well seen in the preservation of the Caerau dolerites (p. 321), and (in a less degree) of the serpentine-suite in Holy Isle, whose aureole is narrower. Of the condition to which the Coedana granite might have been reduced but for its protective hornfels we see something (p. 127) at Bodwrog and other places where the Penmynydd metamorphism has eaten its way through the aureole.</ref>. Again, at the South Stack and similar sections, the intense metamorphism which pervades the whole series is (Plate 1), (Plate 24) plainly related to the Major Secondary folding, and no sign has yet been observed of any pre-existent foliation, which, if present, would have been cut through by it (p. 202). In like manner, the foliation which has (pp. 192, 195, 204) developed along the minor and minimum thrusting is plainly related to and contemporaneous with the minor and minimum folding. Finally, we find that the modification (induced undoubtedly by the Major Secondary folding) in some of the Plutonic Intrusions themselves (p. 108) is of a vastly higher order than the original old pre-intrusion alteration of the invaded sediments; is of the same order, in fact, as the maximum crystallisation of the Bedded Succession in such a tract as Holy Isle.

We may infer, therefore, that the Recumbent Folding induced comparatively slight anamorphic effect; and that the regional anamorphism of the Complex was a work of the Secondary, Ternary, and Tessary movements.

The contrary, we may admit, might have been expected, for it seems but natural to ascribe the highest effects to the greatest of the movements. Their very magnitude, however, is an indication that they met with but little resistance; and it is not free movement, it is frustrated movement that gives rise to anamorphism. Resistance absent, energy can find relief in molar transport; whereas in proportion as that is denied, it is compelled to express itself in readjustments of the molecular kind. The inference drawn from the field-evidence can thus be justified. So long as any given fold was free to move, and able to increase its horizontal amplitude, the molecular effects were insignificant. Presently, meeting with resistance,<ref>Great increase of resistance, to be more strict. The recumbent movement, of course, met with some resistance, and did induce some anamorphism. Thus there would be less molecular inertia for the Secondary folding to overcome, and anamorphism would be greatly facilitated.</ref> transport was arrested, the recumbent limb buckled-up, and underwent intense compression; whereupon, molecular was substituted for molar movement, chemical reaction ensued, and the rocks became recrystallised.

Reconciliation of the metamorphic with the tectonic succession<ref>Interpolate in Chapter VIII, at foot of p. 241.</ref>

An application of the foregoing principle may enable us to remove a serious anomaly, to which attention has been called (p. 242 and footnotes to pp. 200, 227) as the gravest remaining objection to the interpretation of the Complex that is proposed in this work. The anomaly in question is that we have been unable to avoid placing the high-grade Penmynydd anamorphism on high tectonic horizons, while rocks that are but slightly altered have had to be assigned to lower ones, thus apparently violating the principle (p. 241) that metamorphism is a function of depth. We have sought (pp. 200, 241) to alleviate the difficulty, but it could not be removed altogether so long as the regional anamorphism was (tacitly) ascribed to the Recumbent folding. That source of perplexity has now vanished, but another<ref>It might be supposed that there was yet a third; for there seems to be a conflict between the foliation-chronology (p. 205) and the third column of the Table given on p. 241; four metamorphic periods being mentioned on p. 205, whereas only three (the Gneissic and two maxima) are set forth in the Table. Fortunately, however, this is merely a case of ambiguity in wording. The word maxima', be it noted, is in the *plural.* The lower ones in the Table would have been better summarised as 'Maxima of Holy Isle, the West, and Llanffiewyn'. And it ought to have been made clear that the said maxima comprise two metamorphic horizons, those, namely, of Holy Isle and of the Western Region, which are parted (p. 198) by the Valley thrust-planes. Thus the Table does contain all the four metamorphic periods of p. 205; those of Holy Isle and the West being placed in one group of maxima because the metamorphism of Holy Isle, though waning a little as we rise to the Valley thrust-planes, is not parted from that of the West by a minimum such as those of the North and East. The movement on the Valley thrust-planes must have taken place under much deeper load than those of the two latter. As to the Penmynydd maxima, the plural is in a geographical sense, for there seems no reason to ascribe them (p. 227 and below) to movements on widely separated tectonic horizons.</ref> still remains in the tacit ascription (pp. 182–3, 236) of all Major Secondary folding to a single episode.

Not only, however, is that assumption unnecessary, but there is evidence against it. The major isoclines of Holy Isle fail to rise into the tectonic horizon of the Western Region (pp. 196, 212), which is folded by a different impulse, the one having been to some extent (pp. 197–8) superimposed upon the other. The two cannot have been contemporaneous, and so we see that major, minor, and minimum folding<ref>The term 'secondary' (with 'ternary' and 'tessary') still applies, but in relation only to the preceding episode of recumbent folding, not in relation to all such episodes.</ref> cannot have been limited to a single episode, but must have recurred, possibly several times, in the history of the Complex. There is little doubt, indeed, that, on one tectonic horizon or another, folding of all grades was proceeding all the time, each recumbent fold being still driven together under a moving weight, while the one above it was already in process of formation.

Consider, now (duly bearing in mind that the conditions of nature will never be so simple) the case of a tectonic horizon in which buckling and compression are approaching their limit. Anamorphism will set in, but being a function of depth, will wane upwards, dying out al6igether in the higher zones. Recumbent action recurring, let another fold or limb be rolled or thrust over this, and in its turn buckled up and re-crystallised. The older one, having lost much of its adaptability, and thus become relatively rigid and aged<ref>The signs of arrival at this conditionarenot yet known. Certainly the Owna Mélange of Aethwy (pp. 199–200) had not arrived thereat when the next recumbent fold rolled over it.</ref>, will be nothing like so susceptible of metamorphism as the newer one. Even more important is the circumstance that, lying lower down than the plane of the fresh impulse, it will be nearly, perhaps quite, out of its reach. Consequently it may undergo but little further crystalline change along many miles of amplitude, while a high (may he a higher) grade of alteration is developing in the superincumbent masses. Anamorphism remains, as truly as ever, a function of depth, but strictly in relation to the cover that was present at the time it was developing, not in relation to cover that may have been imposed after it had developed; in the light of which principle we are able to remove the anomaly.

Yet another principle, too, must be combined with the foregoing. In ascribing the Regional. Anamorphism to the Major Secondary folding, it is not to be supposed that a uniform allomorphic effect will be induced throughout the whole geographical extent of any given tectonic horizon, for anamorphism, being a result of reaction between impulse and resistance, will vary with resistance. In fact, we have already applied this principle to account for the Pen-mynydd anamorphism of the Middle Region, and need only add that, just as the rocks on the onset-side of the great Coedana-Caradog obstacle are intensely metamorphosed, those under its lee-side are, as might he expected, in a less altered state. Further: an impulse may meet with resistance, not only by coining against a passive obstacle, but by encountering an impulse from the opposite direction. Of such a condition we have an example on a grand scale in the great synclinorium of Aethwy, where, accordingly, we find the Penmynydd anamorphism of that region.

Recapitulation— The anomalies discussed on pp. 200, 240, 242, have thus been doubly removed; for we are now able to see how it is possible for anamorphism to develop upon a higher fold without appreciably intensifying the crystalline condition of a lower one; and how one part of a given tectonic horizon may be far more altered than another; thus accounting at once for the tectonic relations of the Penmynydd anamorphism, and for its having been developed in the particular positions where it is actually found.

Ulterior bearings of the study of the Complex

The minuteness (especially of mapping) with which formations such as those of the Mona Complex have come to be studied in recent years is frequently misunderstood. Geology, it is sometimes said, has left behind it the inspiring days of generalisation, and nothing now remains to us but filling-in of petty detail. What, however, is a geological map of any given rock-formation? It represents the lines of intersection between two curved superficies; one being the bounding-surface of the formation, the other 'being the denudation-surface of the land. If either of these be complicated, the lines on the map will also be complicated. In the present case, the denudation-surface is comparatively simple; but the bounding-surfaces of the members of the Mona Complex are, by reason of its remarkable tectonics, extremely intricate. We have seen that none of the greater folds are (save at the South Stack) visible upon sections in the vertical dimension. But their intersections with the denudation-surface are visible lines which, while on too great a scale to be mentally grasped on the ground itself; can be made accessible to observation by being laid down upon a map. Ideally, the smaller the scale, the more intelligible the map. Owing, however, to the intricacy of the curves, as well as to the necessity of making it possible to refer to exact localities; precision, and therewith reliability, can only be attained by the use of a large scale and the insertion of minute detail; from which, by reduction with abstraction, general views can be obtained.

Now, the intersection-lines thus plotted are the data, by means of which alone we can infer the succession and the true nature of the tectonics. An understanding of the tectonics is a scientific end in itself. But it is also a means to other ends. For, without it, we cannot proceed to any reliable inferences concerning the age of the rocks, their original relations to each other, their thicknesses, their sedimentary facies, their vulcanology, the physiographical conditions at the time of their formation, the circumstances under which they acquired their metamorphisM, or indeed any important question of their formation or development. Minute exactitude in mapping, therefore (carried on, it may be, for years at a time before any of its ends come into sight), is far from being a mere subsequent and subsidiary filling-in of detail; it isa condition precedent to the generalisations which are its underlying motive.

Generalisations such as those suggested above, however, are in their turn means to ends. For, enthralling as is the study of the Mona Complex, even within the narrow confines of the Island, it does but open out far wider problems. To establish its age, leads us on at once to enquire with what other Pre-Cambrian formations its members may be correlated. To formulate its internal succession raises great questions of Pre-Cambrian stratigraphy, vulcanology, and physiography. The intricacies of its tectonics, and the genetic relations thereto of its crystallisation, pertain not merely to the geological history of one little island, they are a part of general orologic and metamorphic theory. Finally, the oldest and scantiest of all its records, deciphered (perhaps long hence) in connexion with those of distant countries, will unveil some portions of the most remote and most obscure of all known epochs in the history of the world. Even to-day, in their very scantiness, those records possess, for the geological imagination, the charm that is inseparable from 'the ghostly language of the ancient earth'.

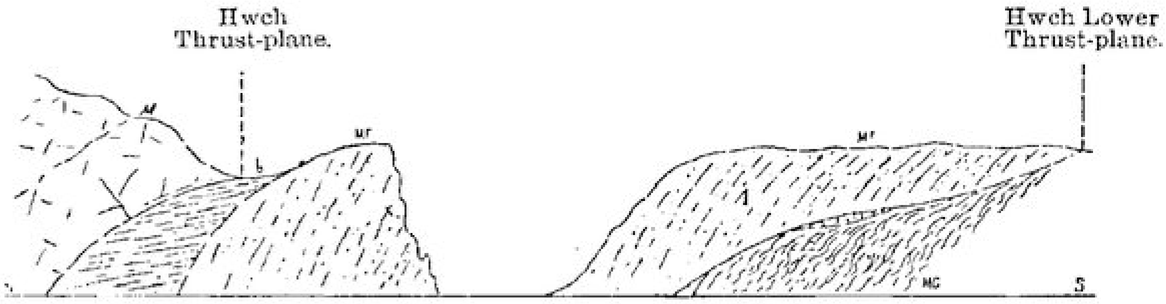
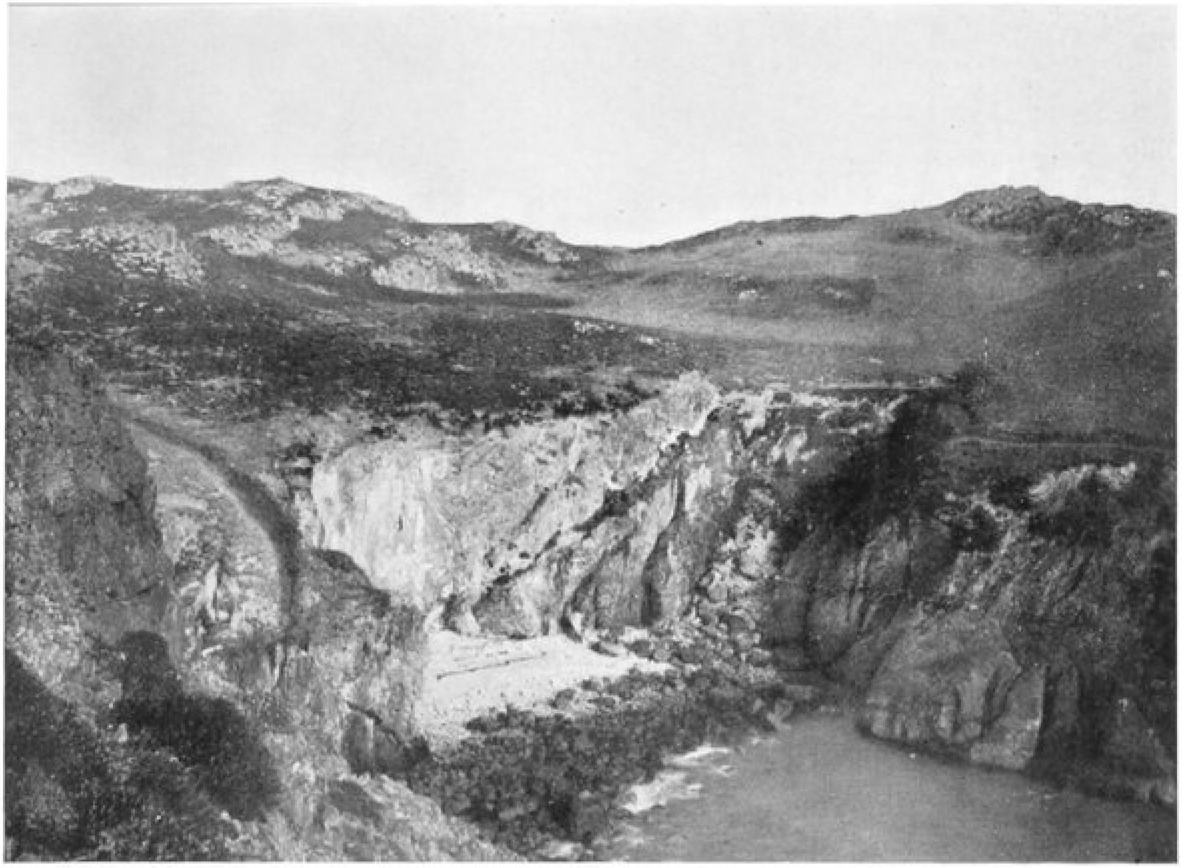
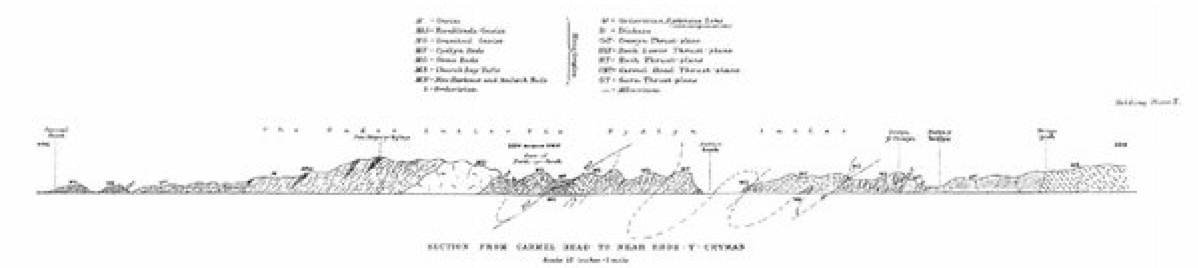


FIG. 130.—SECTION ACROSS THE TWO COVES AT PORTH-YR-HWCH.

(Figure 130) Section across the two coves at Porth-yr-hwch. M= granitoid gneiss. MF = Fydlyn Beds. MG = Gwna Mélange, with limestone. b = Ordovician shale. Height at north end: about 200 feet



(Plate 25) The Hwch lower thrust-plane. Porth-yr-hwch. Fydlyn Felsitic Tuff thrust over Gwana Green-schist.



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

(Plate 17) The Namarch Fault. Porth Namarch.

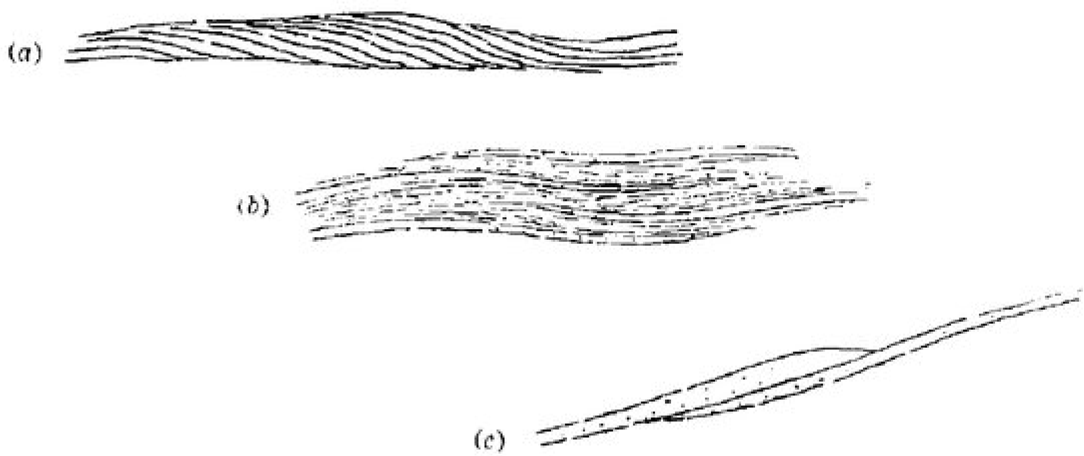
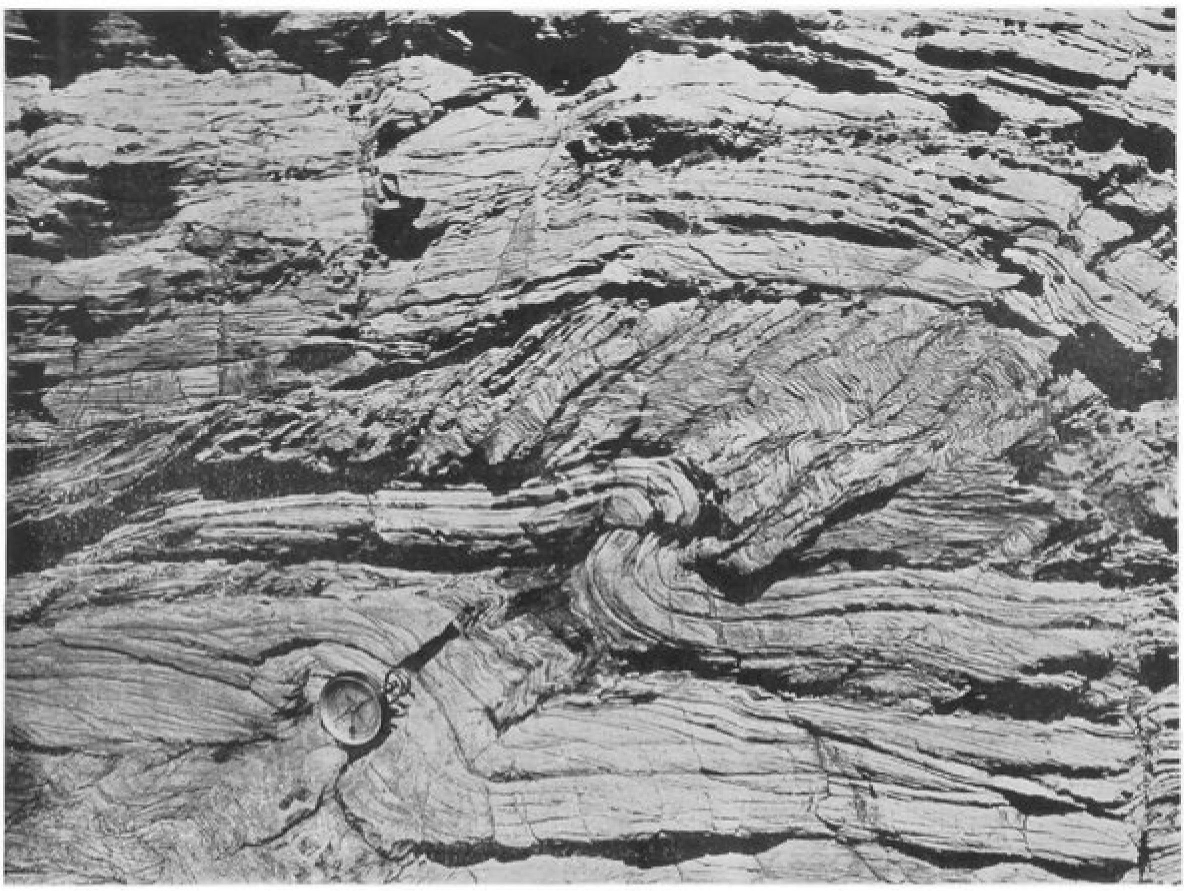


FIG. 65.—STRUCTURES IN THE AMLWCH BEDS.

(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.



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

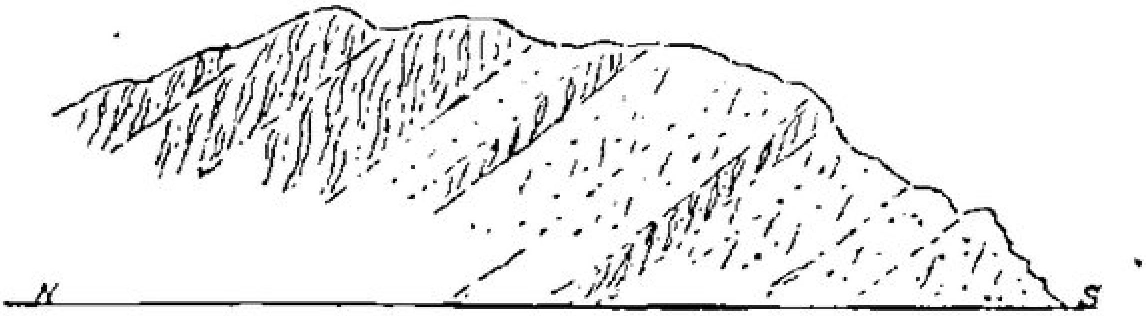
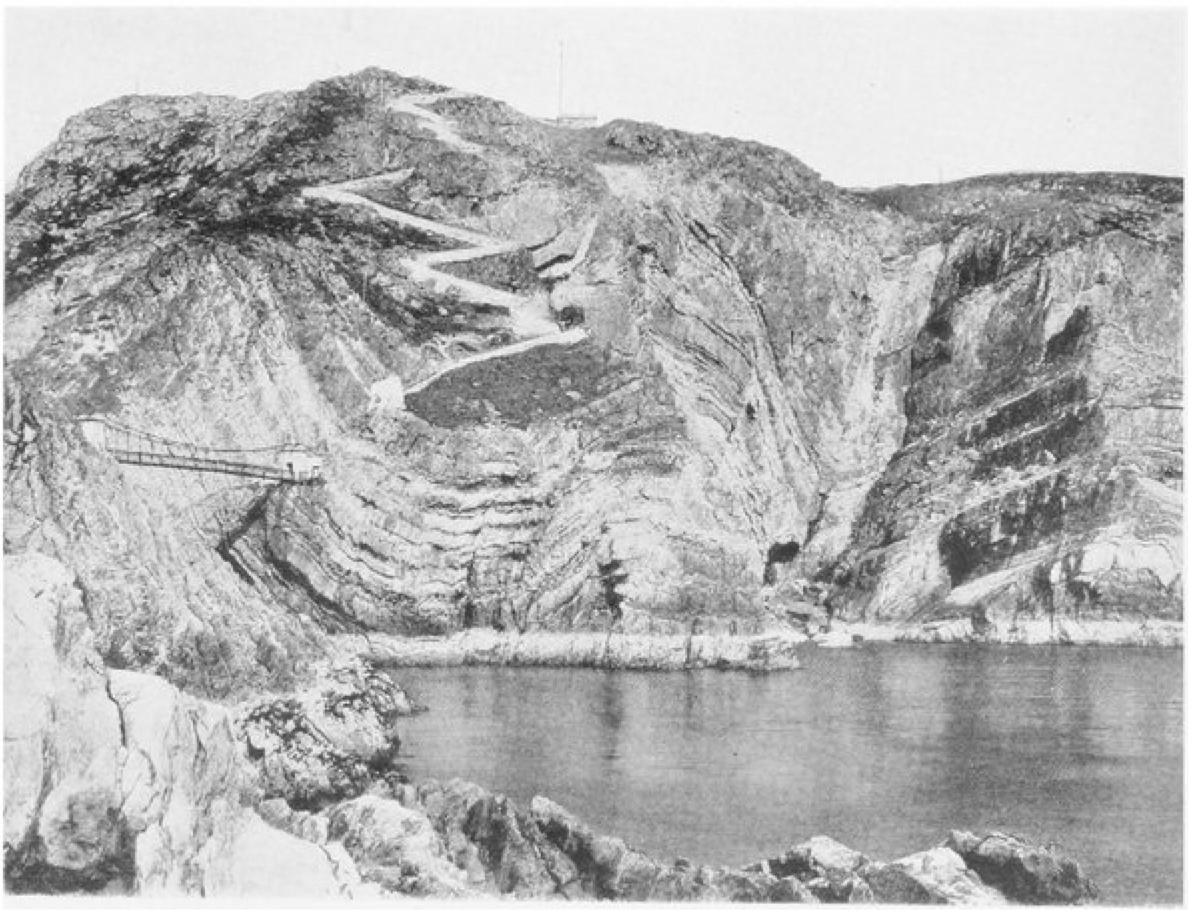


FIG. 32.

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



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

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