Chapter 2 History of previous research

Introductory

The Geology of Anglesey has been described and discussed in a literature that is very extensive considering the moderate area of the Island. The Bibliography contains 215 publications, extending over more than two centuries, for the first paper that is known appeared in 1610; and some are 80 or more pages in length.

This literature may be divided roughly into five periods, characterised by different phases of research:

1. The archaic period: 1610 to 1821
2. The first scientific period: 1822 to 1849
3. The period of the one-inch surveying: 1849 to 1866
4. The period of Pre-Cambrian research 1878 to 1891
5. The period of detailed surveying: 1895 to 1915

The productions of the first period are chiefly of historic interest. In the second period by far the most remarkable work is the memoir by Henslow (now best known, perhaps, as Darwin's tutor), about 100 pages in length. It shows a high degree of scientific penetration, as well as painstaking research, and on his map the lines have already assumed the same general aspect that they have to-day. The third period embraces the work of the Geological Survey, after which ensued a pause of about twelve years. A new epoch was then opened by Hicks, and research was carried on with great activity by Bonney, Hughes, Callaway, and Blake. In 1891 unanimity was reached with regard to the existence in the Island of Pre-Cambrian rocks in an address by Sir Archibald Geikie, in which all but the Northern Region of the Complex was assigned to that period. After a pause of four years, detailed surveying on the six-inch (as well as '25-inch') scale was begun. During its progress various points were discussed by Callaway, Matley, the present writer, and others.

For more than 60 years the question that has attracted more attention than any other has been that of the age of the metamorphic rocks, with which, however, that of the age and relations of the older Palaeozoic sediments is so bound up as to be scarcely separable from it. Yet work went on also, throughout the whole time, upon the many other subjects of the Island. In drawing up the present sketch of the history of research it became evident, accordingly, that a strict adherence to chronological order would make it impossible to bring out the evolution of ideas upon any one subject. The subjects have therefore been separated, and the work done upon each treated by itself, though at the cost of some repetition in the cases of the Mona Complex and the Ordovician.

The Mona Complex

The Mona Complex is spoken of by Henslow as the 'oldest stratified rocks', and described by him under the general title of 'Chlorite-schist'. He excludes a part of the Middle Region, and also the granite, which he regarded as of much later date. He recognised most of the leading lithological types of the Complex, and his descriptions are clear and well-written. A drawing that he gives of the folding at the South Stack will bear being laid side by side with a photograph; and he saw here that bedding was distinct from foliation, which he ascribes to 'crystalline force assisted by moisture and pressure'. Sedgwick at first placed the Complex in his Lower Cambrian, but afterwards excluded it; later on, however, leaving the point an open question, apparently in deference to the views then prevalent.

The work of the Geological Survey in Anglesey seems to have been begun about 1849, the map was published in 1852, the sections in 1857, the first edition of the memoir in 1866, and the second in 1881. The surveying was done by Ramsay, Selwyn, and Warington Smyth, with portions by De la Beche, who supervised the whole. We obtain interesting glimpses of the views that prevailed among the surveyors during the progress of the work from some letters of De la Beche and Ramsay published in the life of the latter by Sir A. Geikie (pp. 154, 170–172, 192). In 1849 Ramsay writes: 'I met Sir H. at Bangor. We had a short rap at Anglesey at very old rocks, older than the Cambrian'; a sentence, as Sir A.

Geikie remarks, of peculiar interest, showing the first impression made on Ramsay's mind. It seems also to imply that De la Beche was of the same opinion. In 1850 De la Beche writes to Ramsay: 'Touching the mica-slates, chlorite-slates, and other matters of the lower ground in Anglesey, they are, of course, what they can be proved to be' (a reminder that is by no means out of date); and goes on, 'Pray keep a bright look-out for the conglomerates; they are most useful in such investigations', from which it is evident that he was thinking of the possibility of Pre-Cambrian rocks. Selwyn certainly considered (*op. cit.,* p. 192) that Cambrian rocks rested unconformably upon the schists. Ramsay's new views had evidently been developed by 1851 (*op. cit.,* p. 192), and found expression in the colouring and lettering of the one-inch maps of the succeeding year. They did not, it should be noted, affect the lines upon the maps, except that the Baron Hill outlier (inserted by Henslow) disappears. In 1853 he gave the first public expression to these views (*Quart. Journ. Geol. Soc.,* 1853, p. 169, 171, 172) saying that he regarded the metamorphic rocks of Anglesey as of the same series as the Harlech grits and the Penrhyn slates, and also that he assigned the metamorphism to 'Lower Silurian' time. In the memoir, accordingly, the schists are described as Cambrian. Here for the first time (Ed. 1, p. 175; repeated with slight alterations in Ed. 2, pp. 222–3), he gives his reasons. They may be summarised as follows: Cambrian rocks 'are considerably altered at Llanberis. Similar rocks are also much altered at Bangor. The strike of these is towards the schists at Beaumaris, among which are many green, grey, and purple beds, with grits, that resemble those of Bangor, 'thus by insensible gradations uniting the whole'. He further urges that the 'Silurian' shales that rest upon the Bangor rocks also strike towards Beaumaris, and can be seen resting upon the schists in Red Wharf Bay. The memoir contains a general description of the metamorphic rocks, with diagrams of folded structures, and discussions of bedding, foliation, and what are now known to be planes of slipping, from the point of view of the theories of the day. Of the rocks of Ceinaes Bay it is interesting to note the remark 'that "smashed" is the only word by which their appearance can be expressed'. The absence of bedding along the cliffs of Church Bay, and the igneous aspect of the rocks, is noted, but ascribed to excessive alteration.. The granite, serpentine, and other igneous members of the Complex are looked upon in general as of metamorphic origin. Ramsay's descriptions are, as such, excellently written, and are, as Blake has truly said, 'full of beautiful touches which recall vividly to the reader the facts he has observed in the field', particularly of the intimate relations of the gneisses and their granites (Ed. 2, pp. 243–4). No attempt is made to sub-divide the Complex or to correlate its members. In the second edition only slight additions and alterations are made, but he italicises several of the phrases bearing upon metamorphic theories.

Just a quarter of a century after the publication of the one-inch maps, the Pre-Cambrian question in Anglesey was re-opened by Hicks, fresh from his Pre-Cambrian researches at St. Davids, and an epoch of active investigation ensued. Hicks did not offer any direct proof of the antiquity of the rocks; he relied on lithological resemblances, but was supported by Prof. Bonney in a petrological appendix. He sought, naturally, for his three Archaean groups, and considered that he could identify them in the vicinity of Ty Croes.

In 1880, stratigraphical evidence of the age of the Complex was brought forward by Dr. Callaway. He showed, however, that the granitoid rock was not the lowest visible, and that the scheme adopted at St. Davids could not be applied. Foliated granites, even when the foliation was very slight, were at that time suspected to be of metamorphic origin, and separated under the name of 'granitoidite'. The stratigraphical evidence, depending as it must upon the age of the sediments that rest upon the Complex, will be found in the history of the work upon those sediments. It may be remarked here that there has throughout been an indecisiveness about it, owing to the absence of the lowest fossiliferous horizons. Confirmatory evidence has all along been needed.

In 1881 appeared a detailed paper by Dr. Callaway, 'The Archaean Geology of Anglesey', with petrological appendix by Prof. Bonney. This was the first serious attempt to work out the general internal stratigraphy of the Complex. Several of the views therein expressed were subsequently abandoned by the author. But the paper, nevertheless, represents an important advance in the investigations. A mental picture of the Complex as a whole became for the first time possible; and, in the second place, the paper bore, indirectly, upon the question of its age. For the magnitude and lithological variety of the Complex being now manifest, correlation with the comparatively homogeneous Cambrian of the adjacent mainland was made much more difficult, and the burden of proof began to be shifted from those who asserted to those who denied its great antiquity. The paper is arranged on a geographical basis, and describes the rocks successively in the several districts. Correlations are attempted, and a sequence suggested. The Complex is divided into two great groups, a Gneissic (the term being used in a wide sense) and a Slaty, the Slaty being regarded as probably the later. The

presence of volcanic rocks is definitely recognised (the age of those of Parys Mountain being regarded as uncertain). An important discovery is made of fragments of older schistose rocks in a member of the Complex called by him the 'Llanfechell' grits. Three generalised sections are appended.

All these writers agreed in making no exception of the northern schists, but in 1880 Prof. Hughes proposed that these should be removed from the Complex, and placed in the Ordovician system, as members of an 'upward succession' from the base of the Palaeozoic to the northern coast. A sketch of the controversy will be found later on. In his paper of 1884 Dr. Callaway deals chiefly with the age of the Complex and its relations to the Ordovician; but he also adduces evidence in favour of the existence of two Pre-Cambrian systems in the Island from the curious ridge near Llyn Traffwll, where granitoid fragments are to be seen within a 'slaty' rock (see Chapter 14).

In 1883 Prof. Bonney added an important piece of evidence as to the age of the Complex, by showing that at Baron Hill an outlier of the ashy grits of Bangor lies upon foliated schists. In 1885 he summed up a brief survey of the evidence in favour of the existence of two Pre-Cambrian series in the Island. As a sequel to these well-known researches, Plant of Manchester, who had a cottage at Rhosneigr, began work upon the Complex near that place. He mapped some parts of it on the one-inch scale in considerable detail, but at the time of his premature death his work was not far advanced, and was never published.

About this time, apparently in 1886, Blake began his Anglesey researches, and after two preliminary notices, published his results in 1888 in the well-known paper called 'The Monian System'. He was also the author of a British Association Report (issued very shortly afterwards) on the microscopical structure of the rocks, based upon the examination of 320 slides. The two publications cover 136 pages, and were by far the most detailed account of the Complex that had yet appeared. They were accompanied by a map on the scale of one third of an inch to the mile, showing the distribution of the sub-divisions that he recognised.<ref>A few years later he mapped a part of the Gneiss of the Middle Region on the six-inch scale, but did not publish his results.</ref> The arrangement of his paper is like -that of Dr. Callaway's of 1881, and his object throughout stratigraphical. He takes the Complex a district at a time, describes the rocks, brings out what he considers to be the succession within that district, and then correlates them all. Failing to find any break within the Complex, he came to regard it as a single, Pre-Cambrian, system, to which he gave the name of 'Monian'. Finally, venturing yet further, he seeks the Monian system in other portions of the British Isles.

It is easy to see that the attempt, though natural, was premature. It is barely possible to-day. At that time not only were several Pre-Cambrian systems already in the field, but none of them were then regarded with much favour, for the illusory effects of earth movements had just become a subject of especial interest. The 'Monian System' appeared in the very same issue of the *Quarterly Journal* as the Report of the Geological Survey upon the North-West Highlands. Blake's methods, in fact, were in great measure those of the stage out of which the science was then passing; and his work has suffered from the circumstance that its reactionary elements were much more conspicuous than its progressive ones. He appears to have been troubled by no misgivings as to the reliability of dips; superposition meant for him succession, and (with certain exceptions) foliation meant bedding, as they had for his predecessors. It was evident that he had failed to assimilate the recent work upon disturbed regions, and, in particular, the extent to which crystalline schists had been reconstructed by planes of movement which destroyed the bedding and the order of succession. His unfortunate theory of the 'quartz-knobs' and sporadic limestones' was due to the same cause (see, however, p. 22), as well as his failure to recognise the deep-seated character of the micaceous gneisses. Yet, in spite of all this, his papers embody a substantial advance in our knowledge of the Complex.

First of all, recognising the plutonic character of the granites and the basic gneisses, he excluded them from the succession in which they had before been placed. He saw, with Callaway, that the north must be included in the Complex. He recognises for the first time the importance of volcanic rocks as members of the series (exaggerating it, as was then inevitable, by inclusion of the cataclastic products), showing that lavas as well as tuffs were present. He was the first to see that the 'South Stack Series' needed to be treated as a separate and important member of the Holyhead succession, though he divorced it from its true connection with the quartzite. In a passing remark he suggests an organic origin for the jaspers, and in another notices the existence of annelids in the South Stack Series. His -account of the microscopical petrology is full of information. Lastly, in the course of his work in Anglesey he discovered the first British variolite (afterwards described in more detail by Prof. Grenville Cole) and the first British glaucophane schist. The papers

are written with a certain directness and '*naivete*', if abruptness, of style, and with great candour in regard to any conflict in his evidence.

In the meantime the views of Dr. Callaway had been undergoing modification. Rejecting the older views of metamorphism, and the order of succession within the Complex that had been based upon them, he had not only come to recognise the eruptive nature of the granites, dioritic gneisses, and hornblende schists, but, going further still, to postulate an igneous origin for what are here called the Penmynydd mica-schists (grey gneiss) and for the 'halleflinta'. In 1887 he had given a brief account of a section at Y Grail, Holland Arms, where a rock still retaining the structure of a felsite was seen to be involved in the foliation of the schists. In 1897, 1898, and 1902, he published three papers that may be described as studies in the metamorphism of different members of the Complex. That of 1898 dealt with the sediments of the north, between Rhosbeirio and the boundary fault, which he found to exhibit a progressive metamorphism in a southerly direction, the crystallisation proceeding, in a general way, *pari passe* with the signs of pressure. Microscopically, the alteration consisted in granoblastic reconstruction of the larger clastic grains, together with a growth of chlorite and mica in the matrix. In those of 1897 and 1902 he describes very fully the passage, near Holland Arms, of felsite into mica-schist, which he shows to have the chemical composition of a felsite. The felsite he regards as intrusive in the diorite and basic gneisses. He describes also the relations of acid and basic schists, distinguishing between gneisses of primary and secondary injection. He then applies these generalisations to the rocks of the centre of the Island, where he regards the mica-schists and halleflinta as also products of the alteration of felsitic intrusive rocks. Proceeding to the analysis of the gneissose tract, he regards the basic gneisses as products of the modification of diorite, first by pressure, and then by the addition of granitic intrusions; and the acid gneisses as arising from felsites by the action of the same two processes. He describes the basic gneiss as, originally, a gigantic xenolith of diorite in granite. The subject of these gneisses, especially the acid mica-gneisses, is still a most perplexing one. But with regard to the Penmynydd mica-schists it is not too much to say that Dr. Callaway's results appear likely to open the way, not only to correct views as to the genetics of the rocks, but to a true correlation of the horizons of the Complex.

In 1890, Sir Archibald Geikie, accompanied (except in the north) by Dr. Peach and Dr. Teall, visited Anglesey, and included an account of his results in his presidential address of 1891, which was repeated, with some alterations, in his 'Ancient Volcanoes' of 1897. His views on the Northern Region will be described further on, and it need only be said here that, removing it once more from its association with the other regions of the schists, he placed it in an upward succession of Ordovician age. Concerning the Llangefni rocks he also expressed some doubts. With these exceptions he considered that the Complex must be of Pre-Cambrian age. Its metamorphism being Pre-Ordovician, and being of regional type, 'could hardly have been restricted to merely the limited area of Anglesey'. On the quarter-inch map of the Geological Survey, issued in 1896, a Pre-Cambrian colour now appears. Unanimity as to the existence of Pre-Cambrian rocks in the Island was thus reached after half a century of discussion.

He recognised, moreover, what appeared to be two groups of rocks. The gneissose group, he pointed out, bore strong resemblances to the Lewisian of the North-West Highlands, and he was inclined to think that it must be much older than the remainder of the Complex. These, chiefly sedimentary, he compared to his Dalradian, and announced the discovery of annelid pipes (noticed by Blake in a passing remark) in the South Stack Series. Both the address and the volume, however, were concerned, not with Pre-Cambrian questions as such, but with vulcanicity. He drew attention, accordingly, to the evidences of this that could be seen within the Complex. The breccias he came, later on, to regard as cataclastic, but they are not the only signs of vulcanicity. Dwelling not merely on the definitely basic schists (some of which might be contemporaneous) but on the generally green and chloritic character even of those of clastic origin, he compared them to the green beds' of the Central Highlands, and suggested that they might represent a 'group of volcanic tuffs and inter-stratified sandy and clayey layers'.

Dr. Matley's three papers, of 1899, 1900, and 1901, with the accompanying maps, represent a further advance in our knowledge of the Mona Complex. The evidence for his conclusions is intimately bound up with his researches into the Ordovician rocks, presently to be reviewed, but the results are, briefly, as follows. Under the provisional name of 'Green Series' he gives a general description of the foliated rocks of the large tract lying between the 'curved fault' and the extreme northern belt that runs from Cemaes to Porth Wen; dealing then, in detail, with those that occur within that belt, which he groups under the name of the 'Llanbadrig Series'. He describes their quartzites, limestones, grits, and phyllites, with their arrangement in the several sections, and proposes a scheme of their internal order of succession. Most

important of all, they are now for the first time satisfactorily disentangled from the associated beds of Ordovician age. The Green Series is conclusively shown by him to be at any rate Pre-Llandeilo', and as it had, by Llandeilo times, already acquired a foliation and had been subjected to some movement and to denudation, he is inclined to regard it as of much greater age. The Llanbadrig Series he also proves to be older than the Llandeilo, and brings forward evidence in favour of its being later than, and unconformable to, the Green Series, but considers that its base may be conformable with' that series. Upon the age of the Llanbadrig Series itself he speaks with some reserve. He points out that pebbles of its rocks are to be found in the conglomerates of the Llandeilo, but also that there is difficulty in detecting a stratigraphical discordance between its quartzites and the base of those conglomerates, and concludes that it 'is a moot point whether there is an unconformity at all between the Llanbadrig and the Llandeilo Series; it is certainly not conspicuous one', adding that 'no more definite assertion of their (Llanbadrig Series) age is made than that they are Pre-Llandeilo.<ref>The beds referred to in this chapter as 'Llandeilo' are termed 'Glenkiln' in other parts of the present work.</ref> In his third paper, however, after identifying the 'Llanfairyng-hornwy Beds' with the Llanbadrig Series, he inserts, though without comment, the word unconformity' between them and the Ordovician of that district in a summary of the succession. A most valuable feature in his papers is the convincing description that he gives of the tremendous disruptive stresses, especially as they affect the Llanbadrig Series, producing thrusts, and in particular 'crush-conglomerates' on a magnificent scale, which enables him to explain the anomalous behaviour of the limestones and quartzites. But owing to the locally inconspicuous character of the unconformability, combined with the perplexity introduced by the circumstance that all the great movements of the region, whether affecting Green, Llanbadrig, or Llandeilo Series, were induced by stresses acting from the same general northerly direction, he does not separate between Pre- and Post-Ordovician movements, but simply determines the last period of great movement in Northern Anglesey as 'Post-Ordovician'.

The two papers on the serpentine and its associates by Prof. Bonney and Miss Raisin lie somewhat on one side from what may be called the main line of the researches upon the Mona Complex. In that of 1881 Prof. Bonney showed that the serpentine was a true igneous rock, resulting from the alteration of various peridotites, some of which were dunites, and that large masses of gabbro were associated with the serpentine. An ophicalcite, a talc-schist, and a chlorite rock were also present. In 1899 many petrological details were added, 'variolitic' and banded varieties of serpentine described, with pyroxenites and actinolitic rocks, and a short account given of the deformation of the group.

Rocks of the Mona Complex were first mapped by the present writer in 1895. In 1896 he was able to show that the relations to it of the Careg-onen Beds furnished yet further evidence of its antiquity. In the same year, describing the quartzite lenticles of the south-east, he ascribed to them, both great and small, a cataclastic origin; and also recorded the existence of sillimanite-gneiss in the Middle Region, connected its presence with the absence of chilled edges to the granitoid rocks, and compared the phenomena to those of Eastern Sutherland. In 1902 he showed that the variolitic diabases of Newborough were typical pillowy lavas, that jasper was associated with them in the same manner as was radiolarian chert with such lavas elsewhere, and that it was associated also with the limestones, inferring that it was an altered radiolarian chert. Dealing with the age of the group, he urged that it could not be placed in the Arenig Beds. Upon its relation to the schists there was conflicting evidence, but he was inclined to regard it as a member of the Complex.

In 1913 Dr. Strahan reviewed the evidence (including some supplied by the present writer) for the Pre-Cambrian age of the Mona Complex.

Baron Hill and Careg-Onen Rocks

When the Pre-Cambrian question was re-opened by Hicks in 1878, attention was at once directed to the unmetamorphosed sedimentary rocks that rest upon those that were supposed to be Pre-Cambrian, and Cambrian Beds were sought for. The progress of research has failed to disclose any rocks of undoubted Cambrian horizon, but some small Pre-Ordovician outliers of somewhat uncertain age have been discovered. These, though insignificant in extent, are of very great importance in connexion with the age of the Mona Complex.

The existence of the Baron Hill outlier was detected by Henslow, who separates it on his map from the 'Chlorite Schist' and colours it with his 'Greywacke'. It was re-discovered by Prof. Bonney from the poor section in the roadway in the year 1880. He recognised the identity of the rocks with those of Bangor, and the great stratigraphical significance of their

position. In 1882 he visited the much better sections then being opened along the new drive, and in 1883 gave a detailed account of the exposures, with petrological descriptions. He showed that the rocks are bedded tuffs like the volcanic series of Bangor, and pointed out the great contrast that there is between their condition and that of the adjacent schists of the ancient Complex. Blake describes a visible junction of the lowest of the beds that are seen along the drive with the schist, but by 1895 this had become obscured. In 1896, the present writer drew attention to the highly disturbed condition of the outlier, and showed that it must be resting upon a plane of movement.

The rocks called in this work the Careg-onen Beds were evidently seen by Henslow, who colours a part of them upon his map, and Blake refers to the existence of rocks like those of Baron Hill in that neighbourhood, though not in the places where they have since been observed in the course of the surveying. In 1895 the section at Careg-onen cove was re-discovered by the writer of this volume. It was shown that the Careg-onen Beds are without doubt unconformable to the adjacent schists. They were also regarded, though with some hesitation, on account of the powerful movements of which there was evidence, as being overlain unconformably by the Ordovician shales, and it was suggested that they might be of Pre-Cambrian age. That they do not belong to the Ordovician is fully confirmed by additional evidence set forth in this work, but it is also shown that the visible unconformity alluded to in the paper of 1896 is certainly a plane of sliding, and cannot be a natural base of the Ordovician as was then supposed.. Sponge spicules were found in them, and described, in the paper quoted, by Dr. G. J. Hinde.

The Ordovician rocks and the Palaeozoic movements

All the Ordovician tracts of any considerable size were recognized by Henslow, and their boundaries laid down upon his map wonderfully well. Most of them he includes in his 'Greywacke' formation, which he places next in order to his 'Chloritic Schist', expressing uncertainty as to whether there was or was not a break between them. He actually discovered the Ordovician fauna at Treiorwerth, Llechcynfarwydd, and a place that was evidently in the Arenig escarpment at Prys Owen, Llanerchymedd, and described the brachiopoda.<ref>Some of these very fossils have been re-examined for the present volume.</ref> Thus he was close upon what would have been at that time a discovery of the first importance. Unfortunately, he assigned most of his Ordovician sandstones, including those from which he obtained the fossils, to his Old Red Sandstone, and thus failed to see their significance. He observed the fault at Porth-y-corwgl, considered that it must be 'carried directly across the island', and lays down its curved course.

The first recognition of the Ordovician of Anglesey as part of the Lower Palaeozoic Series appears to have been made by Sedgwick, who placed it in his Upper Cambrian.

The one-inch maps of the Geological Survey show many advances. The formation is explicitly recognised as 'Lower Silurian', and wedges of it are picked out from among the older rocks in complicated tracts like that of the north-west. In the explanation of the horizontal sections it is said that the rocks could not then be separated out in some of the northern strips. In Ramsay's paper of 1853 he refers very briefly to this formation as representing 'Lingula beds and part of the Bala or Llandeilo rocks', adding that near Amlwch they have been changed by granite intrusions into mica-schist and gneiss. He seems, indeed, to have thought that the whole of the metamorphism of the Island was a plutonic equivalent of the Ordovician vulcanicity of the mainland. In the first edition of the memoir, sub-divisions of the Ordovician are differentiated for the first time in Anglesey. The Lingula flags disappear. The basement sandstone of the Principal Area is assigned to a Caradoc horizon, but Llandeilo forms are recognised at Llangwyllog. Graptolitic shale is recorded at Cemaes, and the 'few poor fossils' of the Mynachdy cliffs are assigned to the Caradoc. Thirteen species in all, are, in text and appendix, recorded from the system. The pebbles in the conglomerates, on which De la Beche laid, such stress in the letter quoted above (p. 6), did not escape Ramsay, and he gives a list of ten types, nine of which are manifestly derived from the Mona Complex, inferring from them an erosive unconformity, but remarks, 'Though on a hasty examination it might be supposed that the metamorphic and granitic pebbles might be derived from some of the Anglesey rocks themselves, it is evident on reflection that such was not the case, the metamorphism of the Anglesey rocks having taken place after the deposition of the lower Silurian strata'.Opposing conclusions appear to have been competing for mastery in this powerful scientific mind, and the candour with which he sets forth evidence that conflicts with' his metamorphic theories is altogether admirable. He notes evidence of folding in the cleaved shales, and first uses the phrase a 'remarkable curved fault' of the Carmel Head thrust-plane. He urges that this line must be one of dislocation,

partly from 'the discordant dips and strikes', partly from the fact that not one of the numerous dykes of the north can be traced across it. Perhaps his most valuable contribution was the bold and discerning theory that he now put forward of a general overlap north-westward from the Merionethshire country, without which it would be impossible to understand the Lower Palaeozoic rocks of Anglesey. In the second edition of the memoir, he quotes the then recent work of Prof. Hughes, and 'Arenig' appears as a recognised horizon. He expresses doubts, however, concerning the fossil evidence for the Tremadoc, as well as that for the Llandovery of Treiorwerth. A tabulated fossil-list is now given, with horizons, in which are 23 species, besides which five more appear in Salter's appendix. The pisolitic ironstone is recorded. Evidently feeling the importance of his theory of overlap, he now devotes a separate chapter to it, and discusses it at greater length. Moreover, both his text and his figure show not merely an overlap, they show a distinct erosive unconformity at the base of the Arenig Beds; and only his metamorphic theory, which led him to suppose Cambrian deposits to be present in force in the Island, prevented him from pursuing the subject still further. The recent work of Mr. Nicholas (kindly communicated to the present writer before its publication) shows that this, unconformity is of much greater magnitude than Ram say himself supposed.

When, in 1878, Hicks (aided petrologically by Prof. Bonney) began his investigations into the ancient rocks of Anglesey, the identification of them as Pre-Cambrian was based, as has been already remarked, upon petrological rather than stratigraphical considerations; and it is not quite clear whether Hicks accepted the Ordovician age of the conglomerates of Llyn Maelog or whether he regarded the lowest parts of them as Cambrian. The absorbing interest of the Ancient Complex was enough for the time, and Hicks does not seem to have sought for fossils in the overlying series. This was, however, undertaken immediately afterwards by Prof. Hughes, who obtained fossils from several localities, and made an investigation of the stratigraphy in the district to the north-east of Llanerchymedd. Prof. Hughes showed that an extensive series of dark shales with banded flags was underlain by a basement sandy group, in which were conglomerates containing pebbles of the local types of schist. In the basement sandstones of the Principal Area some fragments of a trilobite were found, which, being identified with *Neseuretus ramseyensis,* led to these beds being regarded for some years as of Tremadoc age. The associated species of *Orthis* were discussed, and referred to forms intermediate between *O. hicksii* and *O. carausii*, which agreed with the view suggested by the trilobite. Graptolites, named by Prof. Lapworth, were obtained from the overlying shales both in the Principal and the Llangwyllog Areas, and referred to Upper Arenig or Lower Llandeilo, but those from Llangwyllog were identified with some hesitation.

Two months before the publication of Prof. Hughes' first paper, in 1880, Dr. Callaway made the first explicit identification of the pebbles of the Ordovician conglomerates with the local members of the Mona Complex. But the issues then became for a while curiously complicated, partly from the deceptive effects of earth-movements, partly from the influence of the metamorphic theories of the time. During the years 1880, 1881, and 1882, a vigorous discussion arose concerning the massive pebbly grit of Nebo, which resembles that of the Twt Hill of Carnarvon, where a passage was supposed to exist between grit and granite. At Nebo there appears to be a visible unconformity where the Ordovician shales rest upon the grit, and Dr. Callaway urged that the grit must be of Pre-Cambrian age. The visible unconformity was shown by R. D. Roberts to be an illusive effect of earth-movement. But the Cambrian age then assigned to the grit proved in its turn to be erroneous. Yet further complication was introduced by the suggestion of Prof. Hughes (in 1880) that the boundary fault of the north (called in this volume the Carmel Head Thrust-plane) was either non-existent or unimportant. In this view he was supported by R. D. Roberts, who considered that a passage could be traced from the Ordovician into the Schistose rocks at Parys Mountain and Hafod-onen. In the prevalent northerly dips of the whole region he therefore argued that there was a true upward succession, from the proved Arenig Beds of the Principal Ordovician Area, across the 'Gnarled Series', into the supposed Bala or even May Hill shales of the northern coast, so that the 'gnarled schists ' might be regarded as altered, sedimentary equivalents of part of the volcanic series of Snowdon. It is interesting to note the close parallelism there was between this phase of the controversy (which recurred later on) and that concerning the North-West Highlands, then within a year or two of its close. Indeed, in Anglesey, at this time, there was a tangle of issues and cross-issues that cannot of ten have been exceeded in the history of geology.

But in 1884, a single publication cleared the air. In his paper on ' The Archaean and Lower Palaeozoic Rocks of Anglesey', Dr. Callaway, sweeping away one dubious point after another (in which he frankly included his own views upon the Nebo grit), laid clearly down for the first time the leading facts concerning the Ordovician succession and its relations, both stratigraphical and tectonic, to the Mona Complex. With regard to the horizons present, he showed that

the trilobites of the basement sandstone were certainly of Ordovician types; that the fragments referred to *Neseuretus* were insufficient to outweigh the evidence of the others; and that the associated *Orthis* had not been specifically defined in such a way as to justify its use as a zonal form. He concluded, therefore, that no horizon could be recognised lower than Arenig. He also discovered Hartfell graptolites (named by Lapworth), near Llanbabo, thus defining that horizon for the first time, at one of the few localities where it can even yet be recognised. Re-affirming the evident identity of the already-known pebbles in the Arenig conglomerates with rocks of the Mona Complex, he brought similar evidence to bear upon the relations of the Ordovician to the schists of the north and west; showing that pebbles (many of which were submitted to Prof. Bonney) of the western schists are to be found in the conglomerates that fringe that region, and—what was of great significance—that the conglomerates of Llaneilian contain, along with quartzites and other rocks, blocks of a limestone which he correctly identified with that of the Gwna member of the Complex. It thus became evident that if this were the case, the highest members of the supposed upward succession were themselves Pre-Ordovician.<ref>In the discussion he stated his belief that the rocks with Ordovician fossils on the northern coast were 'let down into the midst of the Archaean by faults'.</ref> Turning to the tectonics (and analysing the synclinal structures of Treiorwerth), he affirmed the visibility of the fault upon the coast at Porth-y-corwgl, and of strong contrasts, there and elsewhere along the line, between the rocks on either side. Failing to obtain direct evidence of hade, he felt obliged to draw the boundary fault as vertical, saying that 'on theoretical grounds' he 'should suspect it to be reversed', and describing minor reversed faults that could be seen a short distance to the south of it at Porth-y-gwichiaid and Llanbabo. He explained the persistent northerly dips in the Ordovician sediments as those- of a syncline in which 'by thrust from the north, the strata on the northern side were folded back',adding his expectation that, within this syncline, there would be frequent repetitions, with 'folding back towards the south'.

A few months before the appearance of this paper Hicks had described the conglomerates of Llanfaelog and Llanerchymedd (then regarded as Cambrian), and, in an important petrological appendix, was supported by Prof. Bonney, who not only identified the pebbles with the local rocks of the Mona Complex, but showed that 'the granitoid rocks, and some at least of the schists, had assumed in all important respects their present mineral condition when the conglomerate was formed'.

About this time Prof. Hughes found *Orthis bailyana* Day. and some other Orthides in the green grits of the northern coast west of Porth Wen, and the fossils were discussed at the British Association in 1887.

Blake in his 'Monian System' alludes here and there to the Ordovician rocks. He recognised the dark shales between Cemaes and Bull Bay as of this age from their lithological character, and rightly placed with them the underlying grey conglomerates of Ogof Gynfor and Llanlliana Head, with doubts, however, as to the horizon of the purple conglomerate, which is there so highly sheared. He made the first drawing of the much broken but highly important section along the lofty coast of Ogof Gynfor, and saw that the conglomerate rested unconformably upon the Mona Complex at the cliff's foot, but that the latter was thrust over it at the northern end. In the confusing section through the decomposed rocks on the western side of Porth Wen he failed to separate the green and purple conglomerates from the Mona Complex, and, as he placed the whole of the succession here seen in the older formation, was driven to make the suggestion (though with a natural hesitation) that *Orthis bailyana* should be regarded as a Pre-Cambrian fossil. Discussing the 'curved fault' (the Carmel Head thrust-plane), he rejects the supposed passages across it, accepts the arguments of Dr. Callaway, and adds the discerning consideration that there are discordances all along the line. Further, that whereas the rocks on the south side are tolerably uniform, band after band of the schists on the north side runs out against the junction, which must therefore be either a dislocation or an unconformity. The supposed upper group, he remarks, does not 'run parallel to its boundary', and contains no conglomerates, whereas conglomerates are to be found in the supposed lower groups on the southern side. In an article in the *Geological Magazine in* 1891 he speaks of the fault as a 'thrust'.

The views put forward by Sir Archibald Geikie in his presidential address of 1891, his article in the *Geological Magazine* of 1896, and his 'Ancient Volcanoes' of 1897, have been already referred to in so far as they concern the Mona Complex. Regarding, in the two later publications, the coarse breccias as cataclastic, his views remained unaltered concerning the original' nature and probable age of the rocks. He rightly pointed out, and gave a vivid description of, the evidences of powerful movement in the Arenig Beds of Llanerchymedd; but, in spite of this, considered that there was a general upward succession from these rocks northwards, across the elliptical fault' into the northern schists, and from them across what are now known to be the belts of complication, to the coast.

Admitting that there might be movements along the line of the 'supposed elliptical fault', he considered that at Carmel Head there appeared to be an unbroken sequence, and urged- that there was 'assuredly no one gigantic displacement', adducing in evidence the beds with fossils (then supposed to be of Bala age) and the seams of shale, in the belts of complication: Thus there came about; for a time, a reversion to the view put forward by Prof. Hughes twenty years earlier, before Dr. Callaway's exposition of the nature of the tectonics and before the discovery of the thrust-planes in the North-West Highlands. These views found expression also on the quarter-inch map, issued in 1896, as well as on that of England and Wales on the scale of 10 miles to the inch, upon which the 'curved fault' disappears, and the whole of northern Anglesey is coloured as 'Lower Silurian'.

In 1890 Hicks again reviewed the evidence from the conglomerates, tabulating a. list of twenty types of rock that have been found as pebbles. A short account of the formation at Llangoed and Careg-onen was given by the present writer in 1896; and in 1898, Arenig shales of the zone of *Didymograptus extensus* recorded from the Strait.

The three papers by Dr. Matley (1899, 1900, 1901; reprinted in 1902) on the rocks of the north (already referred to in so far as they bear upon the Mona Complex), form together the most important publication upon the Ordovician rocks since Dr. Callaway's paper of 1884. In the first place, as has been already remarked, he performs the service, so long needed, of disentangling the Ordovician of the northern coast from the associated rocks of the Mona Complex. He then assigns that Ordovician to its true horizon, showing it, by palaeontological evidence, to be wholly of Llandeilo age, and subdividing it into its lithological horizons. Incidentally, he discusses, at greater length than former writers, the *Orthis* (renamed by him *O. proava* in 1911) that had given rise to some confusion, and shows its true affinities. Turning then to the question of the supposed upward succession from the region of Llanerchymedd across the 'Green Series' to the northern coast, he shows conclusively that it is quite incompatible with the fossil evidence. Examining then the 'curved fault', he makes clear from the coast-sections that it is not only existent, but a thrust-plane; and that at Carmel Head it has a low angle, like those of the North-West Highlands. He shows further that the Ordovician rocks are affected internally by many lesser thrusts, and that the presence of strips and wedges of them among the Llanbadrig rocks of the belt of complication is due to movements along planes of the same kind. Not only so, but they have been in placer broken up internally and converted into 'crush-conglomerates', and have also had a cleavage induced in them. He also discusses the general structure of the district. In his third paper he considers the beds on Mynydd-y-garn, and (regarding them also as Llandeilo) correlates them with those of the coast. He shows that they repose unconformably on older rocks, but his views on this subject have been given in connexion with the Mona Complex.

In 1910, the authorities of the Geological Survey, in consultation with the present writer, re-inserted the boundary thrust upon the new edition of the quarter-inch map.

The Silurian rocks

The existence of rocks of Silurian age in Anglesey was inferred, with some hesitation, in 1880 by Prof. T. McK. Hughes from a collection of brachiopoda, with a few corals, made by Henslo w at Treiorwerth, but the true horizon of these forms was not at that time accurately known, and it is almost certain that they came from the Arenig Beds. Two years later, however, the same author announced the discovery by him, when with the late Mr. Fanning Evans, sen., of a loose slab of shale among the mine *débris* of Parys Mountain, upon which were no less than eight species of graptolites, which were determined by Prof. Lapworth, and referred by him to the zone of *Monograptus gregarius.* It was therefore manifest that beds of Llandovery age must exist somewhere in Parys Mountain. But nothing more than this was known for 24 years. Then, in January, 1906, Mr. Griffith J. Williams, H.M. Inspector of Mines for North Wales (who had from time to time searched the shales when visiting the mines), found that shale thrown out from a tunnel that was being driven south from the East Pit contained graptolites, and on searching the material obtained a fine suite of specimens, with 17 species, evidently of Llandovery horizon. In August of the same year the present writer obtained four more species from material that had come from rather further south in the same tunnel. All these fossils were named by Miss Elles, and referred by her to the zones of *Monograptus convolutes* and *M. sedgwicki* respectively, and the results were published by Mr. Williams in 1907.

The Palaeozoic intrusions

Henslow refers to some of the sills, especially to the hornblende-picrite, of which he gives a megascopic description, but he does not separate them from the dioritic rocks of the Mona Complex. A good many of the sills are laid down upon the old one-inch maps, and in the memoir (p. 243) the hornblende-picrite is briefly alluded to, Ramsay inclining to the view that it is of metamorphic origin. In 1881 Prof. Bonney described the rock of a large boulder found at Pen-carnisiog, and identified it as hornblende-picrite, and in 1883 described more of such boulders from near Ty-croes. Slides from this boulder were afterwards figured in Br. Teall's 'British Petrography'. In 1885 he also described hornblende-picrite that had been obtained *in situ* by Prof. Hughes at Llanerchymedd and Llaneilian, so that the boulders were now traced to their sources and the rocks found to be intrusive in the Ordovician sediments. In 1887 Dr. Harker, in the second of a series of three papers in the *Geological Magazine* on 'Some Anglesey Dykes', gives a fuller account of the petrology of the picrites, observing also that the masses 'are not properly dykes'. Blake, in 1888, gave some brief descriptions of some of the diabases, tie special interest of his observations being that he recognised the locally schistose structure of the diabase of Llyn Traffwll.

Descriptions have been given of many of the numerous older dykes of the Island, without, however, separating them from the true later series. Henslow figured with great accuracy some of those by the Menai Strait, and also the larger ones of Holy Isle, and their principal minerals were identified by Cordier, to whom he submitted them, by means of the petrographical method he had devised. Many of the dykes, both acid and basic, are shown on the old one-inch maps, and Ramsay refers briefly (p. 235) to those of the north, inferring from their relations to the boundary 'fault' that they must be 'comparatively old', in which view he was certainly right. In 1887 and 1888, in the first and third of his series of papers already cited, Dr. Harker gives petrological descriptions of the dykes of the Menai shores and also of some of the larger ones of Holy Isle. He showed that the Menai dykes, though doleritic in aspect and often ophitic, were intermediate rather than basic in their affinities, and that their more compact portions are really of the nature of augite-andesites. The coarse rocks from the large dykes of Holy Isle were found by him to contain original hornblende, but secondary hornblende was also present. Blake, in the *Br. Assoc. Rep.* of 1888, describes the acid dykes of the north, noting their 'macrofelsitic', and particularly (in some cases) micro-pegmatitic texture. In 1896 Sir A. Geikie, and in 1899 Dr. Matley, briefly described the dykes in the northern zone of complication, showing that they are clearly later than the movements that have broken up the Gwna Beds of the Mona Complex. (Dr. Matley refers to certain older igneous rocks, but these belong to the Mona Complex itself.) In 1900 the present writer published a paper in which the habit and grouping of some -of the older dykes of the Aethwy Region was described, but as these were not therein separated from the true later series, the inference drawn concerning the age of what is now known to be the older series was incorrect. Dr. Matley in his second paper (also of 1900) gives descriptions, with microscopical notes by Prof. Watts, of some of the dykes of the north, both acid and basic, showing that some of the acid dykes are spherulitic. He also describes the compound dykes, in which acid and basic rocks occur together, the basic being, apparently, the later. He assigns the dykes to a period 'later than the last period of great movement in Anglesey', noting, however, certain movements to which they have been subjected, as well as the fact, remarked upon by Ramsay, that they fail to pass across the boundary thrust. He also comments upon their scarcity in the Ordovician areas.

Metasomatism

No general account of the metasomatisin of Parys Mountain appears to have been written but that by Ramsay which, though brief, conveys a clear idea of the phenomena. On the map, he has rightly separated the felsites from the altered portions of the shales. But, in the memoir, he appears to consider these, as well as the blue flinty matter, to be due to the alteration of argillaceous rocks: and he also ascribes the alteration-to the same cause and the same period as the granitisation of the adjacent gneisses of the Nebo Inlier. With a flash of characteristic penetration, however, he has perceived that the condition of the rocks is due to the introduction of secondary silica, and also that the metallic ores are a product of another phase of the same general process.

The ores have been described by several writers, and references to their works will be found in the 'Bibliography'. The most important are those of Lentin, Fanning Evans, sen., (late manager of the mines), J. A. Phillips. and R. Hunt. Lentin was a German metallurgist who came over to study the processes of raising and smelting the ore of these then famous mines. His work (published in 1800) is hardly geological, but it gives an admirable and vivacious account of the mines at an early stage of their history, and is the only published description at any length of the smelting processes. In 1877

Fanning Evans, sen., gave a clear account of the mines at a much later stage, describing the principal lodes, one only of which appears to have been worked in Lentin's time. His paper has been drawn upon by Phillips and by Hunt, but Phillips points out that the Parys Mountain 'lodes' are not lodes at all in the sense in which that word is usually employed.

In his paper on 'The Monian System', already quoted, Blake refers to certain quartz-knobs', which he regarded as having been deposited from solution in siliceous waters. Most of these are undoubtedly lenticular outcrops of the Gwna quartzites, and are true sediments; but a few of them have certainly been produced by the agency that he invoked, or at any rate from solution in siliceous waters under one condition or another. They include the knobs' of Pen Bryn-yr-eglwys, Porth-yr-hwch, and, especially, of Parys Mountain. Blake's views therefore, on the mode of origin of these particular abnormal quartz rocks, were essentially correct. He was right also as to the origin of one of the limestones which he regarded as sporadic, the dolomite of Porth-y-defaid.

The beautiful crystalline Kaolinite that has now become well known from the figure in Dr. Teall's British Petrography, was first found in a specimen sent up to Murchison in 1859 from Pant-y-gaseg mine. Its composition was determined chemically by Tookey, the analysis being quoted in Percy's Metallurgy, with details as to its occurrence. Its crystalline characters were then investigated by Mr. Allan Dick in 1888 and 1908, and he has also contributed some further particulars to the present volume.

The Old Red Sandstone

This formation was clearly recognised by Henslow, who appears to have been the first to discover it in the Island. He describes its fine red sandstones, and notes the presence of the ' nodular concretions of carbonate of lime'. Unfortunately, he included in it large tracts of Ordovician Sandstone (evidently those which, from local yellow or red colouring, he did not like to place with his Greywacke), and also the Lligwy Sandstone of the Carboniferous.

A good concise description of the formation is given by Ramsay. He recognises its unconformable relations to all the older rocks, and the presence of fragments of them in its conglomerates. He also notes the abundance of the cornstones. He refers the series to the Upper Old Red Sandstone, and regards it as a Continental introduction to the marine beds of the Lower Carboniferous.

The Carboniferous Limestone

Henslow describes many interesting features of this formation, and shows by his sections that he had grasped its general disposition, but the circumstance that he placed its lowest member in the Old Red, and its upper members (including much limestone as well as sandstone) in the Coal Measures, brought confusion into his stratigraphy in several places. He notes the different types of limestone; the shale and the chert, and the unconformability at the base. With great discernment, he points out that the beds throughout the Principal Area keep on striking at the base, so that the line of junction must intersect the strata, obliquely to their course, from the lowest upwards in a regular succession', thus perceiving the great overlap. At Ceint he figures a section showing contortions in the limestone close to the great Berw fault, which is unfortunately not now visible. He notes the identity of the fossils 'with those from the mountain-lime of England'. Placing, as he did, the basement sandstones of the Straitside Area with the Coal Measures, he was led to-separate the limestone there from the Carboniferous, putting it into the Magnesian Limestone'. Ramsay gives a clear general description of the Carboniferous Limestone (with a list of fossils from the Penmon Area by R. Etheridge, sen.). He notes the disturbances at the base at Lligwy Bay, the Penmon dolomite, the red marl of Plâs Newydd Park, and the occurrence of beds of pebbly sandstone at various horizons, with the great irregularity of their relations, 'the beds wedging in and out among each other so irregularly that even on a large scale of map it would probably be very difficult to separate them', a remark that has been found in the present survey to be only too true. He describes the gradual westward thinning of the limestone, saying that there is reason to believe that the beds are gradually overlapped in succession, the higher strata by degrees intruding on the foliated rocks below'.

In 1887, Dr. J. W. Gregory published a detailed account of Puffin Island, with a list of fossils, and in the same year Morton described the Carboniferous fishes of North Wales. The paper by the present writer in 1896, already cited, gave a short

account of the Pentnon Area, noting among other things that there was no sandy series at the base, and that the conglomerates higher up contained pebbles of limestone in which were Carboniferous fossils. In 1900 he described the remarkable sandstone pipes at Trwyn Dwlban, showing that they occurred in the midst of a marine series. He was not then aware that these pipes had been seen by Morton in 1866, as well as by Henslow.

By far the most elaborate paper upon the Carboniferous Limestone of Anglesey was by Morton, published in 1901, a short time after the author's death. It was written with his unfailing care and accuracy, and contains no less than 20 pages of fossil lists, in which the faunas of the Limestone all over North Wales are correlated. These, owing to the well-known scientific methods of Morton in all his work, would still be of the greatest value, but unfortunately he had at that period of his life acquired the habit of naming his fossils (familiar to him as they then were after so many years), on the ground, without adding them to his collection. His determinations cannot, in consequence, be verified in the way that has become necessary since the introduction of the new zonal researches on the Limestone, a great loss to present workers. He examined the formation in all the three districts, recognising his three divisions, the Lower Brown, Middle White, and Upper Grey Limestones in the Principal and Penmon Areas, but being doubtful about the existence of the Upper Grey in the Straitside Area, where he found beds with its fossils, but not having its lithological characters. He notes the sandstones at various horizons within the series, regarding that which fills the pipes at Dwlban Point as a band at a visible junction of the Middle White and Upper Grey Limestones.

In 1907 Prof. Hobbs published a suggestion which he had previously made to the present writer in a letter, that the pipes might find their explanation in the disturbances of underground water that are known to be produced during earthquakes, and the Comte de Montessus de Ballore adopted this suggestion in his work immediately after.

A collection of 430 corals and brachiopoda, made by the present writer in the winter of 1907–8, at the close of the survey of the Principal Area, was very kindly examined by Dr. Vaughan. His work established, at once, the important conclusion that the whole of the limestone of that area (where there was reason to think the succession was most complete) fell within the zone of *Dibunophyllum.* Dr. Vaughan further recognised the presence of subzones ranging from D1 to Dy, and the absence of the lower zones was in complete harmony with the fact that the area is situated within a region of rapid westward overlap. The results of Dr. Vaughan's work were not published in detail, but the main conclusion was stated in the report to the British Association in 1909.

Millstone Grit and Coal Measures

The sandstone at the base of the Coal Measures is alluded to by Henslow, but its first recognition as an horizon is in the map and memoir of the Geological Survey, where it is definitely called 'Millstone Grit', and given a separate colour. The fact that it overlaps the Carboniferous Limestone is recognised by Ramsay, who remarks that the Millstone grit lies on the altered rocks of Bodorgan'.

The existence of Coal in Anglesey has been known for a long time (Chapter 35). Henslow speaks of the coal-mines, and of having observed a 'flag-leaf' in the shale, but he includes a great deal of the Limestone in his 'Coal Measures'. The only geological description of the Coal Measures hitherto published is that by Ramsay. He gives a section across the coal-field, and a column of the succession of the strata, gathered from the mining information of that. time, on the unsatisfactory nature of which he remarks. Even at the present time, it is hardly possible to add much to the general view of the succession which is given by him. But some plans and borings made between 1848 and 1881 evidently did not reach, him, and failed to find their way into the second edition of the memoir, and these do throw some light on the succession and the structure. He gives, however, a good deal of detail concerning the beds about Holland Arms, and lays down, as nearly as the evidence admitted, some of the dip-faults upon the one-inch map.

The Red Measures

The Ferry beds are clearly recognised by Henslow, and correlated with their greater development on the other shore of the Strait. They are referred by him to the 'New Red Sandstone'. They are also described by Ramsay, who notices the pebbles of unknown source in the Llanfair-is-gaer conglomerate. He refers the series, however, to the Coal Measures, on

the ground, apparently, that some thin seams of coal, of which he gives no details, and of which nothing can now be ascertained, had been found in them near Carnarvon.

Those of the Malldraeth were first discovered by Ramsay, from the material, brought up from the upper parts of the shafts near Holland Arms, and, from the evidence of the mines, he inferred their unconformity to the beds upon which they rest. This unconformity led him to separate them from the Ferry beds. He regarded them, nevertheless, as lithologically different from 'any part of the New Red Sandstone', and points out their close resemblance to the 'Permian' of the Denbighshire Coal-field, with which, accordingly, he correlates them.

The later dykes

These have not been distinguished from those of the older series in any publication before the present work, but their field relations and petrology have been described in considerable detail by several authors, especially by Henslow and Dr. Harker. Henslow notes their intrusive relations, the coarseness of their texture, and their tendency to decomposition, and with the aid of Cordier identifies their principal minerals with the exception of the olivine. The chief interest of his work, however, consists in his recognition and excellent descriptions of the contact alteration which they induce in the adjacent rocks, especially in the Carboniferous Limestone and the Coal Measures, which at that time, when the igneous nature of such rocks was under discussion, was a matter of no small importance. His description of the contact phenomena of the Plâs Newydd dyke can still be read with profit. Cumming aided him in the examination of the contact minerals, and they were correctly identified as garnet and analcime. Ramsay alludes briefly to the dykes, and, on the ground that one of them, in the coal mines, had been said to stop at the base of the Red Measures, was inclined to assign to them a Post-Carboniferous but Pre-Permian date. In the first and third of his papers already cited Dr. Harker gives petrological descriptions of several of the later dykes, employing for the most part slides cut from Henslow's specimens. He notes the general presence of olivine, the order of consolidation of the minerals, and the development of two generations of felspar. In the case of the dykes of Holy Isle, however, there is a little uncertainty in some cases as to the source of some of the specimens, as Henslow's map shows that he had, very naturally, joined up one of the later with one of the older dykes. Dr. Harker also examines the contact minerals of the Plâs Newydd dyke, and discusses Cumming's analysis of the analcime.

In the paper by the present writer, to which allusion has been already made, reasons are given for regarding these dykes as members of the great system of Tertiary intrusions. But, as has been remarked above, many of the older dykes, which had not at that time been distinguished as such, were erroneously assigned to the same period.

Glacial and later geology

Henslow devotes a page to the noting, curiously enough, its conical hills', evidently the drumlins, of the north and west, which do not appear to have been remarked upon by any later writer.

The first paper that can really be called 'glacial' is that by Ramsay in 1852. Dealing for the most part with the Mountain-land, he mentions Anglesey but briefly, noting its 'drifts', and the occurrence of a few shells in some of them, also the fact that most of the boulders appear to be from the rocks of the Island itself. He ascribes its glaciation to floating ice, and the reason he gives is interesting, in connexion with the views of which afterwards he became the great exponent. It is that the direction of the striae is from about N. 30 E., 'a direction quite unconnected with that of the glaciers of Carnarvonshire'. In his Old Glaciers of Switzerland and North Wales' he repeats the same view. After 1860 his views underwent a gradual evolution, until he came to ascribe the glaciation of Anglesey as well as that of the Mountain-land to land-ice, and the direction of its striae (first, apparently, observed by him) to the mutual deflections due to the meeting of the two bodies of ice. When he arrived at this view I do not know, but certainly as early as 1870, after which he continued to expound it in all his later works. To the end of his life he appears to have considered that the period of maximum glaciation was followed by the great submergence that has been considered necessary to account for the shelly gravels of Moel Tryfan and other places. But he seems to have supposed that the alternative hypothesis involved a bodily shoving-up' of previously formed gravels to the ground where now they lie: and it is a curious coincidence that the depth which he postulates for the sea-basin ice-sheet is as nearly as possible that which he assigns

to the great submergence. Nor does he seem to have attributed to this submergence any important glacial features or deposits within Anglesey itself. In his paper on 'How Anglesey became an island', first published in 1876, but afterwards introduced as a chapter into the second edition of the memoir in 1881, which was his final pronouncement, he had clearly grasped the great principle of the glaciation of the Island by land-ice from the north-east, to which subsequent research will add many details, and will enrich by illustration, but does not seem likely seriously to modify. His views on the subject are perhaps best known at present in connexion with his theory of the Menai Strait, which, he points out, is but one among a whole series of valleys that trend from north-east to south-west, differing from the rest in the fact that it is deep enough to admit the sea. He then shows that the trend of the other valleys of the system is precisely that of the direction of the glacial striae, and that such valleys may reasonably be ascribed to glacial excavation. If so, however, why should the Strait be considered an exception? And he expresses his conclusion in the words that it is, after all, merely a long and broad glacial groove'. He adds that he arrived at this view while looking at the Strait in the year 1875.

In 1876 Morton published some records of glacial striae; and in 1883 Mellard Reade, in an elaborate paper on a wide area, touched upon the drifts of Anglesey, noticing the reddish tint of the upper boulder-clay at Beaumaris. He refers to boulders of Galloway granite, but does not give localities, so that it is not certain whether he found these in Anglesey. Indeed, although -the occurrence of these and of the rock of Ailsa Craig in the drifts of Anglesey appears to have been taken as established by glacial writers for some time past (there is an explicit reference by Prof. Kendall in 1892), I have not yet found the first records of their discovery.

In 1886 Dr. Strahan (ascribing the glacial phenomena of the lowlands in the main to floating ice) published a paper in which, by means of maps and diagrams, the glaciation of Anglesey is brought into relation with that of the whole southern borders of the Irish Sea as far as Lancashire, special attention being devoted to the borderland of Wales. He shows the dominant directions of the striæ, and describes the characters of the leading types of drift, distinguishing that, of local from that of northern derivation, a valuable feature of the paper being a. line showing the approximate boundary of the two drifts from the Menai Strait as far as the curve of the Dee below Llangollen. This paper should still be studied by any one who wishes to grasp the full significance of the characters of the drifts of Anglesey.

In his account of Puffin Island in 1887 Prof. J. W. Gregory gives a list of seventeen types of rock found there as erratics, which had been examined by Goodchild, most of which were from Southern Scotland and the Lakeland.

In 1896 the present writer described some of the drifts of the east, especially at Peninon, drawing attention to the cross-hatching of striae in that district, attributing these to the changing interactions of the ice-sheet of the sea-basin and of the mountain-land, the latter being individualised into the glaciers of Llanfairfechan, Aber, and the Ogwen. In 1898 he recorded an uplift of boulders at Llandegfan, and in 1900 described the remarkable local deflections and undercut furrows of Trwyn Dwlban. In 1904 he showed that the ice had passed over the summit of Holyhead Mountain; that there had been an uplift thither of boulders through a height of more than 400 feet, and that local glaciers had probably existed there for a short time.

In 1905 the most detailed account of the glaciation of Anglesey given in recent years was published by Mr. Edwards, a native of the Island. He describes most of the coast and some inland sections in drifts in the southern half of the country, adding a valuable feature in the shape of boring records from the drifts of the Malldraeth Marsh, which are below marine alluvium. He collected and identified many. boulders, and made a comparison of those of the Menai side with the rocks of the eastern mountain-land, showing that felsites, which abound near the Strait, decrease rapidly inland, as well as that the granites of the northern drift diminish in a southwesterly direction. An interesting fact to which he draws attention is that large boulders that have not been disturbed by man are apt to lie with their major axes north-east and south-west, and mentions a train of such along which a hedge has been made near Llanfair. He considers that, whatever may be thought of the Moel Tryfan gravels, he knows of 'no deposit that can be classified as marine drift in Anglesey'.

The land surface

Long ago, in his writings on the Menai Strait, his theory of which has been mentioned on p. 27, Ramsay pointed out that Anglesey 'may be looked on as a gently undulating plain, the higher parts of which attain an elevation of from 200 to 300 feet', and that the same plateau extends across into the mainland, noting also that there are a few exceptions to the

average levels'. Although he discusses at some length the age of the high platforms of the Mountain-land, he makes no remark about the age of that of Anglesey.

In 1906 the present writer discussed the origin of the ravine of the Cefni, and showed that more than one system of drainage had existed in the Island. In 1907 he made use of the glacial phenomena of the north-east to obtain the seaward limits of exposure of the Mona Complex. In 1912 he put forward a theory of the Menai Strait.

Chemical analysis

Up to the year 1904 some analyses had been published by various writers, most of which are quoted in the present volume. Special mention may be made of a series of six given by Messrs. Holland and Dickson in 1890, and another of seven by Messrs. Reade and Holland in 1900. In 1904, by generous co-operation between the British Association and the University College of North Wales (the initiative being taken by Prof. Orton), arrangements were made for systematic analysis in connexion with the present survey. A committee of Section C. was appointed, consisting of Mr. Harker (Chairman), Mr. Greenly (Secretary), Mr. Lomas, Dr. Matley, and Prof. Orton. On the lamented death of Mr. Lomas his place was taken by Dr. Horne. Mr. John Owen Hughes, demonstrator in chemistry at the college, was selected to be chemist. Work was begun in 1905, and the committee presented its final report at Dundee in 1912. The rocks were selected and collected by the secretary. Altogether some 80 rocks have been analysed, 12 qualitatively, 68 quantitatively. Of the quantitative analyses 43 have been complete, the rest partial. The total number of estimations made is 730, of which 691 are the work of Mr. Hughes.

The present survey

The survey by the present writer was begun at Beaumaris in May, 1895, and completed at Llaneilian in October, 1910. The Skerries, however, were surveyed in July, 1911. The six-inch maps were used throughout, but in certain districts of unusual complexity, such as Cerrig-ceinwen, Holland Arms, Newborough, Llanddwyn, the Bodorgan Headlands, the Serpentinous group, Mynydd-y-garn, the Northern Sea-board, and The Skerries, the lines were laid down first upon the '25-inch' (.0004) maps, and reduced to the six-inch.

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Methods of reference to publications

With so copious a literature, it is obvious that the present work must repeat innumerable observations that have been made, and conclusions that have been arrived at, by previous authors. To refer to all or nearly all these by footnote would fill the text with reference numbers. But, 'if footnotes are referred to, the thread of the argument is completely broken; and even if they are not referred to, attention is distracted by the consciousness that they are there to be looked at'. (Spencer, 'Principles of Sociology', Preface). It is hoped, therefore, that a perusal of the present chapter will render all the more

important work of previous investigators easily recognisable as soon as it is met with, embedded, as it were, in the text. And their minor observations will be found when desired by reference to the Bibliography.

References to writings on other districts than Anglesey will be referred to by footnote in the usual way. Those to unpublished work, of which a great deal has been done in aid of this memoir, will be found, naturally, in the text itself.