MEMOIRS OF THE GEOLOGICAL SURVEY.

ENGLAND & WALES.

ANGLESEY.

IN TWO VOLUMES.

VOLUME I.

Plate I.

[*Frontispiece.*

THE FOLDING OF THE MONA COMPLEX.

MEMOIRS OF THE GEOLOGICAL SURVEY.

THE GEOLOGY OF ANGLESEY.

BY

EDWARD GREENLY.

VOLUME I.

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PREFACE BY THE DIRECTOR.

THE Island of Anglesey was geologically surveyed on the old series one-inch map in 1849 and the following years, mainly by Ramsay but in part by Selwyn and Warrington Smyth. The map was published in 1852 and was followed by a Memoir on the Geology of North Wales in 1866. The Memoir, except for a palæontological Appendix by Salter, appeared under the authorship of Ramsay, and the preparation of a second edition, which was published in 1881, occupied much of his time towards the close of his tenure of office as Director General.

The author of the present Memoir, after spending six years in the geological surveying of a part of the Highlands of Scotland as a member of the staff of the Geological Survey, resigned his post in 1895. But the fascination of the crystalline schists with their infinitely complicated structures and metamorphism was strong upon him, and within a few weeks, actuated solely by a spirit of research, he commenced, single-handed, the detailed six-inch survey of Anglesey, of which the results are embodied in the following pages and upon the forthcoming one-inch geological map.

There were many reasons for his choice of this island for an investigation that proved to be the work of no small part of his life. It is a naturally defined tract that could be dealt with apart from adjacent ground. There was no doubt that much reconsideration was required of some of the earlier conclusions with regard to the crystalline schists. Little was known of some occurrences of Lower Palæozoic rocks, which were likely on further investigation to furnish connecting links between the Welsh and Scottish types of development. That Old Red Sandstone existed in the Island had long ago been recorded, but its relations to the subdivisions of that formation as recognised elsewhere, remained to be ascertained. The Carboniferous rocks presented several almost unique characters, some of surpassing interest, all of which called for detailed examination; while lastly a study of the glacial deposits, which were not shown on the original map, promised to throw much light on the movements of the ice along the North Wales border and in St. George's Channel. That the examination of an area, presenting problems so numerous and so varied, should have occupied Mr. Greenly's energies for 24 years is no matter for surprise. The wonder is rather that one man should have been able to concentrate on so many subjects, and mete out to each the exhaustive attention which is evidenced in the following pages.

In May, 1908, Mr. Greenly wrote to Sir J. J. H. Teall, at that time Director of the Geological Survey, in the following words. 'The end of my work is now within moderate distance, and I therefore wish, and the act gives me great pleasure, to offer its results to the Geological Survey to which I am so much indebted for training and experience. The only condition I would ask is that the Geological Survey should publish a one-inch map of the Island, together with a descriptive Memoir which I would write to accompany that, as soon as might reasonably be done after the completion of the work.' This generous offer was accepted by Mr. J. A. Pease (Lord Gainford), at that time President of the Board of Education, subject to the map being certified to be satisfactory. Inspection was made at once with the result of showing that the six-inch survey had been made with the utmost care and accuracy, and that the map offered by Mr. Greenly was up to the highest standard of Geological Survey work.

The MS. of the Memoir was completed in 1916, and a suggestion made by Mr. Pease in 1908 that the author should receive the thanks of the President of the Board of Education when the map and memoir were handed over, was adopted by Mr. Pease's successor. The following letter was addressed to Mr. Greenly by Mr. A. Henderson :

'I understand that during the 20 years that have elapsed since you were a member of the staff of the Geological Survey, you have devoted yourself to geological investigations in Anglesey, and that you have now completed a geological memoir to elucidate the map which you have already presented to the Survey.

'I am informed that the map is a work of great skill and precision, and that it will rank among the best productions of the Geological Survey. The memoir which you now offer is, I have no doubt, a lucid interpretation of the geology of the area, and worthy of the map. I wish to convey my personal thanks to you for giving the results of your long labours to the public through your old branch of the Service, and I congratulate you upon the successful completion of so admirable an example of well-directed effort.'

In the meantime however difficulties in preparing the map and printing a memoir had arisen in consequence of the war. Colour-printing of maps was temporarily in abeyance ; there seemed also to be probability of delay in printing, at such a time and as an official publication, a long and detailed memoir that had little direct bearing on war requirements. Influenced by a desire to have perfect freedom as to the time and manner of producing his results, Mr. Greenly offered to bear the whole expense of producing the Memoir, and though the great increase over the estimated cost which resulted from the War rendered this impossible, he has nevertheless contributed a considerable part. Of the results of this generosity the volumes themselves bear evidence. The author has availed himself of his freedom from the official restrictions which were inevitable in a time of stress, not only fully to present his scientific conclusions, but to record the wealth of detailed observations on which those conclusions are based, and at the same time to do justice to the remarkable structures he describes by numerous drawings and photographic reproductions.

This briefly is the history of the Memoir on Anglesey. Ample proof will be found in its pages of the labour and thought which have been bestowed upon it, both as regards its editing and the exhaustive treatment of the geology. Nor has the author hesitated to call upon others who have been engaged in kindred subjects elsewhere, to give him their aid in dealing with the problems presented by this difficult area. The volumes are included among the Geological Survey Memoirs in the confidence that they will rank not only as the standard work on Anglesey, but as a work of reference in several branches of geological research, for many years to come.

A. STRAHAN,
Director.

Geological Survey Office,
28, *Jermyn Street, London, S.W.* 1.
2nd May, 1919.

AUTHOR'S PREFACE.

IN England and Wales there are about a dozen places at which we seem to catch a glimpse of the old floor that underlies all the Palæozoic and later formations. Of these glimpses, the most extensive and varied is that which is afforded us in Anglesey. Yet mists have long hung about this fascinating view. For many years indeed it was held, and that by those who, rightly, commanded most authority, to be but a mirage, a simulation of the sought-for by that which in reality was hiding it from our eyes. The enthusiasm kindled by such a problem did not fail to lead to keen and persistent investigation. Eventually, however, a stage was reached when it became evident that what was needed, not merely as a mode of research but as a reliable basis for future research, was a detailed re-survey upon the lines that had been found so successful in other regions. Hence the present map and memoir. But whatever the interest of the ancient crystalline schists and their associates, hereinafter called (see p. 39) 'The Mona Complex,' they have been accorded no special treatment on the maps, every formation, 'Drift' as well as 'Solid,' having been similarly mapped, in accordance with the practice of the Geological Survey.[1]

In dealing with the Succession in, the Tectonics of, the General View of, and the Age of the Mona Complex (Chapters VI, VII, VIII, IX), unrestricted expression has been given to the interpretations that are advocated ; but in full realization of the hazardous nature of the subject, and with the expectation that they will be modified, perhaps extensively, by criticism and future research. Special attention is asked to the fact that the interpretations in question do not in any way affect the *lines upon the maps*, which were drawn without any reference to them, and in fact, before they had been adopted.[2]

A chapter entitled 'Metamorphism in the Mona Complex,' treating that subject as a connected whole,[3] ought properly to have followed upon Chapter VII. At the time it would have had

[1] Information concerning the various maps that have been used will be found in Appendix I.

[2] The succession in Holy Isle was made out on the completion of the mapping of that isle in 1906, and its tectonic interpretation followed upon a suggestion thrown out by the late C. T. Clough in 1907 ; but the interpretations of the rest of the Complex were not arrived at until after the whole of Anglesey had been surveyed.

[3] Its various aspects are described and discussed in Chapters IV, VII, VIII, and X.

to go to press, however, I had not succeeded in bringing the metamorphic into satisfactory correlation with the tectonic phenomena. The Supplement, and the genetic studies added in Chapter XLI (pp. 900—4 and especially 907—10) partly supply the lack; but I hope, ere long, to deal with the ætiology of this fascinating aspect of the Complex in a systematic manner.

The local detail of the more extensive formations has been relegated to special chapters, in which have also been placed the local fossil lists, with the registered numbers of fossils and microscopic slides. Their prime object has been to provide a guide to the more important exposures; but they also provide means of verifying generalised statements, thus relieving the general descriptions from a distracting multiplicity of place-names and reference-numbers.

The fossils have been determined by specialists: the graptolites by Miss Elles,[1] the Ordovician trilobites by Mr. Lake, the Ordovician brachiopoda by Dr. Matley, and the Ordovician phyllocarida by Dr. Peach. The Carboniferous Limestone fossils were named by the late Dr. Ivor Thomas (some having been previously examined by the late Dr. Vaughan), the Millstone Grit and Coal Measure fish by Mr. E. T. Newton, their mollusca by Dr. Wheelton Hind, and their plants by Dr. Kidston. Some miscellaneous forms, chiefly from glacial and later deposits, were named by Dr. Kitchin, Mr. Allen, and Dr. Ivor Thomas. The late Dr. G. J. Hinde examined all the sponge-spicules and other microscopic organisms. The fossils from the South Stack Series of the Mona Complex were determined by Dr. Peach and Dr. G. J. Hinde.[2] For more than half of these indispensable fossils we are indebted to the skilled and patient collecting of Messrs. Macconochie and Muir, who, sent to Anglesey for that purpose by the Geological Survey, pursued their aim through a succession of visits amounting in the aggregate to a year's work, and with enthusiasm never damped by long searches, often in cleaved and barren rocks.

For the Petrology I am responsible, except for assistance upon the following important subjects, as well as on some others mentioned in the text. Most of the slides and specimens of the spilitic volcanic rocks and of the serpentine-suite of the Mona Complex, as well as of the silicified rocks of Parys Mountain, were examined by Dr. Flett; the igneous boulders of the Skerries conglomerates by Sir J. J. H. Teall; and the Palæozoic Intrusions, the Later Dykes, and the Red Measure sandstones by Dr. H. H. Thomas. More than half of the chemical analyses are the work of Mr. John Owen Hughes, but several other chemists have contributed, and others kindly permit us to quote unpublished analyses.[3]

To all these specialists, and particularly to Miss Elles and Mr. John Owen Hughes, we desire to return the most cordial thanks.

[1] Miss Elles has also kindly contributed a valuable essay on the Graptolite Sub-Faunas.

[2] Particulars of the Survey collection are given in Appendix II.

[3] Statistics of the Anglesey rocks and slides in the collection of the Geological Survey, and of these analyses, will be found in Appendix II.

The work of Miss Elles upon the zonal graptolites has made it possible to determine the effects of the Post-Silurian disturbances, not only upon the Lower Palæozoic rocks themselves, but also upon the Mona Complex, knowledge essential to the interpretation of the Complex. Mr. J. O. Hughes, during seven years, devoted all the time at his disposal to chemical analyses of the rocks of the Island, without which the petrological work would have been seriously defective. The results he has obtained represent an important contribution to petrological science in general, quite apart from their bearing on the geology of Anglesey.

I have also had the great advantage of going over much of the ground with Sir J. J. H. Teall, Sir Aubrey Strahan, Dr. Horne, and Dr. Flett. Dr. Horne, who was detailed in 1908 to inspect the maps, visited the Island again in 1911. And all these officers have been ready at all times with valued aid and advice, especial thanks being due to Sir Aubrey Strahan for his tact and patience throughout the period of difficulty caused by the recent war.

The public-spirited interest which has been taken in this work by the County Council of Anglesey, by the Senate of the University College of North Wales, and by the Agricultural Committee of that college, ought also to be remembered.

The grants generously made, in aid of the chemical analyses, by the British Association and the Senate of the University College are referred to on p. 28.

To the Elder Brethren of the Trinity House we are indebted for a unique opportunity to survey the remote islets of The Skerries at leisure. They not only gave me permission to live for several days in the Skerries Lighthouse, but, with great courtesy, despatched me there and brought me back in their own vessel, the 'Triton.'

To Mr. Thomas Prichard of Llwydiarth Esgob in Anglesey we are indebted for a series of kind actions, continued over a period of some 18 years, too varied and too numerous to specify, but among which may be mentioned his loan of the valuable plants from the Coal Measures.

To him, and, equally, to the generosity of Mr. E. Neil Baynes, we owe nearly all the information of an archæological or historical nature that is given in Chapters I, XXXII, XXXV, and XXXVII. Mr. Baynes has now been working for several years on the archæology of Anglesey.[1]

The late Dr. Callaway's interest in Anglesey problems never flagged, and I had often the privilege of discussing them with him, especially the origin of the Penmynydd mica-schists, on which his views have proved most enlightening. Mr. Barrow also contributed valuable suggestions, chiefly concerning the jaspers and the hornfels;

[1] By the energy and public spirit of Lord Boston and Mr. Baynes, an Anglesey Archæological and Natural History Society has been formed, which has already done excellent work. Its aim is not only research, but preservation of destructible objects of interest, and several of the great erratic boulders of the Island are now included in its watchers' list.

while Prof. Bonney never begrudged the trouble of correspondence upon any question submitted to him. Certain chapters were kindly read by various friends, as follows:—II by Dr. Horne and Dr. Callaway; XIII, XIV, XV, by Miss Elles; XIII by Prof. O. T. Jones; parts of XVI, XXVIII, by Dr. H. H. Thomas; XX, XXIII, XXIV, XXV, XXXV, by Sir A. Strahan; XXX, by Sir J. J. H. Teall, Sir A. Strahan, and Dr. Horne; and all those which contain fossil names by Dr. Kitchin. Mr. Edmund Dickson made five analyses of rocks, and the late J. Hort Player made many reproductions of the field-maps by his photographic contact-process.[1] Microscopic slides were presented to the Survey by Dr. Matley and Mr. Barrow, and lent by Miss Blake, Dr. Callaway (who also lent fossils), Prof. Bonney and Miss Raisin, and the Sedgwick Museum at Cambridge. The plates are from photographs by Mr. J. Rhodes, Junr. (who was sent for that purpose by the Geological Survey), with the exception of Nos. XXVIb, by Mr. Griffith J. Williams; XXXVIII, XLIII, by Mr. J. Trevor Owen; LVI, by Mr. E. Neil Baynes; and LIX, by Mr. H. E. Spencer; who have also presented photographs to the Survey Collection.[2] We are indebted to the Council of the Geological Society for leave to reproduce Figs. 135, 189, 190, 191, 194, 195, 260; to the Editor of the Geological Magazine for Figs. 169, 258, and 289; and to the Council of the Cambridge Philosophical Society for Fig. 305. The half-tone and line blocks are by the Thames Engraving Co., the folding-plates and collotypes by Malby and Huth respectively.

The Coal-mine plans and boring-sections were kindly lent by Lord Boston, the late Hon. Lady Neave, the late Lady Reade, Mr. T. Prichard (on behalf of Sir G. Meyrick), and (through Mr. Bernard Smith) by the Menai Colliery Co., Ltd. Access to the Parys Mountain plans, together with frequently repeated other aid, was cordially given by Mr. T. Fanning-Evans, the Manager of those mines.

For aid on a number of different points we are indebted to the following persons:—the late James Bennie, the late J. F. Blake, Prof. K. Busz, Mr. T. C. Cantrill, the late C. T. Clough, Prof. Grenville A. J. Cole, the late J. R. Dakyns, Prof. J. R. Ainsworth Davis, Mr. H. Dewey, Mr. Allan B. Dick, Sir J. J. Dobbie, Mr. W. C. Evans, Sir Archibald Geikie, Mr. C. T. Gimingham, Dr. Harker, Prof. Harold Hilton, Prof. W. H. Hobbs, the late Prof. T. Rupert Jones, Mr. Lamplugh, Prof. Lapworth and Dr. Stacey Wilson, Prof. J. E. Lloyd, the late Joseph Lomas, Mrs. Longstaff, the Comte de Montessus de Ballore, the Director-General of the Ordnance Survey, Prof. K. J. P. Orton, Mr. E. R. Radley, the late Sir W. Ramsay, the late Clement Reid, Miss Reyner, Mr. J. Rhodes, Sen., Mr. W. Roberts, Dr. R. L. Sherlock, Mr. E. Watson,

[1] The rest of the photographic map-reproductions are by Mr. J. Wickens of Bangor.

[2] Information concerning this collection, and the means of obtaining photographs therefrom, will be found in Appendix II.

Mr. Gilbert Williams, Mr. Griffith J. Williams, Prof. Hudson Williams, and Dr. H. Woodward.

For local aid and information we are indebted to the following residents:—Miss J. H. Adeane, the Town Clerk of Beaumaris, Mr. Barbagli of Bryn-fuches, Lord and Lady Boston, Sir R. W. Bulkeley, the late Admiral Burr, Mr. F. E. Cotton, Mr. T. Clegg, Mr. J. R. Davies, Mr. R. L. Edwards of Bodafon-isaf, Mr. R. Ellis of Llanfairynghornwy, Mr. S. J. Evans (Headmaster of Llangefni County School), Mr. W. Fanning, Mr. J. J. Ffoulkes of Bodrwyn, Col. W. A. Fox-Pitt, the Managers of the Holyhead and of the Porth-wen Silica Works, Mr. H. O. Hughes of Llangaffo, the late James Hughes of Llanerchymedd, Mr. J. Hughes of Parys Mountain Mines, Mr. W. Jones of Llanrhwydrys, Mr. L. D. Jones (Llew Tegid), Mr. W. E. Jones (Agent to the Marquis of Anglesey), Col. Lloyd of Tregaian, Mr. O. J. Lloyd of Llangefni, Capt. McKinstry, Sir G. Meyrick, Messrs. E. Morris and W. E. Williams, Mr. and Mrs. Humphrey Owen of Treddolphin, the late C. F. Priestley, Miss M. F. Rathbone, Mr. J. Rice Roberts, Lord Sheffield, Mr. Toller, Major Lawrence Williams, the late Rev. Chancellor Williams of Llanrhyddlad, Dr. R. M. Williams, the District Superintendent of the London and North-Western Railway, the Secretary of the Holyhead Waterworks; also to the local naval and military officers, and to the county police, for their courtesy and co-operation during the recent war; and, for many years past, to land-owners, farmers, and many others all over the Island.

It is pleasing to reflect upon the magnitude of this body of aid, and upon the cordiality with which it has been given.

There is no one to whom so great a debt is due as to my wife. To mention that she has read both the proofs and the manuscripts of this book, as well as prepared the Index, is to mention but the last of a long series of services, too numerous and varied to be specified, or even to be recalled to memory. But this material aid has been as nothing when compared to the moral aid and support, that has never failed, no matter what the vicissitudes (neither few nor light) of the 24 years through which this work has been in progress. Had dedication been admissible, it should certainly have been to her.

I cannot close this long list of obligations without a tribute of gratitude to those officers of the Scottish Geological Survey (Drs. Horne and Peach) with whom I had the privilege to be thrown when first joining that staff. Also in particular, to the memory of our noble-minded colleague the lamented C. T. Clough, on account of the inspiring standard ever held up in his truly marvellous mapping, an embodiment at once of the highest scientific precision and of lofty devotion to an ideal.

EDWARD GREENLY.

April, 1919.

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Part II.—The Mona Complex. 37—388.

FIGURES IN TEXT.

NOTE.—Where the scale of a section is given, it is the same vertically as horizontally. In the sections marked '*s.l.*' in this list, the base line indicates sea-level. In those not so marked it is merely a local level. In this list many titles have been condensed for economy of space, and many have been modified in order to give a better indication of the subject.

In Chapter IX. The Age of the Mona Complex.

In Chapter X. The Detail of the Mona Complex.

PLATES.

The scale is indicated by a hammer, stick, bag, or compass, or by a human figure, and when there is no such object, the dimensions are stated. The hammer used is 12½ inches long, and the diameter of the compass is 1½ inch.

FOLDING PLATES.

AT END OF BOOK.

The horizontal base-line of the sections indicates sea-level, and the vertical scale is the same as the horizontal in all except XVI, XVII.

Corrigenda.

Page 35 : After Line 13.—Insert '1907. Greenly, E. "Sandstone Pipes in Carboniferous Limestone, Anglesey." *Geol. Mag.* p. 238.'

,, 201 : Line 26.—For 'p. 201' read 'p. 244.'

,, 202 : Line 3 from bottom.—For 'Fig. 37' read 'Fig. 38.'

,, 205 : Note.—For 'Appendix IX' read 'Chapter XLI, pp. 909—10.'

,, 207 : Line 31.—For 'Fig. 36' read 'Fig. 37.'

,, 207 : Line 3 from bottom.—For 'Fig. 38' read 'Fig. 39.'

,, 230 : Line 23.—For '17' read '18.'

,, 242 : Note.—For 'Appendix IX' read 'Chapter XLI, pp. 907—8.'

,, 303 : Line 30.—For 'Bryn-llywd' read 'Bryn-llwyd.'

,, 311 : Line 13.—For 'Dynas Cynfor' read 'Dinas Cynfor.'

,, 329 : Line 14.—For 'Drudwy' read 'Ddrydwy.'

,, 347 : Line 12.—For 'Porth Tywyn-mawr' read 'Porth Twyn-mawr.' They are two distinct places.

,, 362 : Line 4 above Fig. 168.—For '[E. 6091]' read '[E. 6090].'

,, 409 : Line 29.—For '(1911)' read '(1912).'

,, 498 : Bottom.—For 'Appendix IX' read 'Chapter XLI, pp. 892—3.'

,, 515 : Line 30.—For 'evidently older' read 'apparently older.'

,, 520 : Line 12 from bottom.—For 'spherulitic' read 'spheroidal.'

,, 557 : Line 24.—For 'Appendix IX' read 'Chapter XLI, pp. 900—1.'

,, 739 : Line 4.—For 'Trwyn-yr-eryr' read 'Trwyn-cerig-yr-eryr.'

Note.—In the text (see p. 3), Welsh place-names are spelt as on the one-inch map, of which this book is an explanation; but inconsistencies as to hyphens, capitals, &c., in compound names have crept in, owing mainly to the different usages on the six-inch and one-inch maps. In the Index, care has been taken to follow the usage of the new geological one-inch map.

Abolition of 'Appendix IX.'

The matter that was intended to have been placed in this has been transferred to Chapter XLI. Consequently, on pp. 205, 242, 498, 557, (as indicated in the Corrigenda-list) for 'Appendix IX' read 'Chapter XLI, pp. 909—10, 907—8, 892—3, 900—1' respectively. *See also* the Table of Addenda, p. xl.

EXTRA CORRIGENDUM.

On page 921, line 12; The expression "Both editions" is erroneous. The map is issued in one edition, as explained on page 920.

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SIX-INCH MAP NAMES NOT QUOTED AS SUCH.

It is stated at the top of p. 3 that the place names used in this book will be those found on the published One-inch Geological Map, except in a small number of cases, which are indicated in the text. In 23 other cases, however, I have inadvertently made use of names taken from the six-inch maps without indicating that they are such. By means of the following table they can be translated into equivalents that will be found on the one-inch map.

Page 78 : Analysis I.—For 'Capel Soar' read 'Soar.'
" 281 : Line 14 from bottom.—For 'Bryn-palma' read 'Three-eighths of a mile west-south-west of Llynon Hall.'
" 281 : Line 14 from bottom. For 'Pen-yr-argae' read 'Three-eighths of a mile north-east of Tan-yr-allt.'
" 326 : Line 4.—For 'north end of Ty-croes lane' read '277-foot level.'
" 371 : Lines 16–17.—For 'about Bryn-tirion' read 'east of the 178-foot level.'
" 406 : Lines 19–20 from bottom.—For 'Gorlan-goch' read 'Bonw lane.'
" 407 : Line 9 from bottom.—For '275 yards north-west of Gorlan-goch' read '660 yards south-east by east from Bonw.'
" 416 : Line 14.—For 'Gorlan-goch' read 'Bonw lane.'
" 434 : Line 11 from bottom.—For 'at Tan-y-gwreiddyn . . . east-north-east' read '270 yards south of Llanddona Church, the other at a farm 200 yards to the west-south-west.'
" 434 : Line 5 from bottom.—For '233 yards . . . Ty'n-y-pistill' read '700 yards south-west by south from Llanddona Church.'
" 456 : Lines 13–14.—For 'Tyddyn-bach' read 'The farm north-east of Glan-y-gors.'
" 456 : Bottom.—For 'Cefn-du-mawr' read 'Cefn-du.'
" 506 : Line 11 from bottom.—For 'Porth-y-nant' read 'north nook of Porth y Bribys.'
" 507 : Fig 248.—To 'Bathing House' add 'at end of long plantation.'
" 533 : Line 2 from bottom.—For 'by Pen-yr-allt' read '180 yards south of Glasgoed.'
" 542 : Line 2 from bottom.—To 'Llanfairynghornwy Post Office' add 'by the "S" of "Smithy."'
" 545 : Line 8 from bottom.—To 'Llanfairynghornwy Post Office' add 'by the "S" of "Smithy."'
" 550 : Line 20 from bottom.—For 'Castell' read 'the cottage south of the "S" of "Smithy."'
" 562 : Middle.—For 'at Pen-y-nant' read 'east of the "r" of "Parys."'
" 588 : Table.—For 'of Pen-y-braich' read 'south of Penrhyn.'
" 731 : Line 16.—For 'Penrhyn' read 'Porth Penrhyn-mawr.'
" 756 : Line 21 from bottom.—For 'north of Tyddyn-hir' read 'south of Glan-morfa.'
" 767 : Line 14 from bottom.—For 'Pen-yr-allt reefs' read 'reefs west of Bodlasan-groes.'

Addenda.

The additional studies which have been placed in Chapter XLI really belong (as explained on p. 887) to preceding chapters. It is requested that they be read as parts of those chapters. The places at which they should be interpolated can be found from the following table. See also (with regard to four of them) the note on p. 933, concerning the Abolition of Appendix IX.

Chapter	Page	Interpolate addition on
IV	41	Another Analysis of the Holyhead Quartzite.
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VI	159–60	The Gwna-Skerries Junction.
VI	161	The Fydlyn-Gwna Junction.
VI	163	The Relations of the Basic and Acid Gneisses.
VI	167	The Age of the Gneisses.
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VII	205	Folding and Metamorphism.
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XVI	510, 516	The Age of the Palæozoic Intrusions.
XXV	670	Red Measure Erosion.
XXVIII	689	Later Vulcanism.

Interpolation on pp. 615–16. After the paged proofs of Chapter XLI had been passed, papers were read before the Geological Society (Jan. 8, 1919) by Prof. Kendall and Dr. Gilligan, in which they suggested that certain irregularities of bedding in the Coal Measures of England might be due to contemporaneous earthquakes. Their views should, accordingly, be combined with those of Prof. Hobbs and the Comte de Ballore.

Note to p. 799. For the history of Cemlyn pebble-ridge, as well as for several other matters of local history, we are indebted to my friend Mr. Ellis of Llanfairynghornwy.

Note to pp. 264—7. The colour-band on the one-inch map represents the passage-beds, where the basic band itself may be barely visible, as at the spot illustrated by Fig. 112, where also the curved line indicates the base of the zone of passage.

THE GEOLOGY OF ANGLESEY.

PART I.—PRELIMINARY.

CHAPTER I.

INTRODUCTION.

'Or northward unto cloud-roofed Gwynedd, where
The mountains sit together and talk with heaven,
While Mona, pushing forth into the deep,
Looks back for ever on their musing brows.'
William Watson.

THE Island of Anglesey, parted from the mainland only by the long narrow trench of the Menai Strait, though lying on the western sea-board of Great Britain, is nearly central among the British Islands considered as a whole, and its geological formations are therefore nearly in the midst of those that appear upon the British marine platform. From every part of the Island the long front of mountain in which the great Welsh Highland ends off abruptly is a conspicuous feature, forming the whole south-eastern horizon; from its northern coasts the Isle of Man is often to be seen; and from its western headlands even the mountains of the east of Ireland are sometimes visible in clear weather. Most travellers, perhaps, obtain their first view of its curious even sky-line and of its gently undulating and somewhat low but strangely rugged surface, from the track of the Irish mail between Penmaenmawr and Holyhead. Only from the summits of the Mountainland, however, which command a view of almost the whole of the Irish Sea, can the Island be taken in at a single glance. Let the reader suppose that he is seated on the summit of Snowdon or some adjacent mountain, 3,000 or more feet above the sea. Looking thence to the north-west, the line of the trench-like strait can be made out, beyond which a great tract of lowland extends outward into the sea for rather more than twenty miles. This is the Island of Anglesey. The peculiar form that it has upon a map is quite recognisable, but greatly foreshortened, for the angle subtended by its northern parts is only about $1^{\circ}\ 30'$. Seen from this height, it looks so flat and low as to appear hardly more than a shoaling of the sea, with here and there a rounded eminence.

Yet on a nearer approach, this low-seeming land is found to be anything but a true lowland. Seen from near Garth Ferry, it rises very steeply from the water to a height of some 300 feet, and the long, straight, even sky-line that it presents to a traveller on the railway between Llanfairfechan and the Bridges hardly falls below that level for several miles. Entering upon Anglesey itself, the main line of railway, the main Holyhead road, or indeed any traverse north-westward, will take one across a succession of broad, flat-topped ridges, and broad, straight valleys, all trending north-east and south-west, parallel with the Menai Strait. Along the watershed, which keeps about two miles from the eastern coast (and is repeatedly trenched by the dominant troughs), the ridges are about 300 feet in height, whence they fall off gently to about 200 feet along the western coast, where the valleys also broaden into wider tracts of lowland. Overlooking the whole are nine isolated hills, all about 500 feet in height, with the exception of Holyhead Mountain, which reaches 720 feet, and is the highest point in the Island. Most of the surface is under cultivation, chiefly for pastoral purposes, and has been so for centuries—it was known indeed in the Middle Ages, as 'Mon Mam Cymru,' 'Mona the Mother of Wales,' because its crops fed the adjacent mainland. But there are many tracts of wild moorland, the higher hills are bare and rugged, large parts even of the lower country are hardly less so, and rounded bosses of rock rise almost everywhere through the smooth surface of even the cultivated lands.

The total area is 290½ square miles. The principal diameters are :—Puffin Island to the South Stack at Holyhead, 28 miles; Red Wharf Bay to Malldraeth Bay, 10; Aber Menai Point to Dinas Cynfor (south to north), 21; Menai Suspension Bridge to the Skerries (south-east to north-west), 23; Puffin Island to Llanddwyn (north-east to south-west), 21 miles; and the length of the coast-line, about 150 miles. The climate is of the type usual on the western coasts of Britain, but the rainfall is vastly less than that of the adjacent mountain-land, which may often be seen to be wrapped in cloud for hours after sunshine has broken out on Anglesey. Its average annual rainfall is about 37·00 inches, which may be compared with Bristol 28·5, London 22·1, Clacton-on-Sea 16·66, Snowdon (a high corrie) 196·16. There is but little woodland (though much more is described in ancient records), and what there is bears visible marks of the sea-winds by which the Island is swept from three directions, as well as of the prevalence and power of the westerly gales, for even on the eastern side the trees are 'clipped' and driven over from the west.

The population, which is chiefly agricultural, was 50,928 at the last census. The old county town is Beaumaris, with its great mediæval castle. The agricultural centre is Llangefni : Amlwch was the creation of the Parys Mountain mines; Holyhead, the largest town, is (and, according to information kindly supplied by Mr. Edward Watson of the City of Dublin Steam Packet Company, has been since the reign of Queen Elizabeth) the chief port for the Irish mails. The people are for the most part bi-lingual, with a considerable monoglot percentage. The place-names are chiefly Welsh, and it may be as well to say that, throughout this book, they will be spelt as on the Ordnance Survey maps, for the sake of precise and easy identification, whether that spelling be linguistically correct or not. The names, moreover, will be those found on the published one-inch Geological Map, except in a small number of special cases (indicated in the text) where names have been added that will only be found on the six-inch and ·0004 (1 : 2500) maps. For the Island itself, the spelling 'Anglesey,' which is used upon the maps and therefore adopted in this volume, is regarded by etymologists as correct. The first appearance of the term is early in the ninth century. According to the best authorities it is derived from Old Norse 'Ey,' an island, and 'Önguls,' a strait or 'narrow,' an interesting reference to that physical feature which would naturally be the one most likely to impress itself on the minds of the Viking rovers. The Celtic designation, 'Môn,' is far older. It appears in the oldest written references to the Island, those of Ptolemy and Tacitus. The Romans latinised it into 'Mona,' Tacitus referring definitely to 'Monam insulam.'[1] 'Môn' is said to be a mutation of 'Bôn,' 'extremity,' so that 'Ynys Fôn' or 'Mona Insula' would be 'Insula ultima,' 'The Farthest Isle.'

Other old names for Anglesey (probably bardic) are 'Ynys-y-cedeirn,' 'The Heroes' Island,' and 'Ynys-dywyll,' 'The Shady Island.'

The geological formations of the Island are remarkably numerous in proportion to its area, and when to this is added considerable variety in their detail and distribution, the effect is to produce a geological complexity that is unusual even in the British Isles, complex as those are when contrasted with regions in the heart of continents, like the broad plains of Russia. The Mona Complex,[2] the Ordovician and Carboniferous are the principal formations.

Most ancient, and most extensive, is the great Mona Complex, occupying nearly two-thirds of the area. It is regarded as almost certainly of Pre-Cambrian age, and includes a great variety of rocks, nearly all of which are in the condition of crystalline schists. Next in order are some small outliers of uncertain age. Demonstrably Cambrian rocks have not been found, but of their former presence there is little doubt. Then follow extensive Ordovician rocks, including all divisions of the system, and containing many fossils. The Silurian is also represented, but only by its lowest sub-division, the Llandovery. Important igneous intrusions close the Lower Palæozoic record, after which we enter upon a completely new series. At its base is a sheet of Old Red Sandstone, and then follows a varied sequence of Carboniferous deposits, ranging from the Limestone to productive Coal Measures, and the Red Measures, with which the sedimentary record of the Island closes. No Mesozoic rocks have been discovered, but there is no doubt that they once existed in the area. There is, however, a late series of dykes, so that Tertiary time is not unrepresented. Last of all come extensive Glacial drifts and Post-Glacial deposits. A tabular summary of the whole succession is given below.

[1] Confusion arose with the Isle of Man, also sometimes called 'Mon,' and distinctions were invented, one of which developed eventually into 'Man.'

[2] For explanation of this term see pp. 37—39.

LATER SUPERFICIAL DEPOSITS	Blown Sand, Marine and Fresh-water Alluvium, Submerged Forest Bed, Raised Beach, &c.
GLACIAL DEPOSITS	Moraines, Boulder-clays, Gravels.
TERTIARY	Basic Dykes.
CARBONIFEROUS	Red Measures. Coal Measures. Millstone Grit. Carboniferous Limestone Series.
OLD RED SANDSTONE	
METASOMATIC DEPOSITS	
PALÆOZOIC INTRUSIONS	Basic and Acid Sills and Dykes.
SILURIAN	Llandovery.
ORDOVICIAN	Hartfell. Glenkiln. Llanvirn. Arenig.
BARON HILL AND CAREG-ONEN ROCKS	
MONA COMPLEX	Penmynydd Zone of Metamorphism. Plutonic Intrusions. Holyhead Quartzite. South Stack Series. New Harbour Group. Skerries Group. Gwna Group. Fydlyn Group. Gneisses.

CHAPTER II.

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 Palæozoic 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 Cemaes 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 Archæan 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 Archæan 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 Palæozoic 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 XIV).

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.[1] 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

[1] 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.

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 *naïveté*, 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 Graig, 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 passu* 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,[1] 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

[1] The beds referred to in this chapter as 'Llandeilo' are termed 'Glenkiln' in other parts of the present work.

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 a conspicuous one,' adding that 'no more definite assertion of their (Llanbadrig Series) age is made than that they are Pre-Llandeilo.' In his third paper, however, after identifying the 'Llanfairynghornwy 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 PALÆOZOIC 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.[1] 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 Palæozoic 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

[1] Some of these very fossils have been re-examined for the present volume.

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 Palæozoic 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 Ramsay 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 often have been exceeded in the history of geology.

But in 1884, a single publication cleared the air. In his paper on 'The Archæan and Lower Palæozoic 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.[1] 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* Dav. 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.

[1] 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 Archæan by faults.'

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 palæontological 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 places 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 Henslow 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 convolutus* and *M. sedgwicki* respectively, and the results were published by Mr. Williams in 1907.

The Palæozoic 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 Dr. 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, the 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) micropegmatitic 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 metasomatism 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 Penmon 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 D$_1$ 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 XXXV). 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 'Diluvium,' 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 striæ 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 striæ (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 striæ, 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 striæ; 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 Penmon, drawing attention to the cross-hatching of striæ 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 south-westerly 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.

Part II.—The Mona Complex.

CHAPTER III.

INTRODUCTION TO THE MONA COMPLEX.

Its metamorphic rocks have long been the prime interest in the geology of Anglesey, their age and their nature having been the subject of keen discussion for half a century. Not only are they by far the most important formation in the Island, occupying something like two-thirds of its area, but having an outcrop of nearly 200 square miles they are much the largest metamorphic tract of southern Britain. Their diversity of composition is also very great, more than 70 petrological types, containing 66 rock-forming minerals, being now known among them, and the structure is involved in the extreme.

Emerging on the cores of denuded Ordovician anticlines, they appear at the surface in 38 separate tracts, five of which may be called their main regions, and the other 33 their inliers. These will be referred to as follows :—

The Aethwy Region in the south-east, between Llanddona and Llanddwyn (from 'Aethwy,' 'The Narrow Waters,' an old name for the Menai Strait), bounded by a great Post-Carboniferous rupture that will be called the Berw fault.

The Middle Region, between Malldraeth Bay and Mynydd Bodafon.

Holy Isle.

The Western Region, about Llanfachraeth and Llanfaethlu.

The Northern Region, bounded by a master line that will be called the Carmel Head Thrust-plane, which runs from Carmel Head to near Point Lynas.

The inliers are :—

The two Pentraeth Inliers.

The Drri Inlier, north of Mynydd Bodafon.

The Nebo Inlier, west of Ynys Dulas.

The Corwas Inlier, between Pensarn and the Carmel Head Thrust-plane, against which it abuts near Llyn Llaethdy.

The Garn Inlier, at Mynydd y Garn.

The Fydlyn Inlier, at and inland of Ynys y Fydlyn.

The Gader Inlier, at Pen-bryn-yr-eglwys, which is always known locally as 'The Gader.'

the remaining small ones being one west of Mynachdy, eleven in the neighbourhood of Llanerchymedd, five near Bryngwran, two at Nebo, Graig-fryn and four others at Bodafon, and one at Rhyd-y-saint, Pentraeth.

The surface is often extremely rugged, though seldom lofty, rising, however, to 720 feet at Holyhead Mountain, and over 500 feet at four other hills; and there are long lines of coast, so that the rocks are freely exposed.

Owing to the great variety both of material and condition, a brief general picture is not easy to convey. Sedimentary are more extensive than igneous rocks. The most widespread types are pale green schists after sediments in which there is a marked tendency to rapid psammitic and pelitic alternation; but there are thick beds of quartzite and limestone, and thin ones of carbonaceous phyllite, as well as jaspers. Large quantities of volcanic material, basic and acid, pyroclastic and effusive, lie among the sediments, and there are plutonic intrusions that range from acid granites to dunite serpentines. A deep-seated gneissic suite is also present. A unique feature is the development of glaucophane-schist on a large scale. With regard to condition, foliation is completely absent at a few places, but this is rare and local, almost all the rocks being schistose and re-crystallised. Over large parts of the Island the grade of metamorphism is not high, but there are also large tracts (apart from the gneisses) of true lustrous crystalline schists. Yet, even in these, the original characters are seldom obliterated for long together, except in what has been called the Penmynydd Zone of metamorphism, where both basic and acid rocks are holocrystalline schists for miles. In the Gneisses the crystalline grade is of the highest. Rapid folding can be seen almost everywhere, while other parts have been internally ruptured on a great scale, producing extensive tracts of Autoclastic Mélange.

The whole falls into the following sub-divisions:—

9.		The Penmynydd Zone of Metamorphism (Correlated with Groups 2 and 3)	Mica-schist, hornblende-schist, and glaucophane-schist.
8.		The Plutonic Intrusions ...	Granite, diorite, gabbro, serpentine, &c.
7.	The Bedded Succession.	Holyhead Quartzite ...	Quartzite.
6.		South Stack Series ...	Grits and mica-schists.
5.		New Harbour Group ...	Grit, mica-schist, jasper, spilitic lava.
4.		Skerries Group ...	Conglomerate, grit, and tuff.
3.		Gwna Group	Grit, phyllite, quartzite, limestone, jasper, graphitic phyllite, spilitic lava, albite-diabase.
2.		Fydlyn Group	Felsitic lavas and tuffs.
1.		The Gneisses	Basic and acid gneiss.

Group 9 is not a stratigraphical but a metamorphic zone. Groups 3, 4, 5, 6 develop different depositional facies in different parts of the Island. 'Penmynydd,' 'Gwna,' 'Fydlyn,' should be pronounced as 'Penmúnnyth,' 'Goona,' 'Vudlyn' (the 'th' being as in 'thou').

In what follows, there will often be occasion to allude to these rocks, considered as a geological unit; so some concise and euphonious name is needed for them. To calling them 'The Schists' or 'Schistose Series' there is the objection that they are by no means always schistose. They have been called 'Archæan,' but no trace of a 'Beginning' has been found in them. In Chapter IX it will be shown that some at any rate are Pre-Cambrian, and strong evidence is brought forward for regarding the whole of them as such. But as the Cambrian base in North Wales has not yet been zonally defined; and lest, therefore, some Cambrian rocks may have been included (a thesis, however, which will now need to be supported by very cogent evidence, and seems highly improbable), it has been thought better to postpone the use of the term 'Pre-Cambrian' as a formational name. Correlation with Uriconian, Pebidian, and other ancient rocks is not yet possible. The very convenient word 'Monian' was explicitly intended by its author to imply a Pre-Cambrian age; and also that the rocks form a single system, which does not seem to be the case, even if all be Pre-Cambrian. After consultation with Drs. Horne, Strahan, and Teall, and also with the veteran worker on the stratigraphy of these rocks, Dr. Callaway, as well as with Prof. Bonney and Dr. Matley, it has been decided to adopt the term (suggested by Dr. Strahan) of 'THE MONA COMPLEX,' or, briefly, '*The Complex*.'

Though liable to the disadvantage that it cannot be used adjectivally, it seems free from scientific objections, implying only that the rocks are tectonically woven together by secondary structures, and therefore behave as a unit in relation to the other rocks of the Island. It is not thought that any rocks of Ordovician age can have been included (save, possibly, some small strips on the margins of the Fydlyn Inlier, where later shearing made separation difficult). The Mona Complex may therefore be defined; first, in negative terms, as including all the Pre-Silurian rocks of the Island (other than the Baron Hill and Careg-onen rocks) which have been separated from the Ordovician; and secondly, in positive terms, as consisting of the nine groups enumerated on page 38. Evidence will, however, be presently adduced in favour of its possessing much more internal coherence than is implied in either of these definitions. The term is adopted as a temporary expedient, until the time comes (perhaps not very far distant) when these rocks can be correlated with the other ancient rocks of Britain, and placed on definite stratigraphical horizons.

CHAPTER IV.

THE PETROLOGY OF THE MONA COMPLEX.

Introductory.

The petrological descriptions of the rocks will be arranged in the groups mentioned on p. 38, the contents of each group, sedimentary, volcanic, and the like, being described under the group-heading. But the descriptions of metamorphic state cannot often be divorced from those of original material, as in many cases the rocks are only known in that state, which is therefore diagnostic. The rocks known are :—Quartzites, black quartzites, grits of several types, and conglomerates, with slates and phyllites. These give rise to quartzite-schist, grit-schists of several kinds, and a variety of mica-schists, ranging from slightly altered chlorite-sericite-schist to highly crystalline muscovite-schist, and a muscovite-schist with green biotite. With these are limestones, dolomites, and manganous-dolomites, some of which pass into highly crystalline mica-cipolini, and associated with them are graphitic phyllite and graphite-schist. There are spilitic lavas, albite-diabases, keratophyres, and felsites; with spilitic tuffs, rhyolitic tuffs, and mixed tuffs; and important ashy grits. The basic rocks give rise to a suite of chlorite-epidote and chlorite-actinolite-schists. Jaspers and jaspery phyllites occur with the spilites, and pass into hæmatitic schists in places. Green hornblende-schist and glaucophane-schist are developed on a large scale. There are serpentines, gabbros, and pyroxenites, with which occur talc-schist, tremolite-schist, tremolite-marble, ophicalcite, and epidositic hornfels. There are granites of several types, with four or five types of hornfels. Finally, there are hornblende gneisses, biotite gneisses, sillimanite gneisses, forsterite limestones, and granitoid gneisses.

THE HOLYHEAD QUARTZITE.

This rock is perhaps the most conspicuous in Anglesey, for the summit of Holyhead Mountain is composed of it. The characters that strike the eye at once are its whiteness, its uniformity, and the extraordinary massiveness of its bedding. It hardly ever shows a blue core, and even appears, indeed, to become whiter the more deeply it is quarried. Over most of the hill no bedding can be made out at all, but it is occasionally visible on the great sea-cliffs of Gigorth and Rhoscolyn, and at one or two places there are thin beds of mica-schist. The whole mass (except along the foot of the southern escarpment) is traversed by a nearly vertical foliation (Plate XVI), which is as conspicuous as the bedding is obscure.

The clastic character of the rock can be seen by the naked eye on any hand specimen, and it is, for a quartzite, rather coarse, grains one-sixteenth of an inch in diameter being quite plentiful, though the great majority are smaller. The large ones are well rounded, the small ones usually sub-angular. Felspar is rare. The schistosity is determined by well-defined, though impersistent, films of white mica, along which the rock splits readily, though a cross fracture is also easy to obtain. These films are about a quarter of an inch apart, and between them the grains of quartz are often quite undeformed. The rock is, however, typically blastopsammitic, the matrix having been completely reconstructed as a granoblastic schist, with whose elements the clastic grains interlock, their original smooth outline being visible in ordinary light. Internally, their integrity is not much disturbed, and yet the edges of the foliation-micas often penetrate the quartz of a grain that is still a unit optically. Anhedral iron-ores, tourmaline, and zircon are not uncommon. Quartz-veining is abundant. Along the foot of the southern escarpment foliation disappears, and the quartzite is quite massive. This massive rock, especially the finer parts of it, is the only portion that resembles the Gwna quartzites. It is, however, blastopsammitic like the foliated variety, but the clastic grains are closely packed, and there is very little matrix. Hence the massive structure, for in the ordinary quartzite it is the matrix alone that is really foliated. In the massive zone, south-west of Twr, the Quartzite is for a short distance pebbly, with fragments a third of an inch in length. Most of these are venous quartz, but there are some of scarlet Gwna jasper, and some from old granoblastic rocks and mica-schists.

The following analyses, by T. Blair, of Sheffield, were kindly furnished by the manager of the Holyhead Silica Works.

	I.	II.	III.
SiO_2...	96·00	94·25	Less than 87·00
Al_2O_3	1·98	2·24	—
Fe_2O_3	·42	·56	—
CaO	·38	·67	—
MgO	·30	·97	—
K_2O+Na_2O ...	·42	(not stated)	—
Loss on ignition ...	·50	·65	—
	100·00	99·34	—
Spec. Grav.... ...	2·656	—	2·653

All are from the Breakwater quarries. No. I is the most siliceous variety found there, but the massive rock of the southern escarpment [E. 10127] must be still more siliceous. No. III is an unusually micaceous variety. No. II is the ordinary quartzite, such as E. 10126. The specific gravities are given by Mallet, and are not from the same specimens.

THE SOUTH STACK SERIES.

The South Stack Series Proper.

This great series of rocks, which, from its wonderful folding and metamorphism, laid bare in the lofty sea-cliffs, presents some of the most striking geological sections in Great Britain, consists essentially of grits with partings of mica-schist.

These partings were once evidently felspathic shales, so that this group and the Holyhead Quartzite are the only major subdivisions of the Mona Complex that are composed entirely of mechanical sediment. It falls into two main subdivisions, a *Llwyn* (pronounced 'Hloo-yn') Group (named from the Llwyn-y-berth promontory), that has lithological affinities to the New Harbour Beds, and a South Stack Moor (or briefly '*Stack Moor*,' from the moor that extends from the South Stack sea-cliffs eastward for a mile) Group with affinities to the Quartzite. The difference is chiefly in the grits. Throughout both divisions these weather white, but in the Stack Moor part they are very massive, usually 10, and sometimes 30 feet in thickness, so that in shallow inland sections they may easily be mistaken for the Quartzite, while in the Llwyn part they are much thinner, usually about a foot, so that the general aspect here is banded or flaggy, not unlike that of the English Lias. In spite of the affinities just remarked, there is no difficulty in separating the series from the New Harbour Beds on the one hand and the Quartzite on the other. In the adjacent part of the New Harbour Beds the gritty matter is disseminated, and the whole rock is 'thin-seamed' or even laminated ; but the moment we pass into the South Stack Series the grits become sharply individualised, weathering white, a foot or so in thickness, and the alternating type is quite pronounced. The massive Stack Moor Beds, on the other hand, however white and quartzite-like they may be externally, are much more felspathic, and (unlike the Quartzite) pale blue internally, while they never fail to show bedding as soon as a deeper section is obtained. The thinner grits of the Llwyn portion, though often weathering as white as a quartzite, are also always green or blue in a fresh fracture. For so thick a succession of grits they are on the whole rather fine. The massive Stack Moor Beds have about the same texture as the Quartzite, but the Llwyn Grits are really very fine, even their larger grains, which have survived the metamorphism, being quite small. In both divisions, however, there are a few coarse beds, in which grains of as much as three-sixteenths of an inch may be found.

Throughout the deposition of the series a gradual change in the conditions of deposit was going on, from the hypopelitic New Harbour Beds, to the purely psammitic conditions of the Quartzite.

Besides quartz, felspars and white micas are frequent as original constituents, but only the massive upper beds could be called felspathic. The felspar is albite, with a good deal of albite-oligoclase, and a little microperthite. Zircon, tourmaline, rutile, and iron-ores are generally present as accessories. The coarse beds contain a good many composite fragments, most of which are fine grits, often schistose, with a foliation independent, in some cases, of that of the enclosing grit. One or two granitoid rocks have been seen. Some scarlet fragments can be identified with confidence as from the Gwna jaspers. Such clastic grains as retain their original outlines are, in many cases, not very well rounded, but these are usually the larger ones. Blue opalescent quartz is abundant in one of the coarser grits on the South Stack. One fragment of mica-schist [E. 10131] contains a crystal of tourmaline. There is another of true muscovite-biotite gneiss [E. 10135], and good-sized plates of white mica, that are evidently from the same gneisses, are quite abundant in some beds.

Metamorphism.

In spite of the beautiful preservation of their bedding, all these rocks are in reality holocrystalline schists.

The coarser grits are now blastopsammitic, but the finer grits, as well as the matrix of the coarser ones, have been completely re-constructed and are purely granoblastic. A foliation is imparted by thin straight flakes of muscovite and of a green mineral (p. 47), which, except in the more massive beds, are to be found, sparingly, all through the rock, becoming the dominant minerals along the films of parting. Their ends often penetrate the clear quartz of the clastic grains, which nevertheless retains its optical integrity. The green mineral is a biotite, the same as that of the New Harbour Schists. Its optical characters are given on p. 47. Thin plates of muscovite are intergrown with it.

The same two minerals, however, occur also in crystalline lenticular growths, elongated parallel to the general foliation, but in which the basal cleavages and planes of intergrowth are almost at right angles to that. A name for growths of this kind in crystalline schists will be found convenient. Following the lines of Grubenmann's terminology (see footnote to p. 143), they may be called 'Encarsioblastic,' from ἐγκάρσιος = transverse (πλάγιος having, in mineralogy, been used in contradistinction to ὀρθός, is unsuitable, as these growths may be at an angle of 90° to the foliation). (Plate II, Fig. 1.). In these encarsioblasts biotite is usually in excess of muscovite and developed in broader plates. These delicate objects, even with the full tide, as it were, of the foliation sweeping past them, are undeformed. And, when adjoined by grains of quartz, the ends of their plates may even be seen to penetrate it, just as do the foliation-micas, though for a shorter distance. They must therefore be among the latest products of the reconstruction. Some of the finer grits contain great numbers of clear dark green spots, conspicuous even to the unaided eye, and sometimes arranged in bands, which are short encarsioblasts.

Another interesting feature is that some of the larger blastopsammitic felspars with turbid cores have peripheries of clear albite, the whole grain, twinning-planes and all, being optically undisturbed. Weathered felspar has therefore been rejuvenated, so that permeation by sodium solutions must have accompanied the dynamic metamorphism.

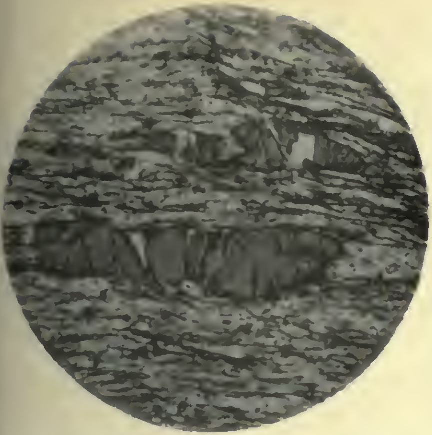
The fine partings, which may be as much as three or four inches thick, often show the colour-banding of the original shale, and sometimes also contain thin seams of fine white quartz-schist. The pelitic matter itself has been completely reconstructed, and is now a perfect lustrous lepidoblastic mica-schist with a pale sea-green tinge, which consists almost entirely of white mica, with a varying proportion of green biotite, and with many minute granules of epidote, zoisite, hæmatite, and other iron-ores. The micas may be half a millimetre in length. Encarsioblasts are an even more striking feature of these beds than of the grits, and in some cases their development has been carried so far that the dominant foliation has become reduced to a series of mere films between them, so as to resemble a strain-slip foliation. Specimens of such rocks [E. 10158] tend to be prismatic in form, and almost devoid of 'cross-fractures,' being bounded by two pairs of foliation planes. The foliation of these encarsioblasts is often sharply corrugated, but their micas do not seem to have suffered from optical distortion. An unexpected feature is that the thin coarse grits are apt to lie along, sometimes partly in, these fine pelitic beds.

Lenticular seams of coarse venous quartz, which may be several inches thick, occur throughout the series; and usually contain chlorite, in irregular aggregates that may be an inch thick, and several inches long, composed of little well-formed plates that sparkle under the lens. In a few cases it is foliated, but the quartz is not. These seams are much more frequently found in the pelitic schists than in the grits, conforming in a general way to the bedding, but transgressing it at a low angle. Thin ones may fold sharply with the beds, and may then cut the foliation at right angles, causing slight deflections of it. They are evidently the last product of the metamorphism, introduced, apparently, when the shearing stresses had nearly but not wholly spent themselves.

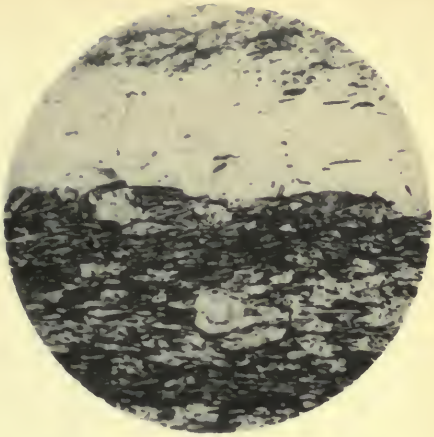
Chemical Composition.

The following analysis of a 'schist from the South Stack, near the Lighthouse,' is given by Messrs. Mellard Reade and Holland in *Proc. Lpl. Geol. Soc.*, 1900, p. 472 and table. It is described as a foliated rock, with a silky texture, and folded laminations, but with no trace of slaty cleavage, composed of minute quartz, with mica in subordinate quantity and some chlorite. Evidently it is neither one of the massive grits nor one of the micaceous partings.

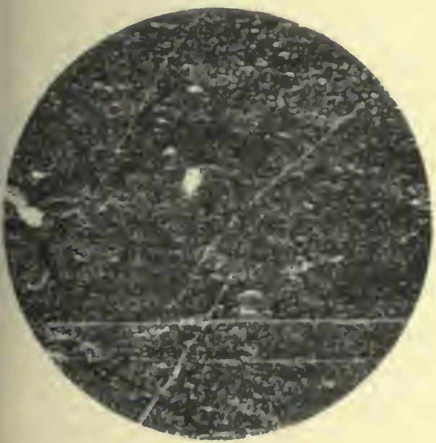
The description corresponds to a fine grit such as E. 10599, the material containing *Planolites*.



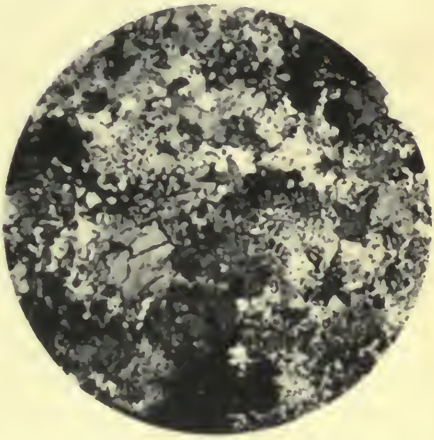
.Schist with encarsioblast.



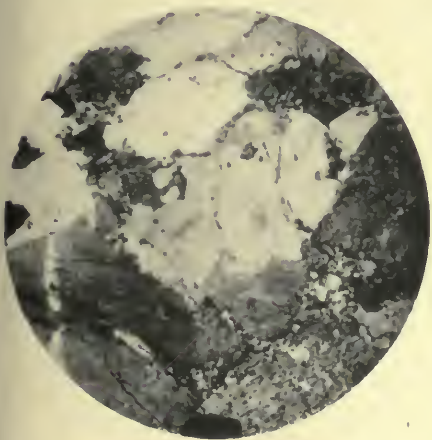
2. Green-mica-schist.



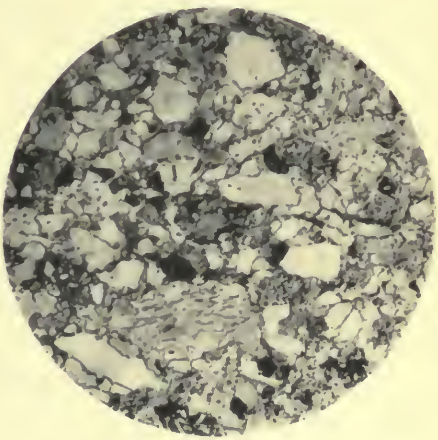
3. Bedded Jasper.



4. Boulder in Skerries Grits.



5. Boulder in Skerries Grits.



6. Tyfry Grit.

Huth coll.

SiO_2	76·77
TiO_2	0·74
Al_2O_3	11·15
Fe_2O_3	1·71
FeO	2·32
MnO	0·12
CaO	0·09
BaO	0·03
MgO	1·06
K_2O	2·85
Na_2O	1·05
P_2O_5	0·11
C	traces
Combined Water ...	2·41
	100·41

As the felspar is albite, it is evident from the percentage of potassium that the white mica must be a muscovite.

The Coeden Beds.

These are regarded as a slightly differing facies of the Llwyn part of the South Stack Series. They are finely developed in the rugged tract known as The Mynydd Mechell, after which they have been called by several authors, but the word 'Coeden' may be found to run more 'trippingly on the tongue.' Like that with which it is correlated [such as E. 9313—4], the group consists of hard, evenly-bedded, greenish-grey grits, fine-grained with few exceptions, and with partings of fissile mica-schist. The grits are from a few inches to a foot thick, the fine partings may attain two or three inches, but seldom exceed a fraction of an inch. Specimens have a flaggy 'moine-like' aspect, and the foliation planes are lustrous, though not brilliantly, the cross-fracture saccharoid. Clastic quartz can usually be seen with the lens. There are also many grains of felspar, most of which is albite or albite-oligoclase. The fragments are sometimes finely rolled, but many must have been sub-angular. There is also a little clastic mica.

But they are now blastopsammitic schists, the matrix being a granoblastic but fine mosaic. Foliation is imparted to it by white mica and chlorite, but the flakes are neither as long, as broad, or as well-formed as in Holy Isle, and encarsioblasts are rare. Iron-ores are usually present. Epidote is an important constituent, its granules often being rounded porphyroblasts. Seams of pistacio-green epidosite are a conspicuous feature of the group. They may be half an inch or more in thickness, but never extend for many feet. The clastic texture still survives in them, but the matrix is crowded with granular epidote. Some are slightly transgressive, showing their secondary date. Zoisite is also present.

The fissile partings are composed almost wholly of white mica, in very thin flakes, closely felted, and with some chlorite intergrown, and granules of iron-ore. Thin seams of quartz-schist are interbanded with it. It is often full of venous quartz in 'sills,' containing reddened felspar, some of which is albite, some apparently decomposing orthoclase.

The group has undergone more crystalline reconstruction than has the country to its north, as has been pointed out by Dr. Callaway. But less than that of the rocks of Holy Isle. Yet the survival power of the clastic grains, and the texture of the mosaic of the matrix are much the same in the two areas. Here, it is true, undulose extinction is much more often seen, which, were it a feature of the metamorphism, would indicate a lower grade. But the Coeden beds are riding upon the Carmel Head thrust-plane, which, being here at a very low angle, cannot be far beneath them anywhere; and some of the dykes by which they are traversed are deformed. Their undulose extinction may, therefore, be referred to movements of a later date.

THE NEW HARBOUR GROUP.

This is named from its fine development about the New Harbour at Holyhead. The term 'New Harbour Beds' will be used in an inclusive sense for the formation as it is found in Holy Isle, in the Western Region, and in the Northern Inliers; the term Amlwch Series in a similar sense for the facies found in the Northern Region; the terms 'Green-mica-schist' and 'Amlwch Beds' for the dominant sedimentary member in each case. The group thus includes the following members:—

Green-mica-schist
Amlwch Beds
Jaspery Phyllites
Bedded Jaspers
Spilitic Lavas and Basic Schists.

The jaspery phyllites, jaspers, and spilites present the same characters in the Amlwch Series as in the New Harbour Beds.

The Green-mica-schists.

These are flaggy or laminated schists of medium grain, with a persistent green colour, and sparkling with little flakes of mica. They are cleanly crystallised, and their green hue is clear, different in quality from the dull muddy green so characteristic of the Gwna Beds. Two elements are present. The greater part of the rock is hard and slabby, saccharoid on cross-fracture, and rather like the Moine Schists of the Scottish Highlands. The other element is a fissile schist with gleaming foliation planes, which occurs as thin partings. The hard bands, however, are seldom as much as a foot, are usually only an inch or so, in thickness, often indeed mere seams, of which eight or more may be counted in an inch. Not only so, but they are thoroughly foliated throughout their whole body. Even the most massive beds that have been seen, a yard or more in thickness, are foliated through and through. So that the granular and the fissile elements are closely bound together in this formation. The fissile beds may reach three or four inches in rare cases, but are generally not much more than a small fraction of an inch, or even mere films.

The rocks are without doubt sedimentary in origin, and their flaggy bands were grits. Where these are tolerably massive, some clastic grains are usually to be seen under the hand-lens, but they are not conspicuous. Most of them are quartz ; but there is a good deal of felspar, nearly all of which is albite, with a few grains like microcline. The albite is often untwinned, and full of minute inclusions, most of which are micas. The only surviving original accessory is tourmaline, some of which has a beautiful dichroism from dark blue to rose-pink, and is sub-hedral. In a few places there are coarser grits, one of which, on the shore below the Coastguard Station at Holyhead, contains fragments a seventh of an inch in diameter, of fine white quartzite of Gwna type. One fragment of a granitoid rock was found in the massive beds at Porth-y-felin.

The rocks are typically blastopsammitic, and have undergone a high degree of alteration (Plate II, Fig. 2). All but the larger clastic grains have disappeared, and even these have been to a considerable extent incorporated, being bounded by a succession of corrosion bays. The larger albites often have a clear margin, as in the South Stack Series. The matrix ranges from granoblastic to lepidoblastic, and in the fissile parts the grains of quartz and albite are often elongated. The secondary minerals are quartz, albite, white and green micaceous plates, epidotes and zoisite, sphene, apatite, and iron-ores. As the felspar is albite, the potassium of the analyses (p. 49) must be contained in the white mica, which is therefore muscovite.

The grass-green mineral which imparts the colour to the rock has been investigated by Dr. H. H. Thomas and the writer, from the specimen E. 10151. It is bi-axial, the axial angle 2 E, being small ; and is optically negative in all cases examined. The cleavage is as in micas, and the acute bisectrix nearly perpendicular to that cleavage. It has a pronounced pleochroism : X pale-green to yellow, Y and Z deep grass-green. The refractive indices are $\alpha=1{\cdot}60$, $\gamma=1{\cdot}63$; so that $\gamma-\alpha=\pm\ {\cdot}03$, β being nearly $=\gamma$. The mineral is therefore a green biotite. It is abundant in the fissile seams, often intergrown with the muscovite. Some of the plates exceed ·75 mm. in length.

Epidote is everywhere abundant, some seams being crowded with its granules, which attain to a diameter of ·5 mm., and are porphyroblastic. Most of it is yellow and pleochroic, with high bi-refringence, but there are pale varieties with low bi-refringence, which give sometimes the characteristic polarization-blues of zoisite.

A large proportion, however, of the granules conspicuous by strong relief, are sphene. There is a good scattering of iron-ores, most of which are ilmenite, often elongated along the foliation; and occasionally apatite in some abundance. In the slide E. 10151 are two grains of a remarkable mineral, which, being quite allotriomorphic, has not been determined with precision. It is bi-axial, with high refringence and bi-refringence, and a pleochroism that for rays vibrating transverse to the major axes of the grains is deep yellow, for rays parallel to the major axes a beautiful rose colour. These characters agree with those of piedmontite, though the rose colour is not so deep as in the celebrated manganese-epidote of Japan. The mineral does not appear to have been recorded hitherto in British crystalline schists, and it is to be hoped that idiomorphic crystals may be found.

Quartz-sheets. Venous quartz in sheets or sills, always with nests of chlorite, of precisely the same kind as those in the South Stack Series, are developed on a great scale in this group. A felspar is often intercrystallised with the quartz, so that these segregations are not mere quartz-veins, but approach in character to pegmatites. The felspar is albite, much of it untwinned. In rare cases the quartz has a rude, and the chlorite a strong foliation, so that though the latest products of the metamorphism, movement had not ceased when some at any rate of them had separated. They are present everywhere, often in such abundance as to be a conspicuous feature on the rugged bosses. There are also seams that are foliated and finely granoblastic; some parallel to the general foliation and graduating laterally into the green schist, others truncating it at a low angle. Separation of quartz must therefore have taken place during three intervals at least of the metamorphism, and it was progressively incorporated. For the granoblastic is a modification of the venous quartz, cores of which survive in it. Quartz being always in excess over chlorite, it is evident that the beds in their original condition must have been more siliceous, considered as a whole, than they are to-day.

These rocks also, therefore, are holocrystalline schists, even more thoroughly foliated than the South Stack Series. Next to the Gneisses and the Penmynydd Schists, they are the most reconstructed rocks in the Island. This character is maintained throughout Holy Isle, but a crystalline degeneration seems to set in upon the main Island, increasing eastwards. To some extent this is really the case. But the appearance is chiefly due to a platy foliation that is there developed, which is later (pp. 196—8) than the foliation-planes of Holy Isle, and on which there is a feebler development of mica, so that the planes of easy splitting are less lustrous.

Subdivisions. Two subdivisions can be recognised. In the first of these the flaggy, alternating, type is pronounced; psammitic matter is dominant; clastic grains are often visible; and the coarser grits are not uncommon. The group may be called the *Soldier's Point Beds.*

The other is much more pelitic, and clastic grains are rarely seen, while the lepidoblastic seams are far more intimately interfelted with the granoblastic, so that the alternation of the two is far less conspicuous. Here, also, the sheets of venous quartz with albite are most abundant. This group may be called the Mynydd-celyn (or briefly, the *Celyn*—pronounced 'Kelyn') Beds. The Celyn beds lie next to the South Stack Series, the Soldier's Point beds adjoin the Skerries Group.

Chemical Composition.

The following analyses have been made, some others being annexed for comparison.

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
SiO_2	72·32	48·52	53·67	78·66	84·86	55·43	60·15	58·38
TiO_2	2·53	2·73	—	0·25	0·41	0·46	0·76	0·65
Al_2O_3	10·23	23·25	—	4·78	5·96	13·84	16·45	15·47
Fe_2O_3	2·31	4·17	—	1·08	1·39	4·00	4·04	4·03
FeO	2·62	5·67	—	0·30	0·84	1·74	2·90	2·46
MnO	0·21	0·15	—	trace	trace	trace	trace	trace
CaO	2·67	1·48	—	5·57	1·06	6·02	1·45	3·17
MgO	1·30	3·29	—	1·17	0·52	2·67	2·32	2·45
K_2O	0·80	5·94	4·41	1·32	1·16	2·67	3·60	3·25
Na_2O	3·08	0·95	2·57	0·45	0·76	1·80	1·01	1·31
H_2O (at 110°) ...	0·09	0·12	—	0·31	0·27	2·11	0·89	1·34
H_2O (above 110°)	1·67	3·81	—	1·33	1·47	3·45	3·82	3·68
CO_2, &c.... ...	—	—	—	5·19	1·16	6·29	3·07	4·27
	99·83	100·08	—	100·41	99·86	100·48	100·46	100·46
Spec. Grav. ...	2·763	2·746						

The specific gravities are given by Mallet, and are not from the same specimens.

I. Typical hard, gritty schist from just north-west of Bryntirion (six-inch map), Holyhead, *i.e.*, 300 yards north-west by west from the new church ('ch.' of one-inch map). No slice, but same type as E. 10282. Anal. J. O. Hughes.

II. Fissile band from same locality [E. 10151]. Anal. J. O. Hughes.

III. Mica-schist of intermediate character, Cromlech Farm, Rhoscolyn [E. 10162]. Anal. J. O. Hughes.

IV. A composite analysis of 253 sandstones; and V, of 371 building-sandstones, from different parts of the United States.

VI. A composite analysis of 27 Mesozoic and Cainozoic Shales; and VII, of 51 Palæozoic Shales.

VIII. The average of VI and VII 'weighted' as three to five.

These composite analyses are from Bull. U.S.G.S., quoted in Sir A. Geikie's 'Text-book of Geology,' Ed. 4 (1903), pp. 165, 170. 'CaO,' here, includes BaO, and 'CO_2, &c.' includes P_2O_5, SO_3, and organic C.

The proportion of titanium in both the Holyhead rocks is remarkable, and shows what a large proportion of the minute granules of high refractive index must be sphene. But, considering the abundance of that mineral, and of epidote, the percentage of lime is small, and more magnesia might have been expected from the chlorite. The alkalies are high, and the reversal of proportions between them in the granular and fissile types indicates that the alkali-mineral of the one is albite, of the other, muscovite. Comparing them with the composite analyses, however, it is evident that the granular component of the group is not a normal grit, nor their fissile component a normal shale. In both types the silica (though allowance must be made for the siliceous segregations) is relatively low, the alkalies and the magnesium high, the iron (especially the ferrous iron) very high, and the titanium quite exceptional. The granular component is far more aluminous than a normal grit, and is rich in sodium, evidently contained in its albite.

Now, in the field, the persistent green tinge of these rocks undoubtedly suggests to the mind that volcanic matter must enter into their composition. Previous observers (p. 11) have noted this, and Dr. Teall, who walked over them with me near Holyhead, received the same impression. Their mineral and chemical composition leaves no doubt that such must be the case. Yet no bands that could be regarded as tuffs have been found except at the top and bottom of the group. If, however, we suppose that the basin of deposit was, throughout the whole time of their formation, within reach of showers of fine volcanic dust produced by the explosion of a basic magma, these characters receive an explanation. Can that magma be identified? We have seen that a singular character of both the psammitic and the pelitic elements is their high percentage of titanium, which is nearly the same in both in spite of all their other differences. Now there are some lavas in the group, and they are spilitic. Such lavas are apt to contain a high percentage of titania, rising to a maximum of 2·95.[1] And the spilite of the New Harbour Beds themselves (p. 55) contains 2·21 per cent. of titania, the average of that of the two components of the Green-mica-schists being 2·63. Why titaniferous particles were disseminated so much more widely than other ones may perhaps be explained in more than one way. However that may be, little doubt can remain that the volcanic element of these beds is the dust of a spilitic lava.

The Amlwch Beds.

The Alternating Beds are thin-bedded schistose grits with partings of fine phyllitic mica-schist, the grits not often exceeding three or four inches in thickness. One or two inches is a common thickness, and towards Llaneilian they have become so thin that it is easy to

[1] Dewey and Flett, *Geol. Mag.*, 1911, p. 207, and *Geol. Surv. Mem.*, Lizard and Meneage, p. 185.

obtain hand-specimens containing five or six grits that are from a quarter to even an eighth of an inch in thickness. All the beds are green, the phyllites pale grey-green, the grits rather darker green internally. There are two distinct types of grit, one which is rather fissile and relatively soft, the other very hard and jointed, weathering out in rectangularly-edged ribs that are sharply marked out from the phyllitic partings. These are the beds that impart such a conspicuously 'alternating' aspect to the series, for they weather to a light cream colour. In the fissile grits there is much more matrix. The fragments are chiefly quartz, but there is much felspar in fair condition. It is albite, sometimes untwinned, often with beautiful polysynthetic twinning. The grains tend to be sub-angular. For the most part these grits are rather fine, and usually there is a good deal of matrix. It has been completely reconstructed, and is now a fine granoblastic schist with chlorite and white mica. Epidote is usually present, and in some slides is abundant. The matrix of the fissile green grits is more full of chlorite than that of the hard bands. In these rocks also the amount of green material points to the presence of basic volcanic dust, probably derived from the spilitic lavas, as in the case of the New Harbour Beds of Holy Isle.

In a few places there are coarser grits, and at Amlwch is a true conglomerate with well-rolled pebbles up to two inches in length. Some of these are derived from Gwna quartzite, some from grits, others from granitoid rocks and albite-quartz-felsites of the same types as those of the Skerries Conglomerates (p. 60), a few are old mica-schists. Boulders, also, as much as four inches or more in diameter (pp. 303—4), are occasionally to be seen in quite fine flaggy beds. They have probably been brought by floating vegetation, as has been suggested in somewhat similar cases that are known in coal seams and in chalk.

These pebbles are in some cases much deformed, especially the igneous ones. Many of the clastic grains in the grits have suffered in like manner, and have begun to enter into sutural relations with the matrix. The fine partings are often a little gritty, but all, except these few grains, have been completely reconstructed; and they are now fine chloritic mica-schists or phyllites. Some of the quartz veins that cut the foliation are traversed by a rude schistosity parallel to that foliation. Bands of epidosite like those in the Coeden beds are rare in this group.

Subdivisions.—Here also there are two divisions. The alternating, psammitic division may be called the Lynas beds; from which can be distinguished a pelitic division that may be called the Bodelwyn Beds. Metamorphism increases in them southwards, but they never reach the crystalline condition of the Celyn beds of Holy Isle: their micas being a fine felt in which the individual flakes are small.

The following are analyses of the grey-green phyllites.

	I.	II.	III.	IV.	V.
SiO_2	57·23	70·58	70·74	—	80·59
TiO_2	0·89	0·62	0·41	—	0·34
Al_2O_3	20·43	13·23	12·79	—	6·45
Fe_2O_3	1·33	4·23	4·76	—	4·77
FeO	5·64	1·24	1·26	—	0·73
MnO	0·05	0·35	0·38	—	0·81
CaO	1·54	—	trace	—	3·64
BaO	0·02	—	—	—	—
MgO	2·09	1·83	2·97	—	0·82
K_2O	2·39	1·92	1·90	3·61	0·24
Na_2O	3·97	3·52	2·35	2·92	0·73
H_2O (combined)	3·94	2·18	2·61	—	1·06
SO_3	0·03	—	—	—	—
P_2O_5	0·54	trace	—	—	—
	100·09	99·70	100·17	—	100·18
Spec. Grav. ...		2·72	2·65		

I. 'Green slate from quarry between Cemlyn and Cemmaes, a finely cleaved glossy green slate.' Anal. Mellard Reade and Holland. *Proc. Lpl. Geol. Soc.*, 1900, p. 466 and table.

II. 'Slate,' 'Borth Bay,' evidently Hen-borth, Mynachdy. Anal. E. Dickson. *Proc. Lpl. Geol. Soc.*, 1890.

III. 'Unaltered Slate,' Porth y Gwartheg, Cemlyn. Anal. E. Dickson, *loc. cit.*

IV. Fine parting. Amlwch, the bathing creek, just where the footpath that runs north-westward from the Coastguard Station reaches the sea [E. 10558]. Anal. J. O. Hughes.

V. 'Greenish-grey infiltrated rock penetrating slate as a sheet, Yr-hen-borth.' The description and locality correspond with those of the bands of epidosite a little to the west of Hen-borth, Mynachdy [E. 10385], (see p. 299). Anal. Reade and Holland, *loc. cit.*

The Jaspery Phyllites.

These are fine, fissile rocks, of a rather uniform purplish red colour, usually not very lustrous on the foliation planes. Transitional types connect them with the green ordinary phyllites, a few of which have a faint purplish tinge indicating the first approach to the purple beds. But the true jaspery phyllites are marked off quite sharply enough to be easily separable on the maps. They are composed chiefly of white mica hæmatite, fine quartz, and a little chlorite. The hæmatite is most of it thin scaly eisenglimmer. Some of the quartz and mica seem to be clastic, but the grains are very small. Rocks with the full red colour are known in Holy Isle only at one place, but in many places the Green-mica-schists contain thin beds that have a tinge of purple, and can be separated roughly on the maps. They are as lustrous as the fissile portions of the mica-schist, and differ only in the presence of abundant scales of eisenglimmer, which are interfelted with the mica, larger and better formed than in the north, but in less quantity. It is not unlikely that, in these highly crystalline schists, the red colour has been partly discharged by reduction of the ferric oxide (*cf.* p. 88).

The Bedded Jaspers.

Intimately related to the jaspery phyllites, these rocks cannot be separated from them on the maps; usually occurring as bands in them that are less than an inch in thickness, the bedding being well preserved, and the jaspers finely banded. They are not fissile, but are hard, compact, and brittle, with a cross-jointing like that often seen in bedded cherts. Their colour differs from that of the phyllites in being brick-red rather than purple; but they never show the bright scarlet of the nodular jaspers of the Gwna Beds. They are composed (Plate II, Fig. 3) almost entirely of quartz and hæmatite, with a very little mica. The hæmatite is in great quantity and gives a deep red colour to a thin section; it is not in scales, but in fine dust, which is aggregated into clots, leaving other parts a paler tinge. The quartz is in a mosaic so fine as to suggest that it has crystallised from colloidal silica. In a few of the slides are much larger elements, some of which are felspar, evidently clastic and also abundant granular epidote. These are from beds that rest upon a spilitic lava, and might easily have received some volcanic dust. Some slides were submitted to Dr. Flett, who remarks: 'These cherts are very like the radiolarian cherts of Cornwall and Devon where they have been flattened by pressure. I do not think there is much room for doubt that they were originally radiolarian, but no radiolarian shells can now be detected in them.' Possibly some lenticular spots now filled with quartz and white mica may be deformed radiolarian casts. The rocks are full of complex veins, a few of which contain a carbonate.

In No. III. of the following analyses it was found impossible to exclude a proportion of the jaspery phyllite, owing to the rapidity of alternation. If it be compared with that of a pure jaspery phyllite (p. 89), no doubt will remain that the silica percentage of the pure jasper must be very high.

	I.	II.	III.
SiO_2	55·34	61·65	67·07
TiO_2	1·94	0·70	0·69
Al_2O_3	20·87	16·82	14·79
Fe_2O_3	7·07	6·61	6·33
FeO	1·19	1·39	0·81
MnO	0·36	1·07	0·26
CaO	0·78	0·15	1·14
BaO	0·07	0·03	not det.
MgO	1·58	2·02	2·23
K_2O	4·76	2·90	1·85
Na_2O	2·80	3·36	3·51
H_2O	—	—	0·07
H_2O (combined)	3·39	3·15	1·78
P_2O_5	0·13	0·08	not det.
SO_3	trace	not fd.	not det.
CO_2	—	—	none
	100·28	99·93	100·53

I. Purple-grey 'slate.' Hen-borth, Mynachdy. Anal. Mellard Reade and Holland. *Proc. Lpl. Geol. Soc.* 1900, p. 469 and table.

II. Purple-grey 'slate (crinkled).' Llanrhwydrys. Anal. Mellard Reade and Holland, *loc. cit.*, p. 467 and table.

III. Jasper. Amlwch. South side of creek, 80 yards north of where the path, running north-westward from the Coastguard Station, reaches the cliff [E. 10535]. Anal. J. O. Hughes.

The Spilitic Lavas

are massive, heavy rocks, normally of a pale sea-green colour, but mottled and shot throughout with the pistacio-green of epidote, some parts being thoroughly epidotised. They have not the dull fracture of the Gwna spilites[1], but look saccharoid under the lens. In many parts they are full of sometimes white but usually yellow spots which range from an eighth to half an inch in diameter. The pillowy structure is well developed, for they are built up of ellipsoidal masses that range from six inches to two feet in length, and that push into each other (Fig. 1) in the manner that gives such a plastic appearance to lavas of this kind. The yellow spots have often a rudely concentric arrangement that conforms to the curves of the pillow's outline, but may be as plentiful in the core as at the margins. Between the pillows are fissile skins of darker colour, in which the spots are also present. Carbonates are often abundant, white, saccharoid, and shot with epidote.

Fig. 1.
Two-foot Ellipsoids.
Chapel, 500 yards north of Llanfwrog Church.

The rocks have been composed of felspar and ferro-magnesian minerals, iron-ores being usually present in but small quantity. Some porphyritic pseudomorphs have the form of olivine. The pyroxene has been completely converted into fine pale actinolitic hornblende, with a varying amount of chlorite. In some there is a little quartz, but epidote is generally present, often in great abundance, and beautifully crystallised in large grains with strong pleochroism. The spots are now entirely composed of it: they are often hollow spheres enclosing cores of the general body of the rock. This body consists of lath-felspars, with which are intergrown the needles of actinolite. Some of the felspars are of fair size (these are usually sericitised), but the great majority, which give nearly straight extinctions, are slender and delicate almost to fibrosity. In the best-preserved specimens they are arranged, throughout, in brushes and subradiate groups, so that the structure is thoroughly variolitic. The needles of actinolite share the same arrangement, so that it is to be supposed that the original pyroxene shared the variolitic disposition which is, as it were, first indicated in the Gwna spilites. Some fine varieties appear to have been glassy, the glass being now chloritised. The rocks are true variolitic spilites like those of the Gwna Beds.

[1] The description of the unaltered Gwna spilites (pp. 71—74) should be read first.

Nor need any doubt be entertained of their having been true lavas. Their associates are too much reconstructed for pyroclastic structure to be recognised: but close to the epidotic variolite of the Cliperau shore some green chlorite-epidote schists, which nevertheless contain much quartz, are interbanded with the green-mica-schists, and can hardly represent anything but fine tuffs. A thin chlorite-epidote-albite schist that occurs just at the junction of the New Harbour Beds and the South Stack Series in Holy Isle is almost certainly a tuff, for it graduates into the sediments above and below. Its chlorite seems to be after hornblende. And we have already seen that the peculiar composition of the New Harbour and the Amlwch Beds indicates that explosions of spilitic dust were taking place from time to time. These variolitic spilites must therefore be regarded as contemporaneous outflows.

The following analysis shows that, while the rock has in a general way the composition of a spilite, it has been modified by epidotisation, as well as having been probably more basic originally.

	I.	II.
SiO_2	39·20	42·26
TiO_2	2·21	—
Al_2O_3	18·80	—
Fe_2O_3	8·61	—
FeO	4·99	—
MnO	none	—
CaO	9·69	—
MgO	10·03	—
K_2O	0·16	—
Na_2O	1·88	—
H_2O (at 110°)	0·10	—
H_2O (above 110°) ...	4·52	—
CO_2	none	—
	100·19	—

I. Variolitic spilite, Amlwch, 100 yards north of the path's end on the cliff, north-west of the Coastguard Station [E. 10529]. Anal. J. O. Hughes.

II. Chlorite-epidote schist, probably a variolitic tuff, 100 yards north of the cottage on the east side of Borth-wen, Rhoscolyn, Holy Isle [E. 10165]. Anal. J. O. Hughes.

Metamorphism.—Under the influence of the great shearing stresses of the Complex the tough ellipsoids of the lavas lend themselves readily to the production of large lenticular augen, about which winds the less obdurate material of the 'skins,' now converted into a chloritic and actinolitic schist; and by further deformation the lenticular cores themselves become attenuated, and finally foliated. But even in the most advanced stages reached some trace of the pillowy structure can generally be detected.

If we now compare the lavas of this horizon with those of the Gwna Beds it would seem that they differed but little in their original condition. Both are spilites with a marked tendency to variolitic structure. The differences are in their dynamic metamorphism. No hornblende has been found in any undeformed Gwna spilite. It does not appear at all, nor does epidote in quantity, until foliation has developed. But in these rocks not merely epidote but actinolite appears in abundance without any breaking down of the delicate variolitic disposition of the felspars. And where foliation is developed there is no concurrent advance in the development of hornblende; the rock does not become a hornblende-schist. If we consider the state of the associated sediments we find that those of the Gwna Beds have suffered severe cataclastic deformation, while those of the New Harbour Beds have been rapidly folded and have acquired a much more crystalline foliation. There can be little doubt that the different condition of the two groups of spilite is in some way connected, first with their positions on the maximum primary folds, and next with the types of stress that were set up in the major secondary folds of the Mona Complex.

THE SKERRIES GROUP.

The formation included in this group are the Skerries Grits, the Church Bay Tuffs, and the Tyfry Beds.

The Church Bay Tuffs.

Its generally unstratified character is the salient feature of this formation, and one that is unusual in deposits that are so fine of grain. At Clegyr-mawr alone can bedding be seen through a thickness of 180 feet, and even this disappears rapidly along the strike. Elsewhere, a thin bed or two coarser than the rest, may be quite sharply marked out, but none of these can be followed for more than about 50 yards; and a banding that is occasionally visible in the fine material dies away in a few feet. Where there is no deformation, the only structure visible is a plexus of irregular joints, and its aspect in the long lines of sea-cliff is that of a massive igneous rock. The typical material is a dull greenish-grey porcellanite, weathering to a cream tint, and almost invariably traversed by a multitude of thin, dark green, anastomosing veinlets, which impart a 'crackled' appearance to the outer crust. On a fresh fracture, minute clastic grains are just perceptible under the hand lens. In thin section, the porcellanous matrix, which is turbid at first sight, resolves itself under a higher power into finely granular epidote and minute clots of sericite, but iron-ores are scanty. Plentifully strewn throughout it are small angular fragments, which often, indeed, have re-entering angles. A few are of quartz, but the great majority are of felspar, now almost entirely sericitised. The sericite, however, is often differently disposed in different lamellæ, so that the twin-lamellation is itself pseudomorphed. The felspar was therefore triclinic. In a few cases it is fresh enough to show a positive optical figure, and extinction angles near to those of albite. In a coarse tuff at Porth-madog it is without doubt albite. The veinlets are partly of chlorite. partly of a honey-coloured pleochroic delessite.

The coarser bands resemble grits externally, but are essentially of the same nature as the porcellanite, their matrix being identical with that. The composite fragments may sometimes be seen to be of spilitic type, but there are also irregular chloritic bodies like lapilli of a basic glass. Fragments of a reddish felsite are also to be seen.

In a few places there are thin, even, bands of purple phyllite and bedded jasper that resemble in every respect the similar beds in the New Harbour Group, some of them being composed of crypto-crystalline silica full of hæmatite dust and containing very minute clastic quartz and mica.

The green porcellanites are not often as homogeneous as at Clegyr-mawr: they commonly have a confusedly mottled aspect, and are full of yellowish matter. At a little cove south of Porth Trwyn a green gritty porcellanite is crowded with clots of pale, compact, epidosite, one-eighth of an inch or less in length, lying in beautifully parallel bands. But often a number of such clots will run together, so as to form a ragged-edged bed. This 'clot bed' is two to three feet thick, and its bedding is parallel to that of the adjacent rock. In other places, the same compact epidosite forms even-sided bands, which are sometimes very fine, but they are apt to be broken up into isolated fragments, and that in rock that shows no sign of deformation.

At Castell, Trefadog, is a sheared volcanic breccia with fragments of acid lavas, while north of Church Bay, fragments of keratophyre and mica-schist occur in a grit, and a massive gritty epidosite contains many pebbles about half an inch, and some of them two inches, in length, of acid igneous rocks, quartzites, and jaspers. They are of great stratigraphical importance, and are discussed on pp. 60, 165.

A specimen of the typical porcellanite was analysed by Mr. J. O. Hughes.

SiO_2	59·62
Al_2O_3	19·59
Fe_2O_3	2·66
FeO	3·59
CaO	2·82
MgO	2·05
K_2O	3·56
Na_2O	3·51
H_2O (at 110°)	0·23
H_2O (above 110°)... ...	2·52
	100·15

TiO_2 with Al_2O_3, MnO with FeO.

E. 9315, from one of the bosses on the high summit, 340 yards south-west of Clegyr-mawr, Llanrhyddlad.

It is therefore evident that the rock is a fine tuff of intermediate composition. Not only, however, are no lavas of andesitic type known in the Mona Complex, but it is difficult to suppose that it can have been produced simply by the explosion of such a magma. The proportions of most of the constituents, especially of its alkalies, are such as may often be found in andesitic lavas, but the calcium it contains is nearer to that of the dacites, for which it does not yield sufficient silica. The nature of the composite fragments of the coarser beds explains the anomaly, showing that the porcellanite must be a spilitic tuff with an admixture of rhyolitic débris.

Metamorphism.

Deformation. There is perhaps a greater mass of undeformed material in this formation than in any other member of the Complex, which is probably due to its remarkable homogeneity, hardly any native planes being provided along which it might begin to give way. But eastward and southward it breaks down, and the process may be studied along the coast. Mylonisation sets in, confined at first to definite slips, but soon extending over zones of several inches. These become frequent, and then the whole rock acquires a rude fissility, along which the epidosite clots, and the veinlets, are drawn out into light and dark green lenticular streaks. In the midst of the massive porcellanitic tuff of Church Bay the process does not often get to this stage ; but at one place a schist with a good long lenticular structure and a dull sheen has been produced for a few yards, which could not be distinguished from much of the material of the Gwna Beds. Near the junction with those beds, however, such material is found in abundance.

Silicification. The tuffs have been sporadically silicified, the final product being a fine white quartz-rock that graduates into the normal dull-green material. This, resisting the deforming stresses, has been cut up and sheared out into augen. The resulting rock simulates closely the Autoclastic Mélange of the Gwna Beds (pp. 65, 66), but its augen, instead of being blastopsammitic, are finely granoblastic. It is clear that the silicification is older than the great movements of the Mona Complex, and it may therefore be ascribed to a geyseritic episode that followed closely upon the eruptions of the tuffs themselves.

The Trwyn Bychan rocks of the north have (except that they are not, perhaps, quite so compact as a whole) the same peculiarities of composition and structure as those of Church Bay, and their extraordinary massiveness is finely displayed on cliffs more than 100 feet in height. In some places their epidosite clots appear to be genuine lapilli. But they have been far more deformed. Few parts have escaped, and considerable tracts have been transformed into a dull but fissile schist.

THE SKERRIES GRITS.

The Skerries Grits are the 'Llanfechell' Grits of Dr. Callaway, but, as in the case of a similar group-name, that word scarcely runs 'trippingly' even off a native tongue; and as all the most interesting and important characters of the rocks are far more strikingly developed on The Skerries than at any other place, that name seems more appropriate as well as more euphonious. They are hard 'greywackes,' generally rather coarse, and often pebbly; greenish grey inland, but green with subordinate grey mottling on The Skerries. The most remarkable thing about them is their unusual massiveness. On most of the sections no bedding whatever can be seen; and except at base and top it is rare throughout. They consist of quartz, felspar, and composite fragments, with abundant secondary epidote, chlorite, and sericite, and some iron-ores, most of which appear to be ilmenite. The felspars are chiefly albite, with some albite-oligoclase and micropegmatite. But the clastic grains are not closely crowded as in ordinary grits; they are visibly isolated by the matrix. This, which is of a low pistacio-green colour, plays an important part, and is identical in appearance with the green clots and mottlings of the Church Bay Tuffs. It looks turbid under a low power, but with a $\frac{1}{5}$-inch objective is resolved into minute granules and prisms of epidote, clots and specks of sericite, and abundant chlorite.

This matrix is therefore the same as the fine epidosite of the Church Bay Tuffs, and as the composite fragments are for the most part volcanic, it is evident that much of the rock is of pyroclastic origin. At the Bull Bay section the proportion of matrix increases rapidly northwards; it then comes on in bands, and these in their turn increase until there is a complete passage by alternation into pure Church Bay Tuff. Further, we have called them 'grits,' but there is reason to suspect that even their quartz is but partly epiclastic. Many of its grains have not the rounded or irregularly sub-angular outlines of ordinary sand; they tend to be quadrangular or triangular, sometimes with bays and re-entering angles. These are forms typical of the phenocrysts of the quartz-felsites. On the East Mouse, grains like them can be seen (p. 318) with still a little matrix adhering, and it is therefore likely that these detached grains are direct products of the explosion of an acid lava. The Skerries Grits, then, are far from being normal sedimentary rocks: the pyroclastic element in them preponderates, and, doubtless, to this is due their extraordinary massiveness.

The Conglomerates.

Composite fragments are more plentiful as well as much larger than in any other member of the Mona Complex, and they are of great importance. Small ones, visible in thin section only, are extremely abundant, often exceeding in quantity the grains of quartz or felspar; and hand specimens usually show a good number that are about an eighth of an inch in diameter; but larger ones are rare upon the mainland, a few only having been found of half an inch or so in length. They are larger on the islets, there being a good many on the East Mouse that are an inch or two, and some even six inches across.

But by far the finest development is on The Skerries. There, and there alone, are true conglomerates in the Mona Complex. Bands occur at intervals all over the little archipelago, the pebbles being usually three or four inches across. But on Ynys Arw the conglomerate may be called a boulder-bed, being full of great oval blocks, most of which are six inches, many of them a foot, and some nearly two feet in diameter. They are well rounded, and being light in tint, stand out in strong contrast to the dark green matrix, so that the beds are very striking in appearance. But so tough and resistant is the matrix that the boulders do not always weather out, some even weathering into cavities. The grits contain many short bands, an inch or so in thickness, of a fine epidositic mudstone, with minute clastic quartz, which is of the same nature as the matrix. These bands may be finely bedded, but in the boulder-beds are broken up into long strips, and these into fragments, many of which are well rounded, so that contemporaneous erosion was at work.

All but a few of the larger pebbles in the Skerries Conglomerates are of acid igneous rocks, with a textural range from quartz-rhyolite to granite, and are very fresh and well preserved. The finest are compact, of a clear bluish purple tinge, and consist of a cryptocrystalline matrix that may once have been vitreous, in which are phenocrysts of quartz, often corroded, and felspar. At the other extremity of the suite are granites (Plate II, Fig. 4) with a good deal of micropegmatite, but no porphyritic crystals. The majority link these extremes. They contain the same phenocrysts as the felsites, but the matrix, no longer cryptocrystalline, comprises two or three varieties of crystalline mosaic, most of which is relatively large of grain, and sometimes is beautifully micropegmatitic (Plate II, Fig. 5). In some of the pebbles the texture varies rapidly, even within a single slide. Good-sized grains of pleochroic epidote, often in clusters, are frequently present. The felspar is a sodium variety near to albite, with which the micropegmatite is often in optical continuity, and it is evident that all are products of one and the same acid sodium-magma. None of them are foliated.[1] The rocks from which these interesting pebbles are derived are never seen *in situ.*

Throughout the Skerries Grits, whether on the other islets or the mainland of Anglesey, the same acid igneous rocks contribute the majority of the larger pebbles, and they play the same rôle in the pebbly portions of the Church Bay Tuffs, as well as in the pebbly beds of the Amlwch alternating series, which are close to the junction of the groups, near the East Mouse. On the Middle Mouse is a

[1] On account of the great importance of these boulders, the slides were submitted to Dr. Teall.

variety composed entirely of micropegmatite with a few phenocrysts of albite. Not infrequent, but never in large fragments, are spilitic lavas of Gwna type.

Less in number, but of great stratigraphical importance, are pebbles of hard fine green grits, fine purple grits and hard purple mudstones, white quartzite, scarlet jasper, and schistose grit. Those of white quartzite (one of which was two inches in diameter) and of jasper were first found upon The Skerries. The jasper has all the characters of that which is known only in the spilitic lavas and limestones of the Gwna Beds, and the quartzite is not of Holyhead but of thorough Gwna type. The green grits are also very common in (though not confined to) that group. Many schistose fragments occur throughout the Skerries Grits, but in most cases their foliation is parallel to (though stronger than) that of the matrix of the grit, and might, perhaps, have been induced *in situ*. Some, however, can be found whose foliation is undoubtedly their own, for it is oblique, sometimes at a high angle, to that of the enclosing rock. The largest of these that has been collected and preserved is shown in Fig. 2. It is a markedly schistose, but not much reconstructed, grit. Small fragments of holocrystalline schists, with well-formed foliated micas have also been found (in the same relation) in microscopic slides [E. 10384]. It is certain, therefore, that a foliated complex exists within the region, whose metamorphism is older than that of the Mona Complex.

FIG. 2.
PEBBLES OF OLD SCHIST IN SKERRIES GRITS, BWLCH.
Natural Size.

A few of the pebbles, in their turn, contain little fragments of yet older rocks. A purple ashy grit pebble from the Middle Mouse encloses pieces of the spilitic lavas. Those of quartzite from the Skerries Conglomerates contain fragments of tourmaline and of mica granulites. The formation from which these have been derived must be of extreme antiquity.[1]

FIG. 3.
DEFORMED BOULDER.
8 inches long.
The Skerries.

Deformation and Foliation.—The Skerries Grits have been unequally deformed. In some parts the pebbles are smooth, oval, and uninjured internally even when quite small, and the secondary products have no definite orientation. Usually, however, the chlorite of the matrix is well foliated, and the sericitised fragments are drawn out into lenticular augen. The power of the deforming forces may be gauged by the fact that along certain zones that cross The Skerries large pebbles of rhyolite and granite are drawn out into thin lenticular strips (Fig. 3). Some degree of

[1] As The Skerries are difficult of access, it may be well to mention that the same pebbles are well seen on the East Mouse, though not so numerous or so large, and usually deformed (p. 318). The East Mouse can be reached easily by a boat from Amlwch Port.

reconstruction always accompanies the deformation. The matrix is full of well-formed secondary mica, and the sericitised felspathic fragments have become streaks of sericitic schist. Minute needles of actinolite have appeared among the foliated chlorite, and they, as well as the edges of the micas, penetrate the clear quartz, and also felspar, of many of the clastic grains. In fact the less resistant portions of the rock have passed into the state of a chloritic mica-schist.

THE TYFRY[1] BEDS.

In the eastern parts of the Middle Region, and along the Malldraeth, where the metamorphism is of a low order, many strips of ashy grit and phyllite have been separated from the surrounding Gwna Beds. Most of them are green, but some are purplish. The contents of the ashy grits link them to the Church Bay Tuffs and Skerries Grits, with which they have accordingly been coloured. They are composed essentially of albite and quartz, with some large flakes of clastic mica, often much chloritic matter in the matrix, and iron-ores. Albite is usually in excess of quartz, and where the rocks are not much deformed the broken albites are sub-angular, often angular, sometimes with re-entering angles. Some are lath-shaped, but most are tolerably broad, and with polysynthetic twinning. The quartz is angular, sometimes tending to be square, as in the Skerries Grits.

Composite fragments are also plentiful. The most abundant are spilitic lavas, albite trachytes, and keratophyres, some of the trachytes containing porphyritic albites with the same broad habit as the isolated broken crystals. Fragments of a quartz-felsite are also present. Many of the spilites are deeply hæmatised, and an albite grit on Llanddwyn, associated with jaspery phyllite, is hæmatised throughout. About Nantnewydd, Llangefni, and especially at Trefdraeth Church, are beds in which the matrix is a pale green epidosite of the same kind as that of the Church Bay Tuffs and Skerries Grits, and some of the finer bands are largely epidositic dust. These are true tuffs, and some of the ashy grits of Tyfry and other places are but slightly mixed with epiclastic sediment. Their volcanic materials were evidently drawn from the same sources as those of the pyroclastic rocks of the north and west, and they are therefore best placed with the Skerries Group. But their spilitic fragments, occasionally hæmatised, and the hæmatisation of some of the beds themselves, link them closely with the Gwna spilites, which are, in their vicinity, developed on a large scale.

Epiclastic fragments.—Besides these pyroclastic fragments the grits contain some epiclastic ones of great interest. These are of a true granoblastic mica-schist (Plate II, Fig. 6), composed of a quartz-mosaic with a little sodium-felspar, white mica, and a chlorite that may be after biotite. The rock is very clean and holocrystalline,

[1] Pronounced 'Tývry.'

the mica well developed, and the foliation strong and even. It might be matched among the adjacent rocks of the Penmynydd Zone, but for two characters. These are that it is poor in epidote, and that it contains tourmaline ; whereas the Penmynydd Mica-schists are very rich in epidote, and tourmaline is an extremely rare mineral in them. The only true tourmalinic member of the Complex, the hornfels (pp. 93—99) is nothing like so rich ; and, from its field relations, cannot have been the source either. In every one of these fragments that has been seen (save one or two that are very small), tourmaline is present, sometimes lying across the foliation planes [E. 9839, 10009, 10117—8]. One pebble, a millimetre in length [E. 10074], contains no less than nine crystals of it ; so that the rock is really a tourmaline-mica-schist. There can be no doubt that it belongs to some very ancient series, whose foliation is older than that of the Mona Complex.

Deformation.—At Tyfry the coarser grits are, for a short distance, free from cleavage, but this is exceptional. In all the other strips that are shown upon the map they are schistose, though usually less so than the surrounding Gwna Beds. About a mile beyond the Malldraeth Marsh, however, they are to be recognised only by their larger fragments, the finer parts having passed into a schist indistinguishable from the Gwna Green-schist. There is little doubt, indeed, that they are separable only in tracts of minimum deformation, and that their boundaries, as drawn, are not stratigraphical but arbitrary. It is impossible to distinguish the finer grits and phyllites with which they are associated (and which have been coloured with them on the maps) from those of the Gwna Beds themselves. No unconformity whatever can be found, and it must be admitted that considerable tracts of them have probably been included with the general schistose mélange which has been termed the Gwna Green-schist.

THE GWNA GROUP.

This group, which is found at intervals all over the Island, is here named after the vale of the little River Gwna, near Bodorgan Station, that being the only district in which every subdivision of the group is to be found.

The subdivisions in question are—

Alternating Green Grit and Phyllite (usually as Mélange)
Spilitic Lavas and Tuffs
Albite Diabases
Keratophyres
Quartzite (and black quartzite)
Limestone
Graphitic Phyllite
Jasper
Jaspery Phyllite

The diabases and keratophyres are closely associated with the spilitic lavas and tuffs, and constitute a single volcanic suite. The formation has a wider distribution than any other in the Island, being found at intervals all the way from Carmel Head to Garth Ferry. Except where it is involved in the Penmynydd Zone of metamorphism (a special phase which will be considered in connexion with that zone), this group has undergone less mineral reconstruction than the rest of the Complex ; but it has been excessively broken up, so that bedding can seldom be traced for more than a few yards. The rocks that will here be termed Alternating Beds, Mélange, and Green-schist are undoubtedly phases of one and the same formation in different states of destruction and reconstruction : but the two last occupy so much more space than the first that they may be regarded, for Anglesey, as the normal states of that formation. On account of their great importance they will be allotted separate headings in this chapter. They have a characteristic aspect, and are not difficult to recognise, even without the aid of the other members of the Gwna Group.

Alternating Grit and Phyllite.

Passage Beds. The original bedding is hardly ever seen for more than a few yards at a time, except in the zones of minimum deformation that skirt the Malldraeth Marsh. Here we find alternations of banded green phyllites and rather fine green grits, with purplish beds that graduate into the jaspery phyllites. They contain minute clastic micas, and the grits have a good deal of angular broken felspar which, when determinable, is found to be allied to albite. The phyllites alternate near Llangefni with the fine epidosites, and the grits graduate by increase in the size of their fragments into the Tyfry Ashy Grits (with which, for convenience sake, both have been coloured on the maps) ; but both graduate, in the other direction, into the general mass of the Gwna sediments. The group must therefore be looked upon as a zone of passage from the Gwna Beds proper into the pyroclastic Skerries Group, and is decidedly more felspathic than the normal Gwna sediment. These passage beds, though traversed by more or less cleavage, retain their bedding well, and it is fine and even. Minute filmy sericite has often developed along the cleavage, and some of the phyllites are excessively chloritic.

Alternating Beds.

A picture of the normal Gwna sediment can be obtained only by consideration of such original characters as can still be made out in the mélange and green-schist. The materials were, speaking generally, grit and shale, the latter, however, having been reconstructed everywhere. Now, from an inspection of the strips and fragments of grit that crowd the mélange, it will be seen that the beds that were broken up to make them could not have been thick or massive (the few massive ones are ashy, and probably nips of the Tyfry Beds). A foot or two was probably the limit, and the average thickness not more than a few inches, much the same being, apparently, the case with the shales; the series was, therefore, one of rapid alternation.

The grits are grey on parts of the northern coast, but everywhere else are greenish, with much chlorite in the matrix. Some are hæmatised. But nearly all of them are siliceous enough to weather white and quartzite-like. Not only are they much less felspathic than the Tyfry Beds, felspar (though always present) being often a mere accessory, but fragments of spilitic and other volcanic rocks are only locally abundant. Their felspar is of the usual sodium types, often albite, with some oligoclase, but orthoclase is also present. Rutile, tourmaline, and zircon are not uncommon, but garnet very rare. Some scarlet fragments are present, but whether these be jasper is not yet certain. The quartz is often of plutonic type, and there are fragments of sodium-granite, micropegmatite, albite-quartz-felsite, hypabyssal albite-rocks like those of The Skerries, keratophyre, and spilite, with some of schistose grit, quartz-schist, and mica-schist. Their texture varies usually between fine and medium, coarse grits with grains one-eighth of an inch across being rather rare. The form of their grains is that of true sediments, for though many are sub-angular, many also are well rounded. Besides the grits that are still visibly clastic, a fine siliceous sediment is an important member of the series, especially in parts of the Aethwy Region. It is a very fine hard granular material, sea-green with chlorite, but weathering white, and on weathered faces remains of clastic texture may sometimes be detected. A felspar of low refractive index is present as well as quartz, but the rock must have been an unusually fine siliceous sand. It occurs in seams that seldom reach a quarter of an inch in thickness, with partings of fissile matter, once a shale, so that the fine-bedded, alternating type of sedimentation is pronounced. These fine siliceous beds appear to have preserved their bedding by reason of their amenability to folding, but they are almost the only ones that have preserved it.

Autoclastic Phyllite-and-Grit Mélange.

This is really a gigantic autoclast, extending over many miles of country in several districts, as does the 'crush-conglomerate' of the Isle of Man, but on a still greater scale. It consists essentially of lenticular strips and lumps of grit (Figs. 4 and 5) floating in a schistose matrix that sweeps curving round them (Plates VII, XXIII). Rounded fragments are rare, but in the Cemaes district the mélange is more of a pseudo-conglomerate than elsewhere, having less parallel structure, both in the forms of the lumps and the

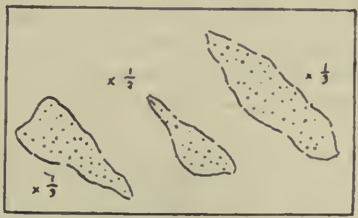


Fig. 4.

Phacoids of Grit in Gwna Mélange. North of Glyn-afon.

nature of the matrix. Almost everywhere the lumps are phacoidal, their boundary curves meeting at sharp angles in the direction of the strike. The matrix is now a fine greenish or pale straw-coloured schist, composed of minutely flaky sericite (see p. 67) in curving sheets and seams, always with a considerable quantity of chlorite and some finely granular quartz. In the matrix of the northern breccias these minerals are but feebly developed, and the colour may be a dull grey. The matrix not only sweeps round the phacoids, but often invades them, so that they are traversed by films of it, along which they tend to part. And where the larger augen are not close together, it is full of smaller and smaller augen, as well as detached clastic grains that have been torn from them. In the cores of the augen the clastic grains retain often their original rounded outlines quite uninjured, but along the margins and the fissile films they are deformed and flattened. This may take place without 'crushing,' but it is possible that matter has been stolen from the sides of the grain, thus thinning it. Undulose extinction is general, but far from universal. The matrix of the grit has become a mosaic, with which almost all the grains, felspar as well as quartz, interlock, especially at their 'ends,' in the direction of the strike; so that the old clastic outlines are better seen in ordinary light than between the nicols. Many of the grains have broken up, optically, into a mosaic. In the unsheared areas there is a tendency to marginal enlargement of the grain at the expense of the matrix. In the shear-zones the mosaic of the grain becomes gradually incorporated with that of the matrix, into which it merges and finally disappears. The crystalline elements of such mosaic tend to be fusiform and nemablastic, especially towards the ends of the augen. These grit-augen are often excessively quartz-veined, especially in the Aethwy Region. There is usually a system parallel to the minor axis, doubtless a 'stretching' system, but more and more come in, sometimes to such an extent that in the meshes of their intricate net-work the original structure of the grit can hardly be made out.[1]

FIG. 5.
PHACOIDS OF GRIT, AETHWY REGION.

[1] This mélange has been treated here because it is the usual condition of the alternating Grit-and-Phyllite member of the Gwna Group, which could hardly be described without reference to it. But it must not be forgotten that the Gwna Group as a whole is usually in the condition of an Autoclastic General Mélange in which *all* the members of the group are involved (Plate XXII) and even sometimes the Tyfry Beds as well. (See Chapter VII.) But in that mélange it is generally possible to separate the several members on the map, whereas the mélange just described has to be treated as a unit even on the six-inch and ·0004 maps. The latter, moreover, broken as it is, functions as a stratigraphical horizon within the group.

The Gwna Green-schist.

This term is proposed as a brief convenient working designation for a widespread type to which, though undoubtedly a petrological unit, it is not easy to give a concise name based either upon its structures or its mineral composition. That it is confined, so far as is known, to the Gwna Beds, appears to be due to an accident of the folding, by reason of which a particular stratigraphical horizon has been brought on to a particular tectonic horizon over the greater part of Anglesey (see Chapters VII, VIII).

The type is more easy to recognise than to describe. It is a pale sea-green schist, whose fissile seams tend to weather to a straw-colour; and usually dull upon the foliation planes, because of the small size of its foliating minerals. The hard parts are really much more siliceous than would be expected from their green colour, and often weather nearly white. Its aspect in the field is more irregular than that of any other member of the Complex, for it is not at all platy or evenly laminated[1]; and hand-specimens have an undulating, almost lumpy, surface, apt also to be scored with fine striæ, due to nemablastic foliation. This aspect is due to its being built up of lenticular overlapping sheets, often rather short and thick, of hard siliceous matter (too irregular to be called augen) with winding fissile seams between them, the whole being usually corrugated, sometimes cross-corrugated also. The essential constituents are quartz, chlorite, and a white mica, usually 'sericitic' but sometimes in larger, though never well-formed flakes.[2] An alkali felspar, which where determinable is albite, seems always present, but not abundantly. There is usually a little hæmatite, and opaque iron-ores. The proportion of mica to chlorite is very variable; sometimes one is in excess, sometimes the other. The chlorite is apt to be in irregular sheets and clots as well as in minute flakes, but never in well-defined crystals; and there is generally less of it than would have been expected from the colour of the rock. A carbonate is not uncommon. Tourmaline, garnet, apatite, and zircon, have been observed, but heavy minerals are rather rare. In the more altered portions, a pale actinolite seems to be developed among the chlorite in minute needles, but its presence is obscured by that of the all-pervading sericite.

The irregular aspect of the rock is determined not merely by its megascopic but by its microscopic structures (Plate IX, Fig. 2). The hard parts are composed of a colourless mosaic (most of which is quartz, with a little alkali felspar), shot through and through with minute flakes of chlorite and sericite. But the texture varies from crypto- to macro-crystalline, and the variations are frequent, often so sudden that the finest may adjoin the coarsest. In much of

[1] Where a platy type does appear, it is really a survivor of the fine siliceous beds described on p. 65.

[2] Where, however, as in the Aethwy and Middle Regions, the rocks approach the Penmynydd Zone of metamorphism, the micas rapidly increase in size, and the grade of crystallisation rises generally.

the mosaic the elements are isodiametric, but almost as often they are fusiform, interlocking, however, diablastically, just as the isodiametric elements do. It is this nemablastic mosaic (called by Blake 'elemental orientation') which imparts to the type its linear foliation, so pronounced in the Aethwy Region. It may adjoin the ordinary mosaic, parted perhaps by a sericitic film; and may contain fusiform grains of alkali felspar as well as of quartz. The fissile seams are almost wholly sericite and chlorite. They divide the hard mosaic into lenticular plates, often stout and short, but these tracts are apt to be very jagged and irregular. Undulose extinction is general, and often pervades all the elements of a mosaic, especially the nemablastic portions, producing a confused effect called by Blake 'micro-spectral polarisation.'

Several varieties may be noted. One is a purple schist or phyllite, which, however, is not the jaspery phyllite, for it contains albite, and differs from the green-schist merely by its richness in hæmatite. Another is a quartz-schist, nearly white (Plate VIII), which again is but a variety of the green-schist so rich in silica that felspar, chlorite, and mica sink to mere accessories. Such felspar as has been detected is albite. The mosaic is fusiform, but so strong is the nemablastic foliation that the tracts of this, about which wind the sericitic films, are themselves fusiform, being several inches in length and about half-an-inch thick, with stout lenticular cross sections. On its pitch escarpments this type of schist resembles nothing so much as a bundle of hard white or cream-coloured pencils, showing all down their subtranslucent sides the fine-drawn threads of their internal nemablastic foliation. Lying among these nemablastic pencils are long lenticular seams of venous quartz (Fig. 6 and Plate VIII), which on the

FIG. 6.—VENOUS QUARTZ PHACOIDS, AETHWY REGION.

escarpments are seen to behave as convoluted sills, conforming in a general way to the corrugations of the nemablastic seams, but frequently transgressing them at low angles, as well as anastomosing, swelling, and thinning in a most capricious manner. They in their turn are slightly nemablastic. Undeformed augen of venous quartz abound, some containing large twinned albites.

The Gwna Green-schists are traversed by vast numbers of quartz-veins at all angles, most of which are only a small fraction of an inch, but many also an inch or two in thickness. One series has separated along small cross-wrenches, imparting to the rock a look as if tied up by little cords at intervals ; and some of the veins that cut across the dominant nemablastic foliation are themselves traversed by a similar one that is in line with it, softening the sharpness of their outlines and making them seem to melt off a little into the adjacent rock. Movement therefore was taking place at intervals, between which the rock was sufficiently brittle to be fissured. Yet the later movement was on the borderline of the molar and the molecular, for the veins are seldom shifted by it. In fact, the amount of segregated quartz in the Gwna Green-schist, especially in the Aethwy Region, is enormous, amounting sometimes to local metasomatism, though there is no reason to suppose that the silica was introduced from without. It is a product of the metamorphism, separating at several different episodes, and the presence of large albites in it shows that the temperature was still high.

Origin of the Type.—The material of the Gwna Green-schist is without doubt of epiclastic origin. In almost all microscopic slides (unless taken from zones of exceptional alteration) a few clastic grains are to be found, and many schists that show no signs of such externally are crowded with small ones, many of which, however, have undergone partial absorption. Its nemablastic mosaic is identical with that into which the grits pass locally by deformation. Moreover, the Green-schist, when considered on the large scale, is found to pass gradually into the Autoclastic Mélange. If we cross the Gwna Beds of either the Middle or the Aethwy Regions in an easterly direction we find first, as we leave the Penmynydd type, a 'green-schist' with well-developed micas ; then a normal green-schist, still completely reconstructed ; then (the rock remaining the same in every other respect) isolated clastic grains appear ; then small knots of them ; then well-defined lenticles ; until, as these increase in number, the type changes to that of the Autoclastic Mélange, whose lepidoblastic matrix differs from that of the schist merely in being rather less well-crystallised.

Put conversely, there is a progressive metamorphism from the Alternating group, through the Autoclastic Mélange, into the Green-schist. In the earlier stages we have disruption and deformation with subordinate mineral reconstruction ; in the later, mineral change is obliterating the effects of deformation. There can be no doubt that the Green-schist is a curiously altered condition of a rapidly alternating grit and shale series, that its lepidoblastic schists represent the shales, and that the hard portions are the grits, now in the condition of siliceous mosaic, some nema-, some granoblastic. But the bedding has totally disappeared, and the schist, in spite of the low grade of anamorphism, often retains no traces of its origin.

The following analyses have been made of Gwna Green-schists and of a grit from the Autoclastic Mélange.

	I.	II.	III.	IV.	V.
SiO_2	72·76	74·19	62·38	63·65	53·75
TiO_2	0·45	not est.	0·46	0·60	0·55
Al_2O_3	12·49	14·52	15·35	17·10	23·15
Fe_2O_3	1·07	0·75	1·75	1·17	1·11
FeO	3·69	2·04	4·77	5·12	5·95
MnO	0·41	not est.	0·20	0·37	0·07
CaO	0·43	0·08	2·36	0·28	0·29
BaO	0·03	not est.	0·02	0·03	0·04
MgO	1·57	1·09	2·80	2·42	3·08
K_2O	2·11	1·21	0·21	3·63	5·22
Na_2O	2·10	4·74	3·64	1·81	1·84
CO_2	0·34	none	1·70	none	none
SO_3	0·06	not est.	0·04	0·02	0·03
P_2O_5	none	not est.	0·14	0·11	0·17
H_2O at 110° ...	—	0·15	—	—	—
H_2O 'combined' ...	2·79	1·13	3·76	3·78	4·69
	100·30	99·90	99·58	100·09	99·94
Spec. Grav. ...	2·735		2·768	2·748	2·784

Nos. I, III, IV, V, were kindly made by Mr. Edmund Dickson, in the year 1900, in aid of the present work. He remarks that a little carbon is present, and that SO_3 belongs to sulphates soluble in hot dilute HCl. It is probably from the oxidation of pyrite.

I. Pale green grit, lenticular mass in Autoclastic Mélange. Same type but not collected at same time as E. 9825. At forking of road between Tai-lawr and Llansadwrn Church (Pencraig of six-inch map). Quarry on south side of road.

II. Hard siliceous part of Gwna Green-schist. Roadside, at a farm (Ysgubor-fawr of six-inch map), 442 yards north-east of Soar Smithy, north of Bodorgan Station [E. 10426]. Anal. J. O. Hughes.

III. Typical Gwna Green-schist. Roadside, 760 yards north-east of Garth Ferry Inn (at B.M. 77·0 on six-inch map) [E. 9911].

IV. Typical Gwna Green-schist. Same locality at Llansadwrn as No. I, but from quarry on north side of road [E. 9934].

V. Gwna Green-schist. Locality record lost, but from near Llansadwrn.

Comparison with the composite analyses given on p. 49 shows that these rocks are not normal grits and shales. Iron is high throughout, and the relative proportions of Fe_2O_3 and FeO are the reverse of those in ordinary sediments. In I and II the alkalies are high, as well as the aluminium, and sodium tends to be higher than potassium, due respectively to muddiness of the grits and to the presence of albite. In III, IV, V the silica, too high for a shale, is due to the intimate interfelting of thin seams of grit, which could not be eliminated in collecting. The relations of sodium to potassium are variable, and there seems less albite in E. 9911 than the sodium would lead one to expect. No. V is nearer to an aluminous shale than the rest are. The variability of CaO and CO_2 is due to a capriciousness in the distribution of calcite.

As in the case of the Green-mica-schists of the New Harbour Group (see p. 50) the persistent green colour of these rocks conveys an impression (shared, again, by Dr. Teall when traversing

[Face page 70.

Ellipsoidal Spilitic Lava. Dunes of Newborough.

them in 1911) that they contain an admixture of volcanic dust, and this is borne out by the analyses. They are rich in iron, their alkalies are high, and their magnesium somewhat (though less than would be expected) above that of normal sediments. In the Gwna Series, as in the New Harbour Group, there are spilitic lavas ; and in this case tuffs are also known. It is reasonable to suppose that fine dust of their explosions was carried in small quantities (probably from some distance away) over the basin of deposit throughout the period represented by the Alternating group, and that this accounts for the composition and colour of the rocks. Moreover, the green colour is most pronounced in the Aethwy and Middle Regions, and those are the regions where the spilitic lavas and their tuffs are developed on the greatest scale. On the northern coast the colour is feeble and often absent altogether, and there, accordingly, the development of the volcanic rocks is feeble also. A noteworthy difference between the New Harbour Beds and the Gwna Green-schist is that the former contain an unusual proportion of titanium, the latter very little. This, again, reflects the composition of the lavas ; for those of the New Harbour Group are rich, those of the Gwna Beds (whether in their original or schistose condition, see pp. 74, 78) poor in that element.

The Spilitic Lavas.

The Spilitic Lavas, where unmodified, are massive, and thoroughly igneous-looking, but too fine in grain for their texture to be visible by the unaided eye. Under the hand-lens, on polished or wet surfaces, a mesh-work of little crystals can be seen, with, sometimes, a few felspar phenocrysts. The normal colour is a pale grey-green, but reddish mottling is rather common, and this may extend itself until the whole rock is of a uniform low purplish tint. Far more striking is their aspect in the field, for, where undeformed, they always display the characteristic ellipsoidal or pillowy structure, sometimes in great perfection. On Llanddwyn Island and among the dunes of Newborough, boss after boss is built up entirely of these curious pillowy bodies, often with small interspaces (which are usually filled with jasper, but sometimes with limestone), often pressing one another's sides into gentle re-entering curves that impart a strangely vivid sense of softness, and suggest the rolling over and over each other of pasty masses, kept from adhering by immersion in such a medium as the water of the sea. Under the incessant sandblast, they are not obscured by soil or vegetation ; are not blurred even by a weathered crust ; are as fresh and clean at the surface as they are within ; and look almost as if their motion had been arrested but yesterday (Plates III, IV). Two types of pillow can be distinguished : large ones, a yard or more in length and ellipsoidal, and smaller ones that are seldom a foot in diameter and tend to be globular. No differences of importance have been seen between the inner and outer parts of the pillows, but there is often a slight concentric banding, and a much darker skin, rudely banded or even fissile, its banding sometimes broken up into a fluxion-breccia. Steam-cavities are small, rare, and of the spherical form usual in spilites, but at Cerrigceinwen there is a rock so vesicular as to be in parts almost a pumice. The vesicles appear to be as numerous in the dark skins as in the pale hard cores of the ellipsoids. Little spherulites, about 1 millimetre in diameter, are to be seen in places, especially in the dark skins. They are usually in bands, but sometimes these bands are concentric shells, parallel to the surfaces of the smaller 'pillows' and conforming even to their in-pushed curves. As a rule, the spherulites occur towards the margins of the pillows, but there may be shell within shell, even to the core.

What may perhaps be called the normal spilite (Plate V, Fig. 1) [E. 9895][1] is composed of lath-felspars and a very pale brown augite such as is usually found in rocks of this kind. There are often a few felspar phenocrysts, occasionally opalescent and usually small, though varieties exist that are porphyritic to the unaided eye, whose phenocrysts are apt to be in groups. Specks of iron-ores and sphene are frequent. Olivine has not been found in any of the writer's slides, but good pseudomorphs after it occur in some from Newborough, kindly lent by Prof. Grenville Cole, and have been figured in his paper. The augite is often in elongated grains, not eumorphic, but apt to be moulded over the ends of the felspars, so that the structure may be described as sub-ophitic. In another type no pyroxenes can have been present, the rock being composed almost entirely of slender laths of felspar. In both kinds the felspar of the body, wherever it can be determined, is albite, or some allied sodium variety. The larger phenocrysts are albite, often with a turbid core. Glassy varieties [E. 11222—3] are found, always much chloritised, but still isotropic in some cases, and even retaining traces of the perlitic structure of the tachylite. One of these (Plate V, Fig. 3) was described by Prof. Grenville Cole for the present writer (*Quart. Journ. Geol. Soc.*, 1902, pp. 430–31) as having been first brecciated during viscid flow, so that a certain blending took place between the firmer glass-fragments and the new material from the matrix that gathered round them. Banding, often very delicate, resulted from the movement of the mingled mass; after which came a second brecciation, affecting both the fragments and the consolidated parts of the banded matrix.

A marked feature of the Gwna spilites (and indeed all the spilites of the Mona Complex) is the frequency with which they display variolitic structure, sometimes in great perfection. It may be remarked that the best variolitic developments have not, so far, been found to be coincident with the strongest developments of the pillowy structure. In some of the augitic rocks no variolitic arrangement is discernible. In others, the little felspars begin to

[1] Nearly all the slides and specimens of the Gwna spilites, tuffs, diabases, and keratophyres, as well as of the spilites of p. 54, were kindly examined by Dr. Flett.

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Interstitial Jasper between Spilitic Ellipsoids. Dunes of Newborough.

form the rudiments of sub-radiate groups and brushes, and sometimes the augite rods also are grouped in the same way, so that we have the beginnings of a variolitic structure. This can be traced in other slides through further stages, until the rock would certainly be called a variolite. The highest developments are reached, however, in the anaugitic rocks, in some of which the whole body is a plexus of radiate groups and brushes of delicate lath-felspars, as in the beautiful variolite [E. 9843] of Plate V, Fig. 2.

The spherulites with definite boundaries, already described as visible to the unaided eye [E. 9956], are usually found in the glassy rocks. They are sharply separated from the chloritised body, and are composed of radiating lath-felspars, closely set, and of extreme delicacy, giving sometimes a good dark cross in polarised light. Partly developed radial groups of microliths may also be found in the glass, which, in E. 11222 (Plate V, Fig. 3), are arranged in bands parallel to the periphery of the ellipsoid. In the dark skins that enwrap some of the pillows, very perfect spherulites, both simple and compound, occur, but they are composed of quartz, and set in granular epidote, all igneous texture having disappeared.

The Gwna spilites display in a high degree the decomposition now known to be characteristic of such rocks. Fresh augite has been found in a few slides only, and the felspar is generally riddled with cavities now filled with chlorite, epidote, sericite, calcite, and quartz. The glasses have been converted into chlorite, epidote, quartz, and iron-ores. Often the decomposition is complete, and the felspars are mere pseudomorphs. The steam-cavities are filled with the same secondary minerals. Hæmatisation, unusual in other British districts, is very frequent in the Gwna spilites, and is the source of the purple colouration already noted. When hæmatite is abundant chlorite is rare, and sometimes every mineral of a lava has been replaced by hæmatite except the felspar, which then, whether fresh or sericitised, is clearly outlined by it, as in E. 9843, Plate V, Fig. 2. Although the felspar, where fresh, is albite or one of its allies, yet the frequency of complete decomposition shows that albitisation is far from general, and Dr. Flett considers that it has gone on to a considerably less extent than in Devon and Cornwall. That the process, where it occurred, was the same is shown by the occurrence of felspars with fresh margins and decomposed cores.

Finally, it can be shown in many cases that the decomposition, the hæmatisation, and the albitisation all took place before the shearing, and therefore before the great movements of the Mona Complex. There are spilites in which all the felspars have the cores decayed and the margins clear and fresh. Where such have been a little sheared many of the felspars are broken and slightly shifted along the planes of movement, sometimes a single crystal by two or three such planes. The fractures are unhealed, and the shifted fragments correspond exactly, margins to margins, cores to cores, each zone being in the same condition in each fragment.

The following analyses will show the relations of these rocks to the spilites of other parts of Britain.

	I.	II.	III.	IV.	V.	VI.
SiO_2	47·45	50·05	51·31	46·4	48·58	47·56
TiO_2	with Al_2O_3	trace	1·92	0·24	1·77	2·40
Al_2O_3	17·54	17·34	12·67	20·4	14·58	14·27
Fe_2O_3	2·04	3·18	0·54	6·9	1·89	1·63
FeO	7·44	7·92	7·99		7·65	6·80
MnO...	not det.	—	0·45	—	0·46	0·30
(Co, Ni)O	not det.	—	? trace	—	0·03	0·08
CaO	10·96	9·06	8·17	7·7	9·80	10·95
MgO...	6·72	—	2·19	3·5	6·36	4·90
K_2O...	trace	—	0·54	0·54	0·43	0·27
Na_2O	3·93	4·43	5·21	6·93	4·02	4·61
H_2O (at 110°) ...	0·23	—	0·04	1·1	0·68	0·42
H_2O (above 110°) ...	2·67	—	2·31		2·93	2·65
CO_2	0·55	—	6·15	5·8	1·00	2·95
P_2O_5, FeS_2, Fe_7S_8, S.	not det.	—	1·37	—	0·45	0·46
	99·53	—	100·86	99·51	100·63	100·25

I. Boss south-west of Bryn Llwd, Newborough Dunes [E. 9895]. Anal. J. O. Hughes.

II. From close to the same spot. Anal. C. T. Gimingham (for which I am indebted to the kindness of Sir William Ramsay) in 1903 [E. 9895].

III. Tayvallich Peninsula, Argyllshire. Anal. E. G. Radley. 'Geology of Knapdale, Jura, and North Kintyre' (*Mem. Geol. Surv.*), p. 87.

IV. New Cumnock, Ayrshire. Anal. J. J. H. Teall. 'The Silurian Rocks of Britain, vol. i, Scotland' (*Mem. Geol. Surv.*), p. 85.

V. Mullion Island, Cornwall. Anal. W. Pollard. 'Geology of the Lizard and Meneage' (*Mem. Geol. Surv.*), p. 185.

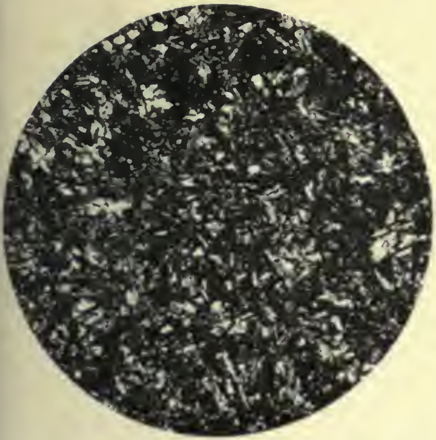
VI. Tregiddon, Cornwall. Anal. E. G. Radley. *Loc. cit.*

Nos. I and II are from the large pillows, shown in Plate III. The rock contains fresh augite, and is hardly variolitic. No. III may very likely be of Pre-Cambrian age. Nos. IV, V, VI, are Ordovician. It will be seen that the Gwna lavas have the characteristic composition of the spilites, being basic alkaline rocks rich in sodium. They differ chiefly in the lack of carbonates (though carbonated specimens could have been selected); and of titanium, in which last they differ also from the other spilites of the Mona Complex.

Compared with those from other British districts, they are on the whole finer, perhaps more often glassy, and olivine is not quite as rare as usual. The tendency to variolitic structure is more pronounced than elsewhere. Though they have undergone the characteristic early decomposition, they have been less extensively albitised, but more often hæmatised, than the other spilites of Britain.

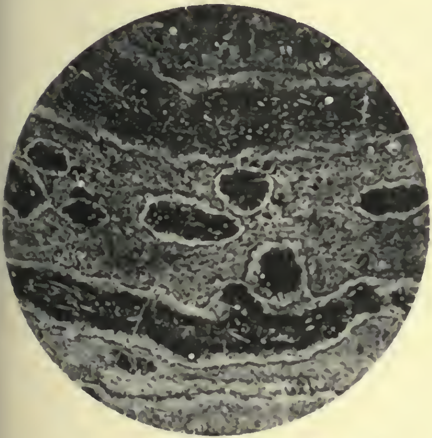
Axinite.—The spilitic lavas are traversed at the north end of Llanddwyn by a six-inch vein of a heavy mineral [E. 11389] with good cleavage, about the hardness of orthoclase, and of a low plum-violet colour. Dr. H. H. Thomas examined it. It is bi-axial with a tolerably wide axial angle, optically negative, and with a mean

Plate V.

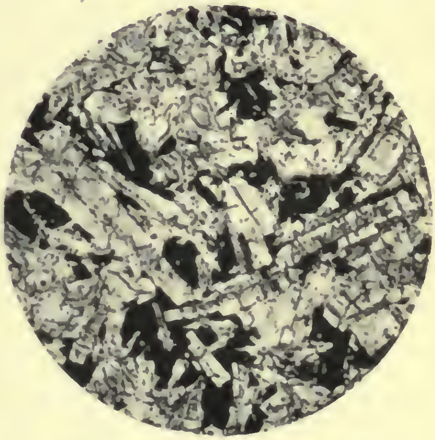


1. Ellipsoidal Spilite.

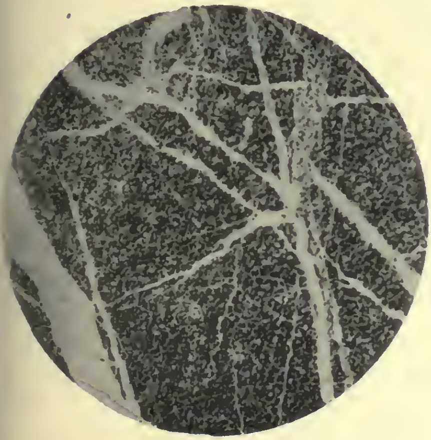
2. Variolitic Spilite.



3. Glassy Variolite.



4. Albite - diabase.



5. Jasper.

6. Spherulitic Jasper.

Huth coll.

refractive index about 1·68—9; fuses before the blowpipe to a green glass, and gives the flame reaction for boron. It is therefore axinite. Axinite has not hitherto been recorded in Wales, nor, apparently, in Britain outside Devon and Cornwall. Its occurrence here is therefore of considerable interest. In the Pyrenees and elsewhere it has been found in association with diabasic rocks, but whether spilitic is not yet known.

The Tuffs.

These are usually green, but sometimes hæmatised. Most of them are of medium grain, but some are agglomerates with fragments of jasper and blocks of the lavas that may be several inches in diameter. Some of these are isolated ellipsoids, as if detached by explosion during flowage under water. The tuffs are distinctly bedded and, at the north end of Llanddwyn, some bands of pillowy lava from one to two feet thick appear to be interbedded with them. They consist of a completely chloritised or hæmatised base in which are (sometimes with a few round grains of quartz) jagged and torn lapilli, sometimes vesicular, of highly felspathic lavas, identical in character with the adjacent spilites, some of them even delicately variolitic. They are true spilite-tuffs, and are of no small interest; for, if any doubt on the point could be entertained, they show that the spilites themselves must be regarded as contemporaneous outflows. Some are full of fragments of the banded glass already described, and are thus allied to the 'palagonite tuffs.'

The Albite-Diabases.

Being externally dull 'greenstones' of medium grain, these present nothing special in their external appearance. They are composed of albite, pale brown augite, iron-ores now generally leucoxenised, and sometimes a few pseudomorphs that may be after olivine. Fresh augite is rather more frequent than in the lavas. Nearly all the determinable felspar is albite, in laths that penetrate the augite ophitically, but porphyritic varieties are occasionally, though very rarely, seen. Sometimes it is decomposed throughout; but there are many zonal felspars whose cores (Plate V, Fig. 4) have been completely sericitised, while the margins are now clear albite, and in a few cases a core at least as basic as andesine (and probably more so) still survives. For the most part they appear to be sills among the spilitic lavas.

Hornblende-diabase.—There is a sill on Llanddwyn composed of large plates of green hornblende and albite, some of which only is in ophitic relation, and large grains of leucoxene. With this may be considered the large epidiorites of Bodowen Warren, heavy green rocks with lustre-mottled fibrous pale hornblendes a third of an inch in length, and full of yellow epidote. Their felspar is albite, but is often almost entirely replaced by pleochroic epidote in large hypidiomorphic crystals, which here and there penetrate the plates of hornblende ophitically ; and there are some iron-ores, partly leucoxenised. The hornblende is in well-formed plates, but contains good-sized cores of a nearly colourless augite, and is therefore, secondary. But it is older than part of the movements, for the product of its deformation is not a hornblendic but merely a chloritic schist. The adjacent Gwna grits and phyllite have been baked and at Bonc Twni cove converted into a true adinole, composed chiefly of albite, with iron-ores.

Keratophyre.

Where recognised *in situ*, this is a fine, dull-green, speckled rock. Small phenocryts of either albite or orthoclase, fairly preserved, are scattered freely in a fine matrix which is now green with chlorite. This has been composed essentially of minute rods of felspar, and there are grains of magnetite, but no recognisable pseudomorphs after ferro-magnesian minerals. The contents of conglomerates (pp. 62, 251) reveal that keratophyres must have been abundant.

Basic Schists.

Catamorphic Schists.—The tracts of undeformed spilite are never wide, and along their margins the lavas break down rapidly, so that even their pillowy structure may become inconspicuous in 100 yards across the strike. The soft 'skins' give way first, then the outer portions of the pillows, which break up along the concentric shells, the fragments shearing into phacoids, and the hard cores into larger phacoids, about which dark green schistose matter winds. This gradually increases at their expense, until all is converted into a dull green schist in which lenticular structure may hardly be discernible, as may be seen very clearly along the western side of Llanddwyn. Internally the process begins by appearance of planes which break the felspar laths that lie across them. More of these appear until they are quite close together, by which time the ferro-magnesian minerals have been converted into a sheet of schistose chlorite, with grains of calcite and epidote. Such a rock, while showing no sign of igneous structure to the unaided eye, will still be full of broken felspars, and may be called a spilite-schist. The felspars then break further down into a micro-breccia, and igneous texture disappears. Finally the felspar breaks down chemically also, into kaolinous and epidotic dust with streaks of sericite, interfelted with the long-since schistose chlorite. Such are the chlorite-schists of Llanddwyn and other zones along the margins of the spilites ; dull-green, with parallel structure, but no banding, rough upon the foliation-planes, unelastic, and shattering under the hammer. Where the spilites had been hæmatised, the resulting schists are purple, and may easily be confused with the purple phyllites that are often their associates. Rocks of this kind are built up of minerals that may arise as products of mere decomposition (though probably not of mere weathering) ; and are to be regarded as degradation-schists, their foliation not being anamorphic.

Anamorphic Schists.—In the Middle Region, however, from Llyn Coron to the Cefni, there is a great zone of basic schist (p. 352), derived from spilitic-lavas (which will be called, from the crags of Cerig-engan, the Engan spilite), that is very different in aspect. It is compact, heavy, dark green, with a fine parallel foliation, smooth upon the planes, and with a faint lustre, sometimes even a banding due to thin epidotic seams, while wriggling epidotic veins cut the foliation, and is tough and elastic, not shattering under the hammer. This rock is a dense felt of chlorite, full of granules of pleochroic epidote, with some iron-ores (often octahedral), a varying amount of quartz, and minute grains that seem to be an alkali felspar. These are still the minerals of the degradation-schists, though they are far better crystallised and interfelted. With a higher power, however, the chlorite is found to be full of minute short needles of a pale green hornblende. The physical properties of the rock are therefore due, not merely to a better foliation, but to the presence of the hornblende. The rock is a true granoblastic anamorphic-schist, though of a relatively low order.

In the Aethwy Region there are also large tracts of basic schist that are just as certainly derived from these same lavas. Heavy, dark-green, while on the whole fine in grain, they are still better foliated than those of the Middle Region. A platy character is general, there is greater fissility, the foliation begins to show small corrugations in a hand specimen, and in the field is seen to be powerfully folded, while the divisional planes, especially towards the western margin where they approach the Penmynydd Zone, acquire a low but a decided lustre. Their mineral components are the same as in the group just described, but the crystal individuals are clearer and larger. Most noteworthy is the amount and the condition of the hornblende, a sure measure of advancing metamorphism. Minute in the Middle Region, this is now easily visible with a one-inch objective. The chlorite is shot through and through with it, flashing up, when the nicols are crossed, in countless needles, which in some cases approach ·5 mm. in length. Perhaps chlorite even then preponderates, but the rock has become an actinolitic epidote-chlorite-schist. Thin pale seams are always present, and swell out locally to an inch or two. Some of these (Plate IX, Fig. 3) are composed of quartz and albite, others of albite only. Both minerals are quite granoblastic, interlock intimately, and both are penetrated by the actinolite. The albite may be untwinned, often shows two good cleavages, and is as clear as the quartz. It is therefore a ternary felspar, having first crystallised from igneous fusion, then undergone albitisation, and finally total re-crystallisation during dynamic metamorphism. There can be little doubt that parts of these large tracts of basic schist are derived from spilitic tuffs and albite diabases, but such have been recognised, so far, at a few places only.

The following analyses of typical basic schists from the Middle and the Aethwy Region respectively show that their composition is essentially the same as that of the spilites, for the differences from any one spilite are no greater than those of the spilites from each other. There are two exceptions : the curious reversal of the proportions of calcium and magnesium in No. II (may this be a slip of the pen in transcribing No. II ?) and its ferric iron, for a consideration of which see p. 88.

	I.	II.	III.
SiO_2	45·94	45·86	47·89
TiO_2	trace	0·97	—
Al_2O_3	17·39	15·83	—
Fe_2O_3	4·68	2·84	—
FeO	7·49	7·96	—
MnO	trace	0·32	—
CaO	11·05	5·64	—
BaO	not det.	0·02	—
MgO	8·29	10·76	—
K_2O	0·14	0·17	—
Na_2O	2·86	3·49	—
H_2O (at 100°)... ...	0·24	—	—
H_2O (above 100°) ...	2·22	5·14*	—
CO_2	none	0·64	—
SO_3	not est.	0·17	—
	100·30	99·81	—

I. Chlorite-epidote-actinolite-schist [E. 10019] ('Engan spilite'). 220 yards east-north-east of Capel Soar Smithy. Anal. J. O. Hughes.

II. Actinolitic epidote-chlorite-schist [E. 9913]. Roadside, 850 yards north-east of Garth Ferry Inn. Anal. Edmund Dickson, F.G.S. * 'Combined water.'

III. Similar schist, but with a little glaucophane [E. 10208]. Shore, 210 yards east-south-east of the church on the islet, Llandysilio. Anal. E. Greenly.

The Quartzites.

These rocks are very massive and uniform, bedding being discernible at a few places only, most of which are on the northern coast ; and on the whole are fine in texture, though clastic grains are usually to be seen under the hand-lens, and often by the unaided eye. Internally there may be a tinge of blue or green ; and they are apt to oxidise to a light brown within a few inches of the surface, but all weather white externally. They are almost wholly composed of quartz, felspar being no more than an accessory, and sometimes absent. All the determinable grains are albite. Zircon, tourmaline, and rutile are generally present, and in some slides quite a number of the two first are to be seen, the zircon being sometimes in beautiful doubly-terminated crystals. A few of them are to be found enclosed in the grains of quartz, in which are also minute 'hairs' like rutile, and moving bubbles, all of which are characters of the quartz of granitoid or gneissoid rocks. Fragments of fine mosaic rocks are not uncommon, a few of which are granoblastic mica-granulites, and one or two of these are foliated and are true mica-schist [E. 10196]. Here and there is a bit of spilitic lava, and one small grain has been found that resembles the Gwna jasper. The quartz is well rounded on the whole, and closely packed, leaving little room for matrix, which in some cases appears to be entirely siliceous, but usually contains a little mica that is probably a product of original felspathic mud. The green varieties may have contained a sprinkling of spilitic dust. The following analysis was kindly communicated by the manager of the Porth Wen Silica Works. The rock is from the large boss of Graig Wen, close to the northern coast, which has long been quarried, and is a typical Gwna quartzite.

SiO_2	96·40
TiO_2	0·05
Al_2O_3	0·84
Fe_2O_3	0·31
CaO	1·22
MgO	0·21
K_2O	0·16
Na_2O	0·04
Loss at 109°	—
Loss over 109°	0·34
CO_2	Nil.
P_2O_5 and SO_3	Nil.
	99·57

Dried at 109°. Anal. J. W. Mellor, D.Sc., Director of the County Pottery Laboratory, Stoke-on-Trent, March, 1909. Material composite, from a number of blocks then at the Basin Wharf, Stoke-on-Trent.

The amount of lime is remarkable, for it cannot have been calcite, and in two slides [E. 10953—4] of the rock no lime-silicate is to be seen, unless the mica be a margarite, and even then the lime would be too high. In any case, it will be seen that this rock is more siliceous than any part of the Holyhead Quartzite, and Dr. Matley was informed (*Quart. Journ.*, 1899, p. 670) that the same rock had yielded 99·60 per cent. SiO_2.

Metamorphism.

An old secondary enlargement of the grains, anterior to the regional metamorphism, and resembling that found in ordinary quartzites of non-metamorphic regions, can here and there be detected ; but it has been obliterated for the most part, and the union of the grains with the elements of the matrix, which is very common, and has in great measure destroyed their epiclastic relations, is due to incipient granoblastism. The matrix has become finely granoblastic, and its micas are often foliated, sometimes enwrapping the clastic quartz, but more often penetrating it after the manner of a true schist. Along planes of deformation the clastic grains begin to break down into a mosaic like the matrix, which grows at their expense. Undulose extinction is common along the northern coast, where the rocks are less reconstructed.

The Quartzite of Mynydd Bodafon has peculiarities of its own. Where unfoliated, this is full of unoriented mica like that of the adjacent hornfels, it has a 'glassy' fracture, and there is reason to think that it has been thermally affected by the granite. It is rich in zircon, one perfect crystal of which (Fig. 7) has been broken and shifted, but not along any visible plane of rupture [E. 10710]. Between the shifted parts a little of the ordinary mosaic of the rock has forced its way, showing that the zircons are not products of the regional metamorphism, but (though perhaps thermally enlarged and perfected) are old clastic elements. Clastic quartz is not often to be seen in this rock, and was probably obliterated in part by thermal influence before the close of the regional metamorphism. The Bodafon Quartzite is of a delicate rose colour, by which fragments can be distinguished at once from every other quartzite in the Island. This is due to minute scales of hæmatite, which tend to be grouped in little aggregates, and as, in the foliated portions of the rock, these are elongated along that structure, it has the aspect of a true metamorphic mineral. The foliation however, is cut sharply by late planes of movement, along which are thin veins of quartz, and the hæmatite scales and aggregates follow these quite as much as they do the foliation ; so that the mineral is later than all the metamorphism, and has no connexion with the old hæmatisation of the spilitic lavas. Some of its aggregates have rectangular outlines, as if about to build up larger idiomorphic crystals. Many small red clots are also seen, and the faces of the veinlets have a coating that soils the fingers, and when teased out in water is found to be composed of minute blood-red scales. It is evident that the staining (which extends into the adjacent schists) is quite a late product ; and it may with confidence be ascribed to percolation from the Old Red Sandstone, which rests immediately upon this quartzite.

FIG. 7.
BROKEN ZIRCON IN BODAFON QUARTZITE.
Highly magnified.

Black Quartzite.

Only one or two thin beds of small extent are known, all on the northern coast ; but much more of it must exist about the middle of the Island, for pebbles abound in the Arenig conglomerates of Bôd-Deiniol, which indeed led the writer to search for it *in situ.* The rock is a true quartzite with conchoidal fracture due to the usual cement of secondary quartz, but is dark almost to blackness. There is russet oxidation on the joints, and a little in the matrix. Two colouring matters are present : one which transmits a faint brown light when cut thin, another which is opaque even in the most minute specks. The first occurs as films in the matrix, the second as little clots and granules that penetrate the clastic grains of quartz along their cracks and along the bands of inclusions that pass from grain to grain. Mr. J. O.

Hughes has investigated the colouring-matter in E. 10508. He first found that the rock became almost white on being strongly heated. Then, decomposing six grammes of its powder by means of HF and a little H_2SO_4, he obtained a residue, which was black. This was filtered, washed, dried at 130°C, and weighed. On strong ignition the blackness disappeared completely, and there was a loss of weight equivalent to 0·35 per cent. of the rock. He does not wish this to be taken as an accurate estimate. But it is evident that the opaque particles, which are the principal colouring matter, consist of carbon. The others are probably a dense hydro-carbon.

Limestones.

Amid many variations, two principal types can be distinguished : the Simple or 'Cemaes' type, and the Complex or 'Llanddwyn' type.

The Simple Type.

The Simple type is, normally, a very massive blue-grey rock, rather fine in grain and uniform in aspect, and is composed of a mosaic of clean calcite. Small round grains of quartz, though very rare at Cemaes, are found in other places. From their form and distribution they are evidently clastic, but in the present condition of the rock interlock with the adjacent calcite. Films of carbon are generally present. Fine parallel bedding can sometimes be seen on the margins of the massive rock. Oolitic structure is not uncommon, and is highly developed at Cemaes Bay, where the rock is, locally, a true pisolite, for a good many of the grains are as much as a quarter of an inch in length. The larger ones are usually flattened, but there is no sign of this being due to deformation, and flattening is also common in the 'Pea-grit' of Cheltenham. Some have good concentric structure, others are mere shells, the mosaic being finer in the oolitic rings than in the matrix. Many of the grains are compound (Fig. 8), being composed of irregular groups of smaller grains enclosed within a large one. Two or three are quite common, and 13 were counted inside one large grain. They do not give a black cross. Some varieties are mottled, and the rock is generally much veined, not only with carbonates but also with quartz, by which fragments of it can be distinguished at once from those of the Carboniferous Limestone. It has been locally dolomitised, often in well-defined bands, and in some places dolomitised throughout, but without losing its general texture and aspect. The following analyses have been made :—

Fig. 8.
Compound Oolitic Grain in Gwna Limestone [E. 10816].

	I.	II.
$CaCO_3$	96·560	53·11
$MgCO_3$	0·776	42·61
$Ca_3(PO_4)_2$ ...	0·091	not est.
SiO_2	1·650	3·70
TiO_2	—	not det.
Al_2O_3	0·040	} 0·44
Fe_2O_3	0·076	
FeO	0·182	not est.
MnO	trace	not est.
K_2O	0·069	none
Na_2O	0·016	none
H_2O ('Combined')	2·270	not est.
C	0·228	not est.
	101·958	100·10
Percentage $CaCO_3$		53·11
,, $MgCO_3$		42·61

I. Fine limestone from Cemaes. Anal. Holland and Dickson. *Proc. Lpl. Geol. Soc.* 1890 [*Cf.* E. 10518].

II. Grey limestone. Pedair-groeslon kiln, 1⅝ mile north of Menai Suspension Bridge [E. 10801]. Anal. J. O. Hughes.

The exact locality of No. I. is not given, but there can be little doubt that it came from the large quarry west-north-west of Gadlys (Penrhyn-mawr of the six-inch map) [E. 10518].

It is not easy to see with what element in such a rock so much water could be combined, and the high total suggests that the powder must have absorbed moisture between weighing and ignition; also possibly CO_2 absorbed by free lime in the $CaCl_2$ used. Mr. J. O. Hughes tells me that he treats his own $CaCl_2$ with a stream of CO_2 before using it. In No. II., 'Residues insol. in HCl' have here been placed under 'SiO_2,' as it can be seen from thin section that there is no such material but quartz, in veins. The body of that rock is therefore a nearly pure dolomite. In the Cemaes rock there is so little granular quartz that the SiO_2 may safely be taken to be that of the veins. If, therefore, we eliminate this, as well as —say—two per cent. for moisture, it will be seen to be a nearly pure calcite-limestone.

The Llanddwyn Type.

This class, well-developed on Llanddwyn, includes really several sub-types, differing considerably from one another. They vary, also, with great rapidity, the character of the rock changing often in the space of a yard or two, so that no adequate picture of the class can be conveyed in words. Three sub-types may be distinguished, namely, rose-coloured, green, and breccia-limestones. Nearly all of them are massive.

The first sub-type is the one that is most characteristic of the class. It has a delicate rose-colour, is of medium grain though saccharoid on fracture, and tends to be rather hard. All the rose limestones are magnesian, and the typical one analysed is a thorough dolomite.

Residues insol. in HCl ...	5·84
$Al_2O_3+Fe_2O_3$	2·72
MnO	trace
CaO	29·93
MgO	18·76
CO_2	42·84
	100·09
Percentage $CaCO_3$	53·44
„ $MgCO_3$	39·19

Llanddwyn Island, south of Lifeboat Station (on six-inch map, at west end of Pilots' Cove Breakwater) [E. 10100]. Anal. W. Roberts, B.Sc. In a specimen from the same place Mr. J. O. Hughes found ·016 $MnCO_3$.

The iron resides chiefly in thin brown skins between some of the elements of the mosaic, but the rose-colour is diffused throughout the grains, and so the carbonate of these rocks may be regarded as a dolomite with a slight isomorphous admixture of rhodochrosite. The tint of the rose limestones, indeed, is precisely that which is found in so many of the manganous salts ; and it is known that surprisingly small quantities of manganese are sufficient to diffuse that tint throughout a crystal. Quartz in allotriomorphic grains and veinlets is always present ; and there are small aggregates of a white mica, flakes of which are also to be found enclosed in the grains both of quartz and dolomite. Sometimes there is a good deal of granoblastic albite.

The green types are really varieties of the rose limestones that are mottled with aggregates of chlorite, usually also with iron-ores. These are the most variable rocks of all, composition, and still more, texture, often changing within the limits of a hand specimen, while a few of them are banded. Others have a rudely spherulitic structure, their chlorite aggregates being set in a frame-like ring of carbonate. In the coarser parts of the mosaic the carbonates are idiomorphic, and sometimes there are rhombic pseudomorphs of chlorite with a core of carbonate. They are also less dolomitic, the larger rhombohedra being zonal, ruddy dolomite within and clear greenish-white calcite without. Their quartz is apt to be moulded on the faces of such rhombohedra. All these limestones are much veined, both by quartz and by a carbonate, which is almost invariably white calcite.

Breccia Limestones.—At a good many places the rose-green limestones are studded with angular green and purple fragments a quarter to half an inch, and sometimes as much as two or three inches, in diameter. Quite half the bulk may be composed of them, so that the limestone comes to function as the matrix of a many-coloured breccia, which is a beautiful and striking rock. All these fragments are volcanic, and those that retain definite internal textures can be recognised as the spilitic lavas. The purple ones (Plate IX, Fig. 1) are deeply hæmatised, but are full of slender felspars, often in radiating groups [E. 10103]. Among the green ones are some of the banded glassy spilites, and the interstitial chlorite and iron-ores are doubtless reconstructed spilite dust. These rocks are developed on a great scale at Llanddwyn. Most of them are massive, but close to the isthmus breakwater is one that is distinctly stratified, and interbedded with green spilite tuff and with a thin lava. They are therefore altered calcareous tuffs or ashy limestones, and must be due to explosions of spilitic lavas into a sea on whose floor calcareous sediment was forming.

Ellipsoidal Limestones.—Some of these limestones, however, have a remarkable ellipsoidal structure, which at once recalls that of the spilitic lavas (Plate VI). In the vicinity of such rocks the inter-ellipsoidal spaces of the lavas themselves are filled with limestone, and for a yard or two from the junction the spilite ellipsoids are completely isolated from each other by it. This limestone is full of spilitic lapilli, so that the marginal portion of the lava seems to be really a spilite agglomerate, whose larger blocks are, like those in the green tuffs, ellipsoids that became detached either by explosion or by sudden cooling in water, the matrix of the agglomerate being, in this case, calcareous. The adjacent parts of the bed of limestone also contain isolated spilite ellipsoids, a passage being thus traceable from calcareous agglomerate to ashy limestone with large blocks. Now the ellipsoids of the agglomerate are traversed by radial cracks, and their cores (evidently of lower chemical stability than their outer parts) decompose, become calcareous, and are in many cases replaced by limestone. In the spilite ellipsoids that lie within the limestone this process has gone still further, and the whole of the core has been more or less replaced, leaving only a shell an inch or two in thickness. But the replacement is not complete, for the limestone core is generally full of small curved survivals of purple spilite (the spilite is usually hæmatised when in the limestone) lying in broken concentric rings. In the final stages the outer shell is reduced to a mere film, or may even disappear, but the carbonate will still retain an ellipsoidal structure. These peculiar limestones appear, therefore, to be metasomatic pseudomorphs after spilite-agglomerates with whose finer lapilli calcareous sediment was mingled.

Dynamical Structures

are not conspicuous, even where the adjacent rocks are highly schistose. Carbonates, however they may be reconstructed under stresses, are not apt to acquire a foliation, and may even protect their enclosures from acquiring it, doubtless from the ease with which the mass yields as a whole. The northern oolites are traversed by slide planes, along which the oolitic grains are cut and shifted. Where the ashy limestones are full of fragments, these are often deformed, and impart a schistose structure to the whole. The

Rose-Limestone with Ellipsoidal Structure. Dunes of Newborough.

[Face page 84.

hæmatised spilite fragments, whose 'eisenglimmer' lends itself to foliation, have become so schistose as to simulate the purple phyllites. But even where massive, it is evident that the limestones have been profoundly reconstructed. The presence of allotriomorphic felspar and of well-formed flakes of mica, reveals that they are truly anamorphic rocks. It is, indeed, somewhat surprising that calc-silicates do not seem to have been formed in them.

Graphitic Phyllite.

Adjacent to the laminated outer parts of the simpler, grey, limestones are beds of soft black schist or phyllite, seldom exceeding a few inches in thickness. They yield a strong black streak, and soil the fingers, but have a faint sheen upon the foliation planes. In the northern districts they are in actual contact with the limestone, and are themselves calcareous, the carbon films of the Cemaes Limestone being really an attenuated form of the same deposit. They are composed of parallel seams of carbon, with fine granular quartz and a little white mica, parted by thin bands of calcite mosaic. The carbon is not mere dust, but is in authigenetic scales, and is evidently graphite.

The Jaspers.

According to the rock in which they are found, these may be termed Limestone- and Spilitic-lava- (or briefly) Lava-Jaspers ; but the two differ in habit only, not petrologically. The lava-jaspers fill the spaces between the ellipsoids of the spilites (Plate IV), so that their forms tend to be bounded by concave and intersecting ellipsoidal planes, and may perhaps be called concave ellipsohedra. Their diameter seldom exceeds a few inches in any direction. The limestone-jaspers occur in irregular nodules. Two of them attain a size of 24×6 feet, but this is quite exceptional. The typical jasper is a compact scarlet rock, as hard as quartz, though very brittle, and with an irregular or conchoidal fracture. Some are paler, some of a darker, purplish tint, which is commoner in limestone than in lava-jaspers. Not many are uniform in tint, the majority having a mottled aspect. Nearly all are traversed by a network of thin veins of quartz, sometimes to such a degree as to look like scarlet breccias with a quartz matrix. A spherulitic structure is often to be seen, the spherulites, though red, being of a lighter colour than the matrix. They are usually two to three millimetres in diameter, but some on Llanddwyn are an inch or more across. These are composed of radiating fibres alternately red and white, with a sort of cellular tissue in the middle. As they crowd against each other their peripheries assume a rudely polygonal form, and weathering hollow in the middle, they recall curiously a colony of corals of the habit of *Cyathophyllum regium* (p. 151). Some limestone-jaspers are composed of red irregular bodies, with many sub-angular oblong ones, lying in almost unstained quartz. Banding, or a tabular habit, is known in limestone jaspers only, and is very rare.

The rocks are composed (Plate V, Fig. 5) essentially of quartz and hæmatite, with a little carbonate (doubtless dolomite, with possibly some siderite) as a frequent, and pyrite or magnetite as a very rare, accessory. No felspar, no siliceous pseudomorphs after it, have been detected even in slides cut across the junction with spilitic lava. Some of the hæmatite has crystallised as definite flakes of 'eisenglimmer,' but most of it is fine dust. The carbonates are usually in isolated rhombohedra, some of which contain zones of hæmatite. The body of the rock is a quartz-mosaic which is extremely variable in texture, with a range from crypto-crystalline to such as is composed of elements ·5 mm. in diameter, but most of it is of medium grain, inclining to be rather fine. The variation is also very rapid ; several types may occur within a single slide, and the finest may adjoin the coarsest. This is especially the case in the limestone-jaspers. Among the mosaic are occasionally groups of small doubly terminated crystals of quartz, whose outlines are picked out by hæmatite. The veins are usually much coarser than the body. The distribution of the hæmatite is no less capricious. In some tracts there may be a mere scattering of dust, in others it may be densely crowded, almost to opacity. But almost everywhere it is gathered into little spots, denser in the middle, which is the cause of the mottling already noticed. Sometimes each of these aggregates lies in the centre of a quartz grain, and is thus confined to the limits of an optical unit (Plate V, Fig. 5).

The spherulites display several stages of development. Some are mere shells of hæmatite dust in ordinary quartz mosaic which has the same structure within and without the shell, so that between the nicols they tend to disappear. The first of the true spherulites are tracts of colourless mosaic in which the elements become elongated, fusiform, and radially arranged, so as to yield an incipient cross. The higher stages of development are approached by these becoming more finely and definitely radial, and at the same time picked out with spherical zones of hæmatite. Some of the larger ones contain only about a dozen elements of quartz, which widen out greatly towards the margin. The most perfect (Plate V, Fig. 6), are composed of a core of nearly colourless mosaic, full of little veins ; then the principal zone, which is finely fibrous, regularly radial, and pale red ; then a narrow, pale zone ; and finally an outer skin almost opaque with hæmatite. These display a strong dark cross between the nicols. They simulate closely the well-known structures of the rhyolites, but it should be remembered that the chalcedony of cherts may also develop spherulites that polarise with a dark cross. Spherulitic cherts with dolomite crystals have been described and figured by Miss Raisin,[1] who points out the remarkable resemblance of their structures to those of many felsites.

Origin of the Jaspers.—From the small dimensions of the jasper-bodies, and from their mode of occurrence, it is impossible that they can have been silicified rhyolites. But the relations of some of

[1] *Proc. Geol. Assoc.*, 1903, pp. 78, 79, Plate XIV.

[Face page 86.

Autoclastic Mélange. Coast, near Porth Cadwaladr, Bodorgan.

them point to their being local silicifications of the spilites. Occasionally the red matter has an outer shell of pale greenish quartz, that seems to graduate into the surrounding igneous material. There are also (as well as the definite and dense inter-ellipsoidal nodules) rather loosely knit aggregates with ragged margins, outside which may be isolated spherulites in the midst of lava substance. Thin vein-like strings, too, may sometimes be seen.

On the other hand, felspar pseudomorphs have not been detected, even where in close contact with the spilites; and so far from their spherulites representing those of the lavas, the latter usually lack spherulitic structure at the junction. The jaspers of the vesicular spilite of Cerrigceinwen have been searched for pseudomorphs of its amygdules, but with indecisive results. For, though they are spherulitic, so are those in many that are not vesicular; and though some contain oval bodies that might represent amygdules, they are grouped as are the spherulites, not as the isolated vesicles. And some nodules in the midst of lava crowded with vesicles are as dense and homogeneous as any in the Island. The identity in character of the limestone- and the lava-jaspers is not in favour of their being silicifications of either of those rocks. Moreover, limestone, banded, fine, and granular, fills (just as in Scotland) some of the interspaces of the lavas instead of jasper; and on Llanddwyn may occasionally be seen to have been the first of the deposits on the walls of the cavity, and to enclose a core of jasper. It is not easy to see how such a jasper core can be a pseudomorph of lava substance.

Their modes of occurrence are, in the one case, that of cataclasts of chert nodules in deformed and reconstructed limestone; in the other, identical with that of radiolarian chert in ellipsoidal spilite, as may be seen by comparing Plate IV with those in the Geological Survey Memoir on the rocks of Southern Scotland. The radiolarian cherts of the spilites of the South of Scotland, moreover, pass locally into scarlet jaspers indistinguishable from those of Anglesey. Associated with the jaspers of the Mona Complex are jaspery phyllites (pp. 52, 88) which, though cherty, are unquestionable sedimentary, not chemical, deposits. The ferric oxide is doubtless a product of the hæmatisation that so often affects the Gwna lavas.

The following are analyses of typical Gwna jaspers:

	I.	II.	III.
SiO_2	88·07	93·52	97·16
Al_2O_3	1·31	None	0·27
Fe_2O_3	10·75	6·56	1·76
Alkalies	None	None	0·51
	100·13	100·08	99·70

I. Lava-Jasper, in interstices of spilite. Cerig-mawr, Newborough, 742 yards north-east of Llanddwyn Island [E. 10306], close to west edge of six-inch sheet 22 south-west. Anal. J. O. Hughes.

II. Limestone-Jasper. 700 yards north-east of Llanddwyn Island: a little to the east of (I). The great (20-ft.) jasper [E. 10307]. Anal. J. O. Hughes.

III. Limestone-Jasper. 300 yards south-west of Hendre-bach, Cerrigceinwen [E. 10012]. Anal. J. O. Hughes.

Except in their high percentage of Fe_2O_3, they compare closely with the analyses of seven cherts given in *Bull. U.S. Geol. Surv.*, No. 224, p. 297, but differ in several respects from those of nine siliceous sinters there given, in which (among other differences) there is a loss on ignition ranging from 2·29 to 7·50 per cent.

Metamorphism of the Jaspers.

The structures described above, though denoting great internal alterations, are found only where the spilitic lavas have suffered little or no deformation ; and are therefore older than the regional metamorphism. Elsewhere, especially in the Middle and Aethwy Regions, they are involved in that process. Torn, by reason of their hardness, from out their enclosing rock, they often become parts of an autoclastic mélange, cut into thin lenticular strips and interfelted with phyllite and with crystalline mica-schist. They then undergo internal deformation, their quartz-mosaic becoming nemablastic and their hæmatite foliated. The structure is not merely catamorphic, for both minerals are now new crystalline grains, and the carbonates are often perfect rhombohedra even in thorough jasper-schist. Thin quartz veins in them are cut and shifted, especially at the micaceous folia, some of which pass right through the shifted vein. The veins are also cross-foliated without being shifted [E. 9965]. Where enclosed in limestone, the easy plastic readjustments of that rock have protected them. But in the Engan belt of the Middle Region, where they are enclosed in great flows of spilite that have been converted into actinolitic epidote-schists, they have not only become schistose but have suffered a metasomatic change. Their concave ellipsohedra have been drawn out into long lenticular augen, and they acquire the foliation just described ; but concurrently with this begin to lose their colour, and finally become bleached altogether, passing into a white quartz-schist.[1]

It would appear as if the iron must have been absorbed by the enclosing rock, and we find, accordingly, that the basic schist of this tract yielded 4·68 Fe_2O_3 as against 2·04 and 3·18 in the Newborough spilite (see pp. 74, 78) and still lower percentages in the Scotch and Cornish rocks. In this district all stages of the bleaching can be studied, but no one would recognise jasper in an isolated specimen of the final product ; and it is possible that some of the siliceous augen of still more altered basic schists may have originated in this manner (pp. 118, 120).

The Jaspery Phyllites.

These are fissile purple rocks, closely resembling those of Amlwch (see p. 52). They contain minute clastic quartz and white mica, and are undoubtedly hæmatitic shales, the bedding even surviving on Llanddwyn, where one of them is associated with a fine purple grit, full of broken albites, with a little tourmaline. But some

[1] Many years ago Dr. Horne drew my attention to a loss of colour in the Torridon Sandstone where traversed by the Post-Cambrian thrust-planes. See also 'Geology of the North-West Highlands of Scotland' (*Mem. Geol. Surv.*), pp. 581, 585.

Plate VIII.

[Face page 88.

Siliceous Gwna Green-schist with venous-quartz augen.

Ynys Gaint, Menai Strait.

are jaspery, and have a crypto-crystalline matrix, of the kind that replaces colloidal silica. Some contain oval chlorite bodies, like those in the Penrhyn slates, an analysis of which is given for comparison.

	I.	II.
SiO_2	63·93	63·59
Al_2O_3	17·55	16·28
Fe_2O_3	6·54	8·42
FeO	0·73	0·66
MnO	—	0·42
CaO	0·60	0·72
MgO	5·88	1·95
K_2O	2·47	2·98
Na_2O	0·34	2·14
H_2O	1·46	2·92
CO_2	None	None
	99·50	100·08

I. Jaspery Phyllite, 300 yards south-west of Hendre-bach, Cerrigceinwen [E. 10011]. Anal. J. O. Hughes.

II. Purple Slate, Penrhyn Quarry, Bethesda. Anal. Holland and Reade, *Proc. Lpl. Geol. Soc.*, 1898, p. 293. SiO_2 includes 0·58 TiO_2.

Some red slates quoted by Clarke in *Bull. U.S. Geol. Surv.*, 1900, have as much MgO as I., whose chlorite accounts for it. The excess of potassium over sodium is unusual in the Mona Complex, but a frequent character of red slates.

THE FYDLYN GROUP.

This group, well seen on the sea cliffs of the Fydlyn Inlier, is composed of peculiar white rocks of highly acid character, whose original structures are tolerably well preserved, in spite of the innumerable planes of schistose deformation. For the most part they seem to have been rather massive (Plate XXV), and their whiteness is remarkable, for where slightly decomposed they soil the fingers almost like hard chalk, but are seldom compact throughout, being rough, hackly, and usually full of rounded or sub-angular quartz. The most solid cores are composed of a crypto-crystalline felsitic mosaic (now considerably sericitised) in which are large grains of quartz, eaten into by corrosion bays, and many phenocrysts of albite, with some of oligoclase. These are undoubtedly sodium felsites. Some of their sheared cores are rudely rounded, suggesting original nodularity. Other parts vary rapidly in texture, being locally free from phenocrysts, while close by they may be so crowded with broken ones, largely quartz, as to have the aspect of a white grit, with but little matrix. Yet, in these grit-like parts, the matrix is still the same crypto-crystalline felsitic mosaic, and the quartz fragments are sub-angular, often with re-entering angles. There are also bands full of small clastic felspars. Such rocks are certainly neither lavas nor sediments, they can differ but little in composition from the felsites, and must be regarded as felsitic tuffs. This is confirmed by the fact that near the junctions with the Gwna Beds, they graduate into true sediments, chiefly grit, but with thin bands of grey phyllite. Some of these felsitic tuffs are very massive. Their matrix, in its present state, cannot be distinguished from that of the true felsites, and is doubtless compacted felsitic dust. The deformation that the group has undergone has broken down the original junctions, and made it impossible, so far, to separate lavas from tuffs in the field, even on the clear cliff-sections, and to estimate the proportions of the two, but the latter seems to be dominant. From the intimate relations of the types, it is evident also that the felsites are not intrusive but effusive.

Many of the hard cores are considerably silicified, and, as these are older than the planes of deformation, which sweep round them, they are to be referred to the volcanic episode itself, as products of geyserisation that set in towards its close.

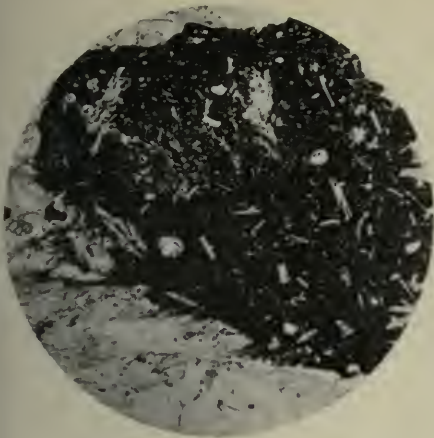
The rocks have been powerfully deformed, and their less resistant parts have become fissile. Anamorphism, however, is low, and is restricted to the production of minute white mica. The phenocrysts are not often sheared out into phacoids.

THE COEDANA GRANITE.

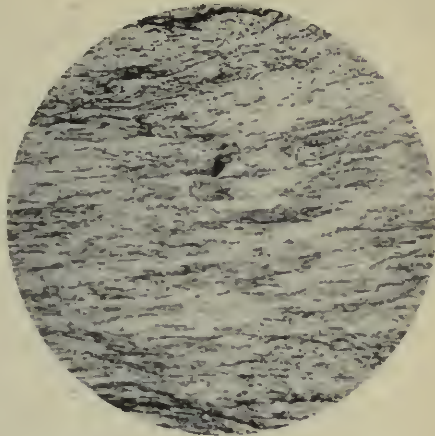
Four principal types can be distinguished, which may be called the Normal Granite, the Porphyritic Granite, the White Mica Granite, and the Fine Veins. The first three are often foliated, and all very frequently schistose or crushed. The normal granite has a good deal of slight local variation, but is generally rather coarse, its crystals often exceeding a quarter of an inch in diameter, and in colour may be grey or sea-green, but is usually a salmon-pink, mottled with grey and with dark green aggregates. The porphyritic is a variety of the normal rock that is full of large pink felspars. The white mica type, which is marginal, is decidedly finer than the normal, and is a clean white glistening rock. The fine types, which, when their junctions are exposed, are seen to be veins, are rare. The great intrusion of the Middle Region may be called the Coedana Granite (pronounced ‘Koidánna’).

The minerals of the normal granite are quartz, felspars, biotite, and white mica. Accessories are rare, but apatite, garnet, and zircon are occasionally found. The biotite (which was brown) is usually chloritised, and this chlorite is often studded with secondary ilmenite and leucoxene. The nature of the alkalies of the white

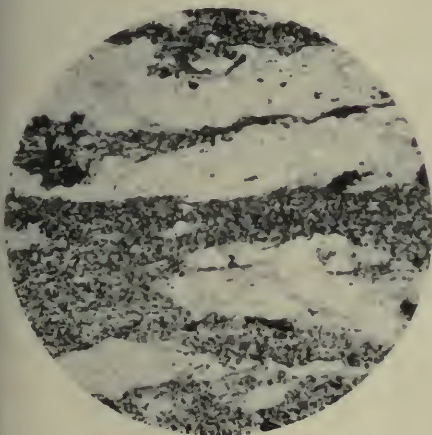
Plate IX.



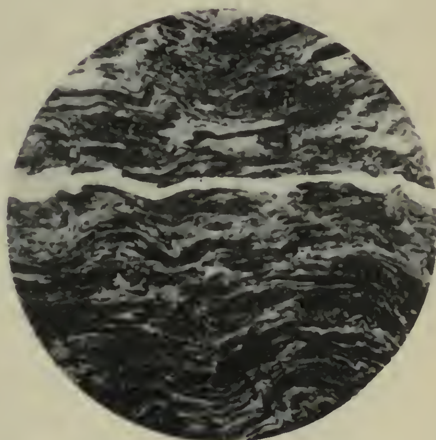
1. Limestone with Spilite.



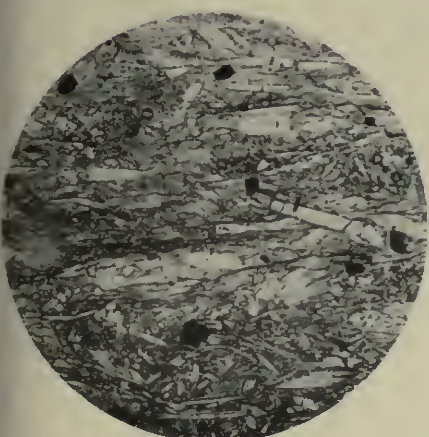
2. Gwna Green-schist.



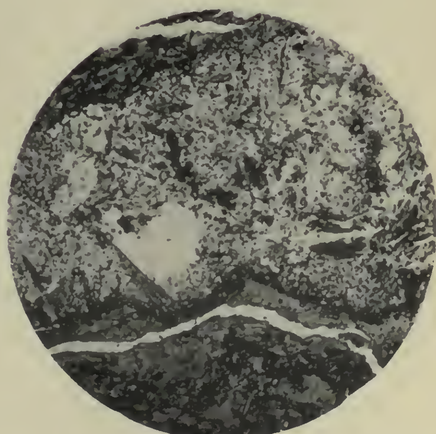
3. Gwna basic schist.



4. Gabbro-schist.



5. Tremolite-schist.



6. Actinolite-epidosite.

micas has not been determined for any of the Coedana granites. Epidote, and rarely zoisite, also occur as alteration products, but in small quantity. The rock was rather poor in micas, brown was in excess of white, which is intergrown with it; and both micas are somewhat unevenly distributed, being found in nests with several plates close together. The dominant felspar is albite, sometimes with lamellar twinning, sometimes simple, often twinned on both planes with a microcline-like structure. But orthoclase is present as well, in varying proportions, and it may be accompanied by microcline. There are some perthitic intergrowths, and veinlets of albite penetrate the orthoclase. The structure of the rock is typically granitoid.

The porphyritic differs from the normal granite in containing conspicuous phenocrysts of pink orthoclase an inch or more in length. They are distributed rather capriciously, a few yards of rock being often closely crowded with them, while in the surrounding parts they may be scanty. From a comparison of their refractive index with that of orthoclase of known composition, it is probable that they contain about two per cent. Na_2O. Some are Carlsbad twins; but they are hypidiomorphic, often only developing the pinacoidal, and sometimes no crystal faces at all. Faces, even when developed, may be invaded by any of the minerals, even by quartz, and the interior of the crystal usually encloses grains of the albite of the ground-mass. Although early, they cannot, therefore, be a first product of the consolidation unless modified by corrosion as that went on. Inclusions of the same kind are found, though on a much smaller scale, in the idiomorphic phenocrysts of Shap.[1] In the foliated varieties there is a tendency to parallelism in the micas and to elongation of the quartz. But the foliation is never conspicuous, and scarcely affects the arrangement of the phenocrysts in the porphyritic rock.

The white mica granite is more acid, and though containing also the same three felspars, appears to be rather richer in orthoclase than the normal granite, but is never porphyritic. It contains no biotite, but is rather rich in white mica, probably muscovite. Foliated varieties are found, in which a parallel arrangement of the micas is conspicuous.

In the fine veins pink orthoclase appears to be the dominant felspar, and white-mica, which is abundant, certainly the dominant if not the only mica. One of them contains a good deal of garnet. They are the only varieties with much micropegmatite.

All these granites are more or less affected by the latest movements of the Complex. They are sometimes crushed to mere endoclasts; are traversed by innumerable seams of greenish mylonite; are often optically strained; and frequently rendered rudely schistose. But this schistosity can easily be distinguished from the true foliation, which it may traverse at any angle, the late structure striking steadily north-east, the older in more than one

[1] Marr and Harker, *Quart. Journ. Geol. Soc.*, 1891, p. 278.

direction. The old foliation is not accompanied by destruction of the minerals, and sometimes its elongated quartz elements will send out rounded tongues transversely (Fig. 9). Although the white mica variety and the veins are finer than the normal type, they are still truly granitoid. No sign of a chilled selvage has been found on the margin of any granite of the Complex, even in contact with the finest of the crypto-crystalline hornfels. Junctions with the crystalline hornfels are well seen in many places, especially between Tre-ddolphin and the Holyhead main road (Figs. 145—53), and there is no degeneration of crystalline texture, even at the contact. A slight marginal greisenisation is to be seen here and there. Tourmaline appears locally in the granite close to the mica-hornfels, and at one of the junctions north of Tre-ddolphin the felspar of some micropegmatite has been pseudomorphed in white mica. But it is evident that the rocks into which the granite found its way were already at a high temperature, as appears to be generally the case with the granites of metamorphic regions.

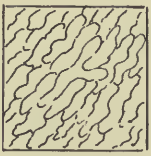


FIG. 9.
OLD FOLIATION IN COEDANA GRANITE.
West-south-west of Coedana Church.

It is of interest to note that the Pre-Cambrian granites of Pembrokeshire are also rich in sodium.[1] The Coedana rock resembles them in the dominance of albite, in the titaniferous character of its biotite, and in its poverty in accessories. It differs from them in the presence of porphyritic orthoclase, in the presence of some orthoclase, microcline, and muscovite in its ground mass, and in the rarity of perthitic and pegmatitic structures. It is also nearly related to the granites of Eastern Sutherland,[2] a relation partially disguised by the injuries inflicted by the last movements of the Complex. It differs from these somewhat in composition, for they contain more biotite, no muscovite, and their dominant felspar is oligoclase. Structurally its resemblance to their less foliated portions is much greater, especially as they contain red phenocrysts of natron orthoclase which are but hypidiomorphic and enclose many grains of the oligoclase of the ground mass. The affinities of the Coedana granite to some great Pre-Cambrian and 'Metamorphic' granites are therefore close. Its relations to the granitoid parts of the adjacent gneisses will be discussed later on.

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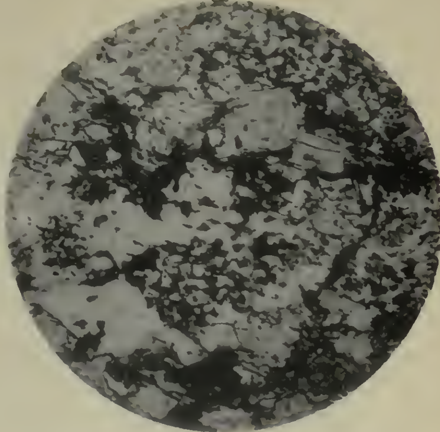
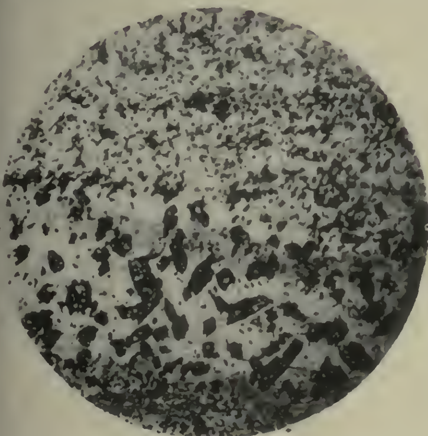
[1] Thomas and Jones, *Quart. Journ. Geol. Soc.*, 1912, p. 387.

[2] Horne and Greenly, *Quart. Journ. Geol. Soc.*, 1896.

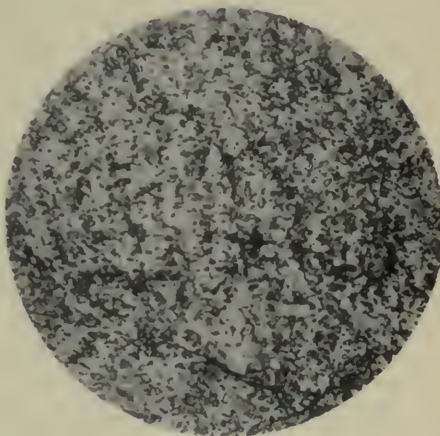
. Cryptocrystalline Hornfels.



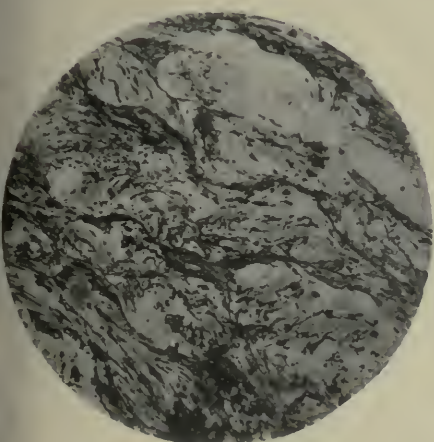
2. Mica-hornfels.



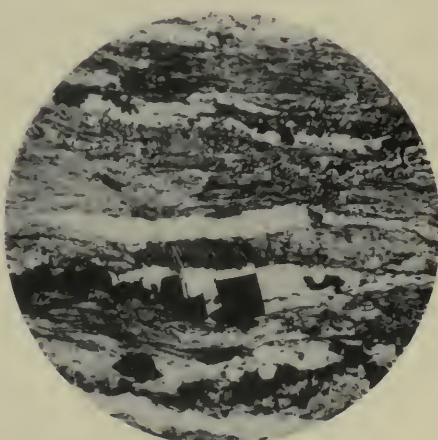
3. Hornblende-hornfels.



4. Epidote-hornfels.



5. Albite-schist.



6. Graphitic Schist.

Huth coll.

HORNFELS.

The rocks grouped under this name are all found in association with the Coedana granite. Some of them are highly crystalline, and can only be termed hornfels in accordance with the extended use of the word that has been made in recent years. The compact varieties (which predominate) may be termed Crypto-crystalline, the others Phanero-crystalline, or briefly Crystalline Hornfels.

The Crypto-crystalline Hornfels.

These are compact grey-green rocks with a rudely conchoidal fracture, seldom, but sometimes harder than steel, and weathering to a light cream colour. But this material, though a large proportion of the whole, usually occurs in rather slender, curving, lenticular cores, between which a decided though never strong schistosity appears, the rock remaining otherwise much the same. Sometimes a strong parallel banding that cannot be anything but bedding can be traced for a few yards, and on the moor north-west of Gwalchmai it is thoroughly stratified over a considerable area. Spotted hornfels also occurs.

The essential minerals are quartz, alkali felspar, a green mineral most of which is now chlorite, magnetite, and white and brown mica. What proportion of the colourless mosaic is felspar is difficult to determine on account of the fineness of the grain, but it must often be considerable. Some of the felspar, which is very seldom twinned, is albite, but some is negative and must be an orthoclase. The white micas are very small. Sometimes the iron ore is larger than usual, and is then seen to be octahedral, and being strongly magnetic, must be magnetite. Idiomorphic tourmaline of bluish-brown tint in small prisms is almost always present as an important accessory. Pseudomorphs after andalusite have been found at Bodafon Moor. Minute granules of sphene are often plentiful, and also leucoxenised ilmenite, from which doubtless the sphene has been derived. The spots are complex encarsioblasts of a green mineral in which, though much chloritised, portions that are still a xanthophyllite[1] can be identified, though not so well preserved as in the graphite-schist. The banded varieties have the same composition as the rest.

The texture is finely granoblastic (Plate X, Fig. 1), and cannot be called lepidoblastic even in the most foliated varieties. In the hard cores the minute micas lie in all directions, and the structure is that of a typical hornfels.

The Crystalline Hornfels.

Three principal kinds are known, Mica-Hornfels, Hornblende-Hornfels, and Epidote-Hornfels. All are holocrystalline and granoblastic.

[1] For the characters of this mineral, where better preserved, see p. 113.

Mica-Hornfels.

The mica-hornfels is a saccharoid sea-green rock spangled with bright micas that lie in all directions. Often it has a parallel structure that is not a foliation, and it is interbedded with white fine siliceous bands in a way that is unmistakably stratification. The essential minerals are quartz, alkali felspar, white mica, brown mica now much chloritised, and iron-ores, tourmaline also rising in some beds to the rank of an essential. Cordierite has not been found. Apatite and sphene occur occasionally. Besides the white micas of the body, there are abundant white mica porphyroblasts which when in crystal units are often one millimetre and when compound often two to three millimetres in diameter. (Plate X, Fig. 2.) Tourmaline prisms may be four millimetres in length, and are of a bluish tint. In some beds are oval (not lenticular) groups of felspar seven millimetres across. Both these and the felspars of the body are chiefly orthoclase, and some of the large oval groups are composed of micropegmatite ; but albite is also present. The two micas are often intergrown, and the whole mosaic is rather complex. It is thoroughly granoblastic, and there is no true foliation. Perhaps the majority of the micas of the body lie at a low angle, or nearly parallel, to the banding, but almost as many are oblique, many even at right angles to it : and the porphyroblasts of tourmaline and white mica are devoid of orientation.

Hornblende-Hornfels.

This, which is found as a zone in mica-hornfels, is a dark green but light-weathering rock of medium grain, saccharoid, and with a fine, steady, parallel banding that is manifestly bedding. It is homœoblastic, and composed of alkali-felspar, hornblende, and quartz, with minute epidote, zoisite, iron-ores, and sphene. In the colourless mosaic felspar predominates over quartz. It is untwinned, the refractive index unusually low as a whole, and as some is negative, some positive, it is evidently orthoclase with a large quantity of albite. The hornblende is of a good clear tint, and pleochroic, thus : X, pale straw-colour, Y, rather strong brownish-green, Z, grass-green. It is hypidiomorphic, and in one coarse band (Plate X, Fig. 3) almost porphyroblastic, with development of the prism-faces and cleavages, but the crystals riddled with inclusions of the quartzo-felspathic mosaic. The rock is quite unfoliated, and the larger hornblendes often stand at right angles to the banding.

Epidote-Hornfels.

The epidote-hornfels is a finely saccharoid, pistacio-green rock, sometimes with an even banding and well-bedded siliceous seams, but sometimes rather massive. It is a homœoblastic mosaic (Plate X, Fig. 4) of alkali felspar, epidote, and hornblende, with some quartz and a good deal of brown sphene, a little iron-ore and zoisite ; and some chlorite, calcite, and dusty epidote that are all evidently due to alteration. The colourless mosaic is almost entirely a clear, untwinned felspar with a very low refractive index, which does not often yield a good optical figure. But the refractive index of a few grains of albite that are present is decidedly higher, so this felspar must be orthoclase, a conclusion amply confirmed by the analysis of the rock. The epidote, which has high bi-refringence and strong pleochroism, is in clear grains but seldom hypidiomorphic. The hornblende is very pale, with pleochroism—X, colourless, Y, pale grass-green, Z, pale blue-green, in ragged plates that include the other minerals, and there is a speckled variety of the rock with larger and darker hornblendes.

Unity of the Hornfels.

The crypto-crystalline hornfels, though not observed to pass into typical mica-hornfels with large porphyroblasts of muscovite, becomes here and there so much less compact, with such much larger micas, as to constitute an intermediate type ; and another intermediate type is a fine but saccharoid hornfels with alkali felspar and a little white and brown mica that is developed on rather a large scale on Gwalchmai Moor. The persistent presence of tourmaline also links the types. Epidotic bands link the crypto-crystalline with the true epidote-hornfels. The epidote-hornfels at Cwm rests upon a bedded mica-hornfels and is seen to graduate into this in clear section ; while hornblende- and mica-hornfels come into similar relations in the section near Coedana. All the types are therefore linked up together, and must be regarded as varieties of one and the same product.

Chemical Analyses.

The following are analyses of different types of hornfels :—

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.
SiO_2 ...	74·02	58·40	60·08	58·87	—	62·91	60·36	55·58	74·02	55·58
TiO_2 ...	not det.	not det.	not det.	not det.	—	0·53	none	not det.	—	—
Al_2O_3 ...	12·13	23·42	17·93	18·74	—	16·52	16·81	13·96	23·42	12·13
Fe_2O_3 ...	0·89	3·10	6·46	6·54	—	4·39	1·12	4·76	6·54	0·89
FeO ...	3·62	2·26	1·88	3·43	—	4·47	4·85	2·20	4·85	1·88
CaO ...	1·10	0·11	3·89	1·23	—	1·41	5·13	9·73	9·73	0·11
MgO ...	1·95	1·52	2·27	2·07	—	2·41	2·77	4·88	4·88	1·52
K_2O ...	1·89	6·59	7·21	8·97	4·04	2·57	3·69	6·97	6·97	1·89
Na_2O ...	3·19	0·29			1·57	2·99	3·76	0·20	3·76	0·20
H_2O (at 110°)	none	0·46	0·17	0·31	—	0·31	0·15	—	0·46	0·15
H_2O (above 110°)	1·54	3·53			—	1·83	0·99	1·09	3·53	0·99
CO_2 ...	none	none	none	0·42	—	0·19	none	0·63	0·63	—
	100·33	99·68	99·89	100·58	—	100·53	99·63	100·00	—	—

I. Banded crypto-crystalline hornfels [E. 10188] ; coast, 353 yards north of the 'a' of Porth Nobla. (Bonc y Bedd of six-inch map.) A slide cut from close by [E. 11190] showed abundant clastic grains. Anal. J. O. Hughes.

II. Bedded crypto-crystalline hornfels [E. 10345] south end of Mynydd Bodafon; 300 yards east by north from the '329' level, close to quartzite. Anal. J. O. Hughes.

III. Crypto-crystalline hornfels, 200 yards north of Ynys-fawr, Coedana [E. 10003]. Anal. J. O. Hughes.

IV. Spotted xanthophyllite-hornfels [E. 9888]; 170 yards east-north-east of Llanfaelog Church. Anal. J. O. Hughes.

V. Banded crypto-crystalline hornfels [E. 9972]; half mile west of Bodwrog Church. Anal. J. O. Hughes.

VI. Crystalline mica-hornfels [E. 9806]; 425 yards west of Caer-glaw cross-roads, Gwalchmai. Anal. J. O. Hughes.

VII. Crystalline hornblende-hornfels [E. 10002]; 240 yards north of 'o' of Coedana (200 yards north-west of Maengwyn farm of six-inch map). Anal. J. O. Hughes.

VIII. Crystalline epidote-hornfels [E. 9949]; Cwm, Llandrygarn. Anal. under superintendence of Dr. Dobbie, Univ. Coll., N. Wales, to whom I am indebted for it.

IX. Maximum percentages of the constituents in I—VIII.

X. Minimum percentages of the same.

It will be seen at once that there is a great variety of composition, affecting every element estimated, even the aluminium; and the range of the variations can be gauged at a glance from columns IX and X. The combined alkalies range from 5·08 to 8·97. A number of different rocks must, therefore, have been converted into hornfels. It will also be noted that a mean of the separated alkalies in I, II, V, VI, VII, VIII, yields $K_2O = 4{\cdot}29$, $Na_2O = 2{\cdot}00$, and that in II and VIII potassium is almost the only alkali, a reversal of the proportions usual in the Mona Complex. From this it follows that orthoclase must be the dominant felspar of the fine mosaic, and that the minute white mica must be muscovite.

Origin of the Hornfels.

1. *Original Structures* are found at several places. A parallel interbanding of different kinds of material, often of coarser and finer material, is frequently to be seen both in the crypto-crystalline and crystalline varieties, which resembles in every way a true sedimentary stratification, and at a place 275 yards south-south-east of the tenth milestone at Gwalchmai thin bands of quartzite lie along this. A purple phyllite occurs within the zone 190 yards east of this quartzite. The crystalline types are completely reconstructed, but a banded crypto-crystalline hornfels a few yards from the rock of analysis No. I contains numerous undoubted clastic grains of quartz and albite [E. 11190], between which are the little micas of the hornfels. Similar characters are seen in a slide ('No. 9, 1899') from the same place, belonging to Mr. Barrow. Bedded crypto-crystalline hornfels dips under the quartzite of Mynydd Bodafon. There are good natural exposures, but in 1908 a small quarry was opened at the south end of the quartzite, 300 yards east by north from the '329' level, in which its junction with that quartzite was completely cut through. About 30 feet of well-bedded rocks are seen [E. 10341—7], all their structures being parallel to the 'base' of the quartzite. One is a crystalline

biotite-hornfels, others are fissile and fine like those which contain the andalusite, but most of them are perfectly typical crypto-crystalline grey-green hornfels (Plate X, Fig. 1), indistinguishable from the best examples of the type. Their external aspect and internal structures are the same, they are composed of the same minerals, they have the same 'criss-cross' micas, and even the same small idiomorphic tourmalines. Now these rocks contain undoubted clastic grains of quartz; they are members of a well-bedded series; the one analysed yields 23·42 per cent. Al_2O_3; and there cannot be a moment's doubt as to their sedimentary nature.

2. *Chemical Composition.*—From the remarkable range of composition shown in the analyses it is evident that rocks of very different character and origin have, in this zone, been converted into hornfels. One or two have the composition of acid and basic igneous rocks, another (No. II) that of a sediment, others of neither normal igneous rocks nor normal sediments. Taken singly, No. I might be supposed to have been a rhyolite, No. VII a diorite. Yet No. I has a stratified structure and contains clastic grains, No. VII is also stratified and is a band in mica-hornfels that resembles No. VI, which is totally unlike either a diorite or any ordinary igneous rock, but resembles many sediments in composition. Nos. I, III, IV, V, again, have close community of structure with No. II, which is undoubtedly a sediment; while No. VII is related structurally to No. VIII, which cannot possibly be dioritic. Yet none of them, not even No. II, can be normal sedimentary rocks, and No. VIII, with its 9·73 per cent. of CaO and its 6·97 per cent. of K_2O, is abnormal altogether. The outstanding feature of the zone, in short, is community of structure with diversity of composition. The structure which they have in common is not of a kind that is known to result from the alteration of igneous rocks, but is well-known to result from the alteration of sedimentary rocks, and these undoubtedly exist within the zone; yet the composition of the majority of them is not that of any known sediments. Now there is one class of deposits, and one only, in which such a range of composition is at all probable, combined with a community of original structure capable of giving rise to a community of alteration structure. That is an alternating group of bedded tuffs with psammitic and pelitic sediments into which have been showered varying proportions of pyroclastic dust; and such deposits are known to exist within the Mona Complex, which contains both spilitic and rhyolitic tuffs (pp. 57, 75, 90). The hornfels, moreover, passes laterally into the Penmynydd Zone of metamorphism, which, as will be seen, must include rocks of both sedimentary and pyroclastic origin. The crypto-crystalline hornfels with clastic quartz may therefore be regarded as composed of gritty shales with rhyolitic and other dust, the mica-hornfels may be produced from similar material, the hornblende-hornfels would be a basic, and the epidote-hornfels a calcareous tuff. Much of the crypto-crystalline

hornfels has in the field a strong resemblance to the Church Bay Tuffs, in which, moreover, we find precisely the same rare, local, and pronounced but impersistent bedding.

3. *Causes of the alteration.*—Among the many metamorphic types of the Mona Complex the rocks here called hornfels are unique in that they are found in one association only. The distribution of the rest is regional : the hornfels, of whatever type, clings to the Coëdana granite. The crypto-crystalline hornfels is for the most part external ; behaving, indeed (though small xenoliths are found), as an aureole along the flanks of the granitic tract : the crystalline hornfels is only found in the great xenoliths (one of which is a mile in length) of its interior, where the temperature would be higher and maintained for a longer time. In the crypto-crystalline hornfels granite apophyses are rather rare, but the crystalline xenoliths are riddled by innumerable sills and veins, and no chilled selvages are known.

The textures and composition of the hornfels itself are fully in harmony with its dependence on the granite. The flinty fracture, the spotting, the frequent absence of parallelism in the micas, the presence of large porphyroblasts whose position is independent of the direction of the banding, and of large ragged encarsioblasts full of small inclusions, are all characters of thermal as distinct from dynamic metamorphism. Tourmaline (which is found also in the granite at the margin), andalusite, and the chloritoids are all contact minerals, both micas are well known in that connexion, and the hornfels of Gwalchmai Moor has the structure of an adinole. The epidote rock with its pale hornblende is an impure calc-silicate-hornfels.[1] There can be no doubt, therefore, that the special characters which distinguish these rocks from the rest of the Mona Complex are due to the thermal influence of the granite.

Foliated Hornfels.

Their frequent lack of any foliation being a matter of importance in these rocks, attention has been focussed on it. Yet the fissile parts of the crypto-crystalline varieties are finely foliated. What is the relation of this foliation to the thermo-metamorphism ? Now, tourmaline prisms are found in many slides of the foliated parts, but they never show the slightest deformation, and in some cases [E. 10346] cross the foliation at right angles. That foliation can be traced, uninterrupted, through the large ragged encarsioblasts of chloritised xanthophyllite, and in one case even through an idiomorphic tourmaline. It is therefore not the result of dynamo-metamorphism acting upon completed hornfels. At Foel (p. 331) the granite is seen to cut across an old pre-intrusion folding. Evidently the rocks into which the granite was intruded had already undergone considerable deformation, and their fine

[1] The preponderance of potassium over sodium, so exceptional in the Complex, is also curious, and suggests that some of the potassium of the Coedana granite (the only great orthoclase rock of the Complex) has found its way out into the aureole.

parts acquired an incipient schistosity. When the intrusions began, the small new thermal micas developed in great measure along the pre-existing planes of cleavage; the xanthophyllite and tourmaline developing later on.

DIORITES.

Rocks of this type are (except in the Gneisses, whose basic members are described under the heading of that formation) both small and few, and are all either within the Penmynydd Zone or the Coedana granite. The small cores of albite-diorite that are found in some of the hornblende-schists are described on p. 115. The diorite of Llangaffo cutting is coarse, but slightly foliated even in the centre, while its margins pass into hornblende-schist. It contains greenish bodies that look like pseudomorphs after deformed porphyritic felspars, but none of the slides contain sections of them. On the Aberffraw coast at Ynysoedd Duon are some singular amphibolites, grey-green, tolerably coarse, and quite unfoliated in the middle. They are composed of large ragged plates of pale hornblende with pleochroism: *X*, colourless; *Y*, pale brown; *Z*, very pale blue-green, in a matrix of zoisite and albite. The albite is granular, the zoisite chiefly granular but sometimes eumorphic. This matrix is penetrated in all directions by good-sized plates of a white mica, chiefly grouped in aggregates that are sometimes rudely rectangular, as if pseudomorphs after a porphyritic felspar. Epidote and calcite are also present, and plates of hæmatite are intergrown with those of mica. On its margins this rock, which may be called a mica-zoisite-amphibolite, acquires a foliation, in which, however, the micas hardly participate. In an undeformed specimen [E. 10175] from 200 yards east of Ynysoedd Duon, Mr. J. O. Hughes found 47·06 per cent. SiO_2. The zoisite, when idiomorphic, shows good pinacoidal cleavages, and the gliding-planes parallel to the base. It displays the blue polarisation-tints beautifully, and is often zoned, the inner parts having a slightly higher bi-refringence. The crystals often show merely the emergence of one optic axis, but the optic-axial plane appears to be always transverse to the prism, and the bisectrix negative. The extinctions are sometimes nearly straight, but usually at about 10°—15°. Whether the amphibole of the above-mentioned rocks is in all cases original is not yet certain.

Dioritic rocks with amphibole that must be original are found at a few places within the Coedana granite, especially at Tre-ddolphin and by the side of the Holyhead main road near Treban, but the nature of some of these suggests that they may be xenoliths of the basic gneisses. Four small diorites of much more unequivocal character occur within the granite at the curve of the Caradog river near Y Werthyr. As they seem to graduate into hornblende-granite, and adjoin mica-hornfels, they may safely be regarded as basic portions of the Coedana granite magma. But they need further investigation.

THE SERPENTINE-SUITE.

On either side of the winding Strait of Holy Isle (as the channel isolating that island may conveniently be called), a number of plutonic rocks have been intruded into the New Harbour Beds. All are basic, but several types are present,[1] and each of the larger masses is of the nature of an igneous complex. Isolated bodies of the same kind are found also about the mouth of the River Alaw, and among the Amlwch Beds of the north. The intrusions are composed chiefly of serpentine and gabbro, the serpentine being somewhat in excess. Coarse pyroxenites are present, and certain dolerites of the north appear to belong to the same suite of intrusions. Associated with them are a number of interesting metamorphic products, including talc-schist, tremolite-schist, tremolite-marble, ophicalcite, chlorite-chromite-magnetite-schist, andalusite-hornfels, epidote-hornfels, and epidosite, all of which owe either their existence or their condition to the basic intrusions.

Serpentine.

Nearly all the serpentine is dark green, red varieties being rare. It is usually granular, with a clean, subtranslucent aspect. Locally it is mottled with a lighter green variety, and has then the appearance of 'noble serpentine.' In perhaps the greater part of the rock the only visible crystals that interrupt the general uniformity are iron-ores, but varieties containing plates of a fissile pyroxene are common. Sometimes there is a rude banding.

The granular body is a serpentine with the mesh-work structure denoting derivation from olivine. The opaque iron-ores are, when tested, found to be magnetite; but brown spinellids (chromite or picotite) are frequent. Both minerals have a tendency to cluster. The pyroxene was largely enstatite, but diallage is also present. These pyroxenes are generally scattered about in the serpentinous body, but sometimes grains of olivine-serpentine are poikilitically enclosed in them. Their plates are often large, attaining a diameter of five inches at Rhyd-bont creek, so that the original peridotites must have been coarse, and were evidently deep-seated intrusions.

The homogeneous granular material is a true dunite-serpentine; thence, by the coming in of enstatite, it passes into a saxonite-serpentine; again, where diallage is also present, it becomes a

[1] Most of the slides and specimens of these rocks were kindly examined by Dr. Flett.

lherzolite-serpentine ; while some varieties may be regarded as chromite-serpentine. But it would not be easy to lay down lines for these types upon a map.

The following analysis (No. I) was published by Prof. Bonney in 1881 :—

	I.	II.	III.
SiO_2	38·62	40·12	39·58
TiO_2	not est.	tr.	0·10
Al_2O_3	4·15	0·98	3·19
Fe_2O_3	5·21	6·52	4·70
Cr_2O_3	not est.	0·28	0·20
V_2O_3	not est.	tr.	not fd.
FeO	4·34	1·21	2·76
MnO	tr.	0·52	0·34
(CoNi)O	not est.	0·15	0·16
BaO...	not est.	not fd.	not fd.
CaO...	tr.	0·12	1·09
MgO	33·83	35·78	36·21
K_2O	0·70	0·08	0·06
Na_2O		0·24	0·28
Li_2O		not fd.	tr.
H_2O at 105° ...	12·52	1·69	0·51
H_2O above 105° ...		12·17	10·79
P_2O_5	not est.	0·10	0·16
FeS_2	not est.	0·01	not fd.
CO_2...	—	0·15	0·24
	99·37	100·12	100·37

(Two serpentines from the 'Geology of the Lizard and Meneage' are given also.)

I. Serpentine, from close to the 't' of 'Pen-y-bont,' Valley. Anal. F. T. S. Houghton.

II. Dunite-serpentine [E. 5172], 70 yards west of Parc Bean Cove, south side Predannack, Lizard. Anal. E. G. Radley.

III. Bastite (lherzolite)-serpentine [E. 5031], Poltesco Mill, Ruan Minor, Lizard. Anal. E. G. Radley.

The rock seems to have been a dunite-serpentine with a little enstatite, but contains much more aluminium than the dunite-serpentine of the Lizard. Comparison, however, must not be made too closely between analyses differing in date by 30 years.

Serpentinisation.

The peridotites are highly serpentinised, fresh olivine being not yet recorded, while the fissile pyroxenes are for the most part converted into bastite. The serpentine is partly fibrous, partly in well-formed crystalline elements with varying bi-refringence, and some of it is nearly isotropic. Tremolite has also grown upon the plates of diallage and bastite, and sometimes the serpentine has been to a great extent replaced by carbonates.

A quasi-spherulitic variety, which has been found at several places, is also due to alteration. In this case a compact serpentine is full of pale green spherulitic bodies ranging from one-eighth to one-third of an inch in diameter, so as to simulate a variolitic spilite. The bodies tend to crowd into groups, or even into confused aggregates, which often take the form of rows like those of a spherulitic obsidian. They tend to weather out, but also weather hollow. The matrix is usually an olivine-serpentine with rather irregular mesh-work. Many of the bodies are not spherical, but subangular, or even rudely rhombic. They are composed of a mineral that resembles actinolite in short needles, intergrown in varying proportions with a carbonate, sometimes almost entirely of the carbonate. Concentric structure is rare, and radial arrangement, though common, is usually confined to the marginal portions, the interior being matted, with an approach to an interlacing of the needles at angles of about 55°. These bodies are therefore products of a late stage of alteration, when the serpentine was being replaced by carbonates. Signs of cleavage are perceptible in some, and as the effects of malachite staining show (Prof. Bonney and Miss Raisin remark) that these cannot have been olivine, they would seem to be pseudomorphs of enstatite. Elsewhere, however, the mesh-work of olivine, still traceable by winding trains of iron-ores, may be seen to pass through the body of a spherulite. The rocks may therefore be regarded as lherzolite- or saxonite-serpentines in which the pyroxene, and portions of the olivine, have been replaced by ternary quasi-spherulitic structures that are later than most of the serpentinisation.

At Mynachdy is a serpentine rich in minute garnets, in clusters and veinlets, together with stars of antigorite. Bundles of asbestos, also, several inches long, are still to be found in it. The refractive index is 1·4 and the extinction parallel. They are therefore chrysotile.

Pyroxenites.

Though important links in the plutonic sequence, and composed of large and beautiful crystals, these rocks are of small bulk, being found but rarely, and in aggregates or veins that cannot be traced for more than a few yards in any direction. The *diallage-rock* is almost wholly composed of that mineral in lustrous plates that attain an inch and a half in diameter, with poikilitically intergrown pseudomorphs after enstatite and olivine. The *enstatite-rock* may be nearly pure, containing, besides a little augite, only a few grains of a mineral that seems to be perofskite. The enstatite is bounded by the faces 010 and 110, and may be half an inch in length. Its smaller plates, broken across the cleavage, simulate a green matrix on fresh fractures. *Websterites* are also found, which were composed of diallage and enstatite with little or no olivine, while others contain a good deal of serpentine. Mineralogically, therefore, transitions can be found from all the types of pyroxenite into the peridotites. The enstatite of these pyroxenites is usually bastitised; their diallage is often fresh, but sometimes replaced by chlorite or carbonates; and both pyroxenes are locally amphibolised.

GABBROS.

Enstatite-gabbro.—A vein is known that consists of augite, kaolinised felspar, serpentine after enstatite, and granules doubtfully ascribed to garnet and perofskite. This rock therefore links the pyroxenites to the true gabbros. The *gabbro proper* is a pale green rock with a rather confused aspect on fresh fracture, though diallage and saussurite can always be made out on examination. Usually it is not coarse, the diallage being from one-eighth to a quarter of an inch across, but the texture may vary even in a hand-specimen. Large plates of diallage are quite rare, but some have been found an inch and a quarter across. Even where least modified, pale amphibole has been developed in and around the diallage in fringing acicular growths and compact plates. There seems no trace of enstatite or olivine. The saussurite of the matrix is composed of granular epidote and small irregular plates of untwinned felspar optically positive and probably albite. Some, however, is fine or even crypto-crystalline. A gabbro that is unusually massive has been analysed. Its differences from those of the Lizard and Skye, both of which contain olivine, are considerable.

	I.	II.	III.
SiO_2	47·02	50·69	47·28
Al_2O_3	15·85	20·98	21·39
Fe_2O_3	0·94	1·65	3·52
FeO	3·96	3·26	4·06
CaO	11·42	11·99	13·42
MgO	13·99	6·84	8·06
K_2O	0·20	n.f.	0·29
Na_2O	1·91	3·36	1·52
H_2O (at 110°) ...	0·18	0·18	0·13
H_2O (above 110°)	4·49	0·94	0·53
	99·96	99·89	100·20

I. Gabbro, 'hyphen' of 'Pwll-pillo,' at the foot of a high boss, by the lane leading to Cerig-moelion (six-inch map) [E. 10213]. Anal. J. O. Hughes.

II. Olivine-gabbro, Coverack, Lizard. Anal. E. G. Radley. 'Geology of the Lizard and Meneage,' p. 100 (0·16 of P_2O_3 and FeS_2 omitted).

III. Olivine-gabbro, Cuillin, Skye. Anal. W. Pollard. 'Tertiary Igneous Rocks of Skye,' p. 103.

DOLERITES.

Those that have been investigated are now deeply amphibolised, but contain cores of brown augite and are ophitic. Their felspar is labradorite. They have chilled selvages and are thus less deep-seated than the gabbros, but are (p. 321) certainly apophyses from an unseen and doubtless gabbroid intrusion.

MUTUAL RELATIONS.

Between the several members of the suite, neither chilled selvages nor clear intrusive junctions of any kind are known. But pyroxenite and enstatite-gabbro certainly vein serpentine, and are never known to vein gabbro. The distribution of the gabbro itself, as shown upon the maps, particularly its ring-dykes (Fig. 122) within the large western serpentine, point to its being later than that rock. The plutonic sequence may be taken to be: first peridotite, then pyroxenite, then enstatite-gabbro, and finally gabbro.

Associated Metamorphic Rocks.

Talc-Schist.—This is grey, platy, rather fine, usually well foliated, and very unctuous to the touch. It consists often almost entirely of talc, with a few scales of chlorite and octahedra of magnetite. Bright scales with a strong basal cleavage are present in some varieties (AP. 281). They show a uniaxial cross, or a bisectrix with a very small and variable axial angle, and are optically positive. The refractive index is very close to 1·570. They are therefore brucite. The composition of the typical rock should be compared with those of theoretical talc, of peridotites, and of the tremolite-schist, to the latter of which it is evidently related, aluminium, however, taking the place of calcium.

Tremolite-Schist.—Some of these rocks are white, others have a very pale tinge of green. The finer ones are perfectly foliated and even fissile, with a silky lustre; but the prisms of colourless amphibole are often large enough to be seen easily with the hand-lens. They are composed (Plate IX, Fig. 5) of eumorphic blades of tremolite with perfect prism cleavages, octahedral magnetite, a little sphene, and a quantity of talc in scaly aggregates. A later generation of porphyroblastic actinolite sometimes is present, cutting the foliation. One of the most beautiful rocks in the Island consists chiefly of prisms, a third of an inch in length, of clear, colourless tremolite, with a tendency to radial grouping. From their chemical composition it is evident that these rocks are derived from the peridotites.

	I.	II.	III.
SiO_2	56·34	63·49	53·65
TiO_2	—	—	0·06
Al_2O_3	8·21	—	3·24
Fe_2O_3	3·04	—	3·48
FeO...	2·00	—	3·88
MnO	traces	—	0·13
CaO...	0·52	—	9·23
MgO	25·43	31·75	24·51
K_2O	—	—	none
Na_2O	0·79	—	0·51
H_2O (at 110°) ...	—	—	0·03
H_2O (above 110°)...	2·86	4·76	1·36
	99·19	100·00	100·08

I. Talc-schist (E. 10168 is from the same locality.) Quarry 250 yards north of Bronddel. (80 yards south-west of Plâs-coch on six-inch map.) Anal. F. T. S. Houghton. Published by Prof. Bonney in 1881. All H_2O given simply as 'Water.'

II. Theoretical talc, $Mg_2H_2Si_4O_{12}$, given by Dana.

III. Tremolite-schist [E. 10226], 413 yards south-west of Cae'r-sais (and 250 yards west-north-west of B.M. 32·6 on six-inch map), in a nook of a boss, close to gabbro. Anal. J. O. Hughes.

Tremolite-Limestone and Ophicalcite.—These peculiar crystalline limestones fall into two groups according to the nature of the dominant silicate. A beautiful gneissose marble [E. 10563], composed of granular carbonates, tremolite, and talc, with some iron-ores and chromite, forms part of the same band as the radial tremolite rock just described. It resembles the limestones of the Loch Maree Group in the Lewisian Gneiss, its radial tremolites recalling those of the beautiful rock of Glen Tulacha.[1] Most of the tremolite-limestones are light in tint, but some are dark grey, and are fine and rather hard. These consist of dolomite, penetrated by a few needles of tremolite, with some serpentine. The dark tint is due to octahedral magnetite and chromite.

From the tremolite-limestones there is a gradual transition to the ophicalcites. To convey a clear general picture of these rocks is not easy. They are composed of saccharoidal carbonate intergrown in various ways with clear green serpentine. The carbonate may be white or with a tinge of green from flecks of serpentine. Generally more or less schistose, they are often banded, but very frequent is a brecciated structure, fragments of serpentine being embedded in the crystalline carbonate, and rapid passages are common from one structure to another. The beautiful ophicalcite of the old marble quarry at the 'w' of 'Pwll-pillo' (Cerig-moelion lane of six-inch map) consists of snow-white granoblastic calcite with scales and films of serpentine, an abundance of tremolite needles, talcose scales, iron-ores, and a spinel, probably chromite. About Llanfwrog there are talc-marbles, composed of talc with varying proportions of a white carbonate, sometimes calcite, sometimes dolomite or perhaps magnesite, and some chromite and magnetite. The ophicalcites are therefore serpentine-limestones, generally containing tremolite and talc, and thus connected by gradations with the tremolite-limestones, which in their turn are specially calcareous parts of the tremolite-schists.

The following analyses will enable the types to be compared, but it must be understood that the proportion of silicates varies greatly in both groups. Mr. J. O. Hughes writes: 'The effect of using hot HCl (20 per cent.) was a decrease of 8 to 12 per cent. in the insoluble residues, and increases of some 2 per cent. of MgO and 4 per cent. of $Al_2O_3 + Fe_2O_3$ in the solution obtained, the percentage of CO_2 being unaffected. Nos. I and IV were decomposed by hot hydrochloric, Nos. II and III by acetic acid. No Mn was found in the solutions.'

[1] 'Geological Structure of the north-west Highlands' (*Mem. Geol. Surv.*), p. 235.

	I.	II.	III.	IV.
Insoluble residues ...	5·29	34·45	28·17	15·01
$Al_2O_3+Fe_2O_3$	6·50	0·43	0·13	4·27
CaO	32·68	26·85	38·95	27·55
MgO	14·49	7·52	0·49	14·83
CO_2	41·26	29·42	31·10	38·11
H_2O	—	1·15	1·11	—
	100·22	99·82	99·95	99·77
Percentage $CaCO_3$ ...	58·35	47·94	69·52	49·20
" $MgCO_3$ ...	30·27	15·71	—	31·14

I. Dark hard limestone [E. 10217], 630 yards east of Gareg-lwyd ; 233 yards south-south-east of Cerig-moelion (six-inch map). Anal. J. O. Hughes.

II. Tremolite-marble with radial structure [E. 10563], seven yards south-east of Gareg-lwyd new house. Anal. J. O. Hughes.

III. Ophicalcite [E. 10214], Quarry at the 'w' of 'Pwll-pillo,' by lane leading to Cerig-moelion (six-inch map). Anal. J. O. Hughes.

IV. Reddish limestone. A few yards west of the house at Tyddyn-dai, Amlwch. Anal. J. O. Hughes.

That these ophicalcites are metasomatic products of the serpentines is hardly to be doubted. One of them [E. 10388] shows the mesh-work structure of serpentinised olivine preserved in dolomite and picked out in hæmatite dust, so it is inferred that they are carbonate pseudomorphs after serpentinised peridotites. Moreover, the calcitisation can be dated. The rocks being essentially one with the tremolite- and talc-schists, it is evident that their calcium and magnesium are from the same source as the tremolite and talc, and that their carbonates are true minerals of anamorphism. Some of the ophicalcites are traversed by numerous veins of pale actinolite, so that the carbonate must belong to the anamorphic process, of which it is not even the last product. The low percentage of magnesium in the carbonate of No. II may be ascribed to the development of tremolite. The absence of that metal in No. III, which is the only pure calcium-ophicalcite known in the Island, is due partly to the same cause, but even more to de-dolomitisation at a late stage, during the formation of the veins of actinolite.

Chlorite-chromite-magnetite-schist.—At several places a peculiar basic rock appears, which is never more than a few feet, usually only a few inches, thick. Sometimes well foliated, sometimes rather massive, it is dark green, soft, and studded with black octahedra which attain a diameter of nearly a quarter of an inch. The green matrix is a felt of chlorite with some granules of epidote and iron-ore. The nature of the chlorite has been discussed by Prof. Bonney[1], and he writes me that he has now no doubt that the mineral is one of the chlorites. The large octahedra were ground out of his slide and so left undetermined. If, however, they be tested by an ordinary magnet, they rise briskly on edge, but do not leap to it as would

[1] *Geol. Mag.* 1890, pp. 539, 540.

magnetite. If a fragment from a single crystal be finely crushed, the dust is found to be partly opaque, partly translucent with the deep colour of chromite. It is therefore probable that the crystals are isomorphous intergrowths of magnetite and chromite. The following analysis was published by Prof. Bonney in his paper of 1881. It is, however, of the green matrix only, the octahedra having been removed. The rock must therefore be even more basic than this analysis, and must contain a high percentage of iron with a considerable amount of chromium. It does not correspond in composition to any other known rock in Anglesey, and is doubtless a secondary product.

SiO_2	28·56
Al_2O_3	39·54
Fe_2O_3	0·99
FeO	2·87
Cr_2O_3	traces
MnO...	traces
CaO	1·73
MgO...	15·79
Alkalies	0·70
Water	11·09
	101·27

Chlorite-chromite-magnetite-schist, adjoining talc-schist (pp. 104, 277). Quarry 250 yards north of Bronddel (south-west of Plâs-coch, six-inch map). Anal. F. T. S. Houghton.

Deformation and Metamorphism.

These intrusions have been considerably affected by the dynamical metamorphism of the Mona Complex. It is probably safe to say that the greater part of the serpentine is undeformed, but such a statement, unqualified, would convey a most misleading picture. For it is so riddled with planes of gliding that the lenticular cores of massive rock are seldom as much as a few yards in length, and usually a foot or a few inches only. Round them sweep schistose films, generally light yellow, slickensided, shiny, slippery, and unctuous to the touch. So strong is the tendency of the rock to part along these planes that hardly any others are presented on the faces of exposures, and it is often rather difficult to obtain specimens with good cross fracture. Sometimes the serpentine is thoroughly schistose for a width of 30 or 40 yards, though anamorphism is limited to the production of antigorite. It would seem as if the ease with which serpentine gives way along planes of molar movement is a substitute for the molecular movement that results in a truly anamorphic schist ; and it thus appears that the serpentinisation of the peridotite preceded its deformation.

In the gabbro, massive cores are far larger, often 80 yards or so in length, and from these its great steep-sided bosses have been shaped. Yet a rude parallel structure is often to be seen, and at a few places it passes into a perfect, fissile, gabbro-schist (Plate IX,

Fig. 4). Reconstruction is as general as it is exceptional in the serpentine. A pale hornblende is present even in the massive cores; and when visibly deformed, this has completely replaced the diallage, streams of it winding along the planes of movement. The fissile schist is composed of epidote and fine actinolite. Both the serpentine-schist and the gabbro-schist reach, where most fissile, a further stage, and are minutely puckered.

The associated metamorphic rocks are all true crystalline schists, and in the tremolite-schists and tremolite-marble anamorphism has been carried very far. In the ophicalcites, the relations of the silicates to the carbonate-mosaic are those which are usual in the crystalline limestones of regional metamorphism. What local conditions determined the production of such rocks, instead of merely schistose serpentine, from the peridotites, is not yet known.

Speaking generally, there can be no doubt that these intrusions, and their products, have been far more than merely deformed; they have been affected in a considerable degree by the anamorphism that has produced the foliation of the Mona Complex.

Marginal Rocks.

Andalusite-mica-hornfels.—A wide halo of induration that surrounds the dolerites of the north is described on pp. 320—1. Its more crystalline parts are chiefly composed of 'criss-cross' white and brown mica, in which are porphyroblastic pseudomorphs, now chiefly composed of white mica, but sometimes idiomorphic, zonal, and with outlines as of andalusite.

Epidote-hornfels and Epidosite.—Skirting the margins of the intrusions of the Strait of Holy Isle are interrupted borders of peculiar altered rocks. Though possessing certain characters in common, such as the general presence of epidote and absence of a fissile structure, they fall into two natural groups.

Those here termed 'hornfels' are compact, with a conchoidal fracture. In colour they range from a grey green like that of the New Harbour Beds to a pistacio green due to disseminated epidote. They are composed of quartz (often crypto-crystalline), chlorite, epidote, a little pale hornblende, and albite. That they are of sedimentary origin there is no doubt. They have a fine even banding, and some of the quartz retains a clastic aspect. This bedding is folded sharply and the folds are cut by shear lines. Along the southern shore of Rhyd-bont Creek one of them is clearly seen to be a modification of the New Harbour Beds, and at the creek-head it is full of needles of actinolite that lie in all directions and penetrate all the structures. Those here called 'epidosite' are developed on a much greater scale. Along the southern margin of the large intrusion of Holy Isle, a zone of them a quarter of a mile wide extends for more than a mile. They are of medium grain, but rapidly variable, so as to weather lumpily and ruggedly. Weathered surfaces look well-foliated, but on fracture the fissility is found to be almost obliterated, and they are extremely tough under the hammer. In places they retain a grey-green tint like that of the Green-mica-schists, with granular and fissile bands as at Holyhead, the quartz being sometimes also 'rodded'; but these types pass rapidly into pistacio-tinted epidote-granulite in which all fissility has disappeared. The minerals of this are quartz, epidote, chlorite, and amphiboles, with some albite and carbonates. The epidote occurs both in granules, rods, and large glandular aggregates; it is partly colourless, but chiefly coloured and strongly pleochroic. The amphibole is for the most part very pale, and finely matted. The rudely lenticular seams of quartz, which contain albite and a little carbonate, are often yellow with rows of epidote granules, which occur also freely in the seams of chlorite. The quartz of some is full of slender hairs of amphibole. Many specimens [E. 9755, 9758] are penetrated by needles of green pleochroic actinolite (Plate IX, Fig. 6), with good idiomorphic cross-sections and prismatic cleavages, which attain a third of an inch in length. They pierce the quartz-albite folia, sometimes at right angles, and are not cut by any planes of movement.

In the heart of the zone the rocks are highly reconstructed; but on the craggy platform above the talc-schist north of Bronddel, and by the ruin 433 yards north-west of Bodior Lane, schist with the same epidote and amphibole, contain undoubted clastic quartz; and at the '36' level, bedded jaspers are found within the zone, with their quartz seams epidotised. These epidosites must therefore be regarded as a special state of alteration of the New Harbour Beds, whose pyroclastic element probably accounts for the amphibole and epidote.

It must be admitted that the zone contains none of the minerals usually regarded as thermo-metamorphic. Yet epidosites resembling these have been found in a thermal aureole at Old Lizard Head,[1] and the destruction or prevention of fissility as well as the mode of occurrence of the actinolite points to contact alteration. The epidosite zones undoubtedly behave as an aureole to the basic intrusions, and may with confidence be looked upon as their thermal product.

Chronology.—It is evident that when this thermal influence was exerted the foliation of the New Harbour Beds was imperfectly developed, though it had been initiated, and the same is the case with the epidote-hornfels, as well as with the andalusite-mica-hornfels of the north. We have seen that the serpentines and gabbros became in their turn deformed and foliated. Their intrusion must therefore have taken place during an interval, or intervals,[2] of the great movements of the Mona Complex.

[1] 'Geology of the Lizard and Meneage,' p. 36.
[2] This is confirmed (see pp. 208, 211, 321) by their field-relations.

THE PENMYNYDD ZONE OF METAMORPHISM.

The Penmynydd Schists, named after a village in the midst of their principal district, are to be regarded not as a stratigraphical but as a metamorphic horizon. Several, possibly all of them, indeed, can be identified elsewhere in a less altered state. But whatever their origin, the rocks of the zone, in the condition in which they are found in it, are marked and important metamorphic types, and as such they will be considered in this section. All of them are holocrystalline schists, and next to the Gneisses are the most highly reconstructed rocks in the Island. They are :

Mica-schists	Rutiliferous-schists
Quartz-schists	Hornblende-schists
Limestones	Glaucophane-schists
Graphite-schists	Banded Marginal Rocks

The Mica-Schists.

The Mica-schists are by far the most extensive, being, indeed, a foliated 'country' in which lenticular masses of all the others float. Two leading types may be recognised : a flaggy or evenly foliated, and a flaser or lenticularly foliated. Intermediate types connect them, and there are sub-types of each too numerous for description here.

The flaggy type tends to be rather fine, its mica, though well and sharply formed, being usually small, though there are exceptions to this. On the whole, its aspect recalls the rocks that are found immediately above the mylonites of the Moine thrust-plane in Scotland. The essential minerals are quartz, felspar, white and brown mica, and iron-ores, accessories being unimportant. The brown mica is often chloritised, but when fresh has a moderate pleochroism. The felspar is an alkali variety, usually untwinned, but where determined is a sodium species. The flaser or lenticular type, which is more extensively developed than the flaggy, is more highly crystalline and with a greater variety of minerals. Instead of being even, it is wavy on the foliation-planes, an appearance due to its being built up of overlapping lenticular seams, one-eighth to a quarter of an inch in thickness, of saccharoid granular matter, about which bend the fissile folia. The rock is very clean and fresh, and the foliation-surfaces brilliant, with a tinge of pale sea-green upon them. The flaser structure is further emphasised by conspicuous augen and twisted lenticular sheets of white venous quartz (Plate XI).

The essential minerals are quartz, felspar and white mica. Epidote often rises to the rank of an essential. An abundance of accessories is a feature of the type. They are epidote, zoisite, garnet, sphene, zircon, apatite, rutile, hæmatite, biotite, chlorite, and opaque iron-ores. The felspar is albite, with an occasional grain of microcline, and this being the case, it results from the

[Face page 110.

Folded Penmynydd Mica-schist with quartz-augen. Graig-fawr, Holland Arms.

analyses (p. 112) that the white mica must be muscovite. The albite is generally clear (save for inclusions in the larger grains) and often untwinned. The muscovite is well formed, in flakes that may exceed one millimetre in diameter. The epidote is largely in yellow pleochroic prisms, with usually high but often variable bi-refringence, and some give the polarisation hues of zoisite. The garnets are usually small, and sometimes idiomorphic. Small flakes of blood-red hæmatite are a feature of the schists. Tourmaline is very rare. Some slides are so crowded with minute accessories of high refractive index that it is not easy to say what are the proportions among them of the several minerals. Delessite in radiating groups fills small fissures. The structure is granoblastic, with lepidoblastic seams. But some of the rocks (Plate X, Fig. 5) contain porphyroblastic felspars of irregularly oval outline, deeply embayed by the matrix, more than a millimetre in length. They are albite, or rather albite-oligoclase, for the mean refractive index is about 1·538, and they seem to be both positive and negative for ordinary light. Dr. H. H. Thomas (who examined a slide) suggests, accordingly, that 2V may be nearly 90°. They sometimes exhibit binary but very seldom lamellar twinning, some are irregularly compound, and there are a few similar porphyroblasts of microperthite. The albite porphyroblasts are almost always water-clear, and their central parts are apt to be poicilobastically crowded with long microliths, among which are epidote, zircon, rutile, sphene, iron-ores, occasionally zoisite, and rarely tourmaline. These inclusions lie for the most part with their longer axes parallel to the foliation of the rock, which thus appears to stream through the large albites; but almost as often lie obliquely, or even at right angles to it, while in a few cases the inclusion-streams are bent, as if the porphyroblasts had been turned round. Yet there is no sign of optical strain in these albites, and different inclusion-streams may even have different directions within the same crystal. Except that there is no approach to hypidiomorphism, the structures are identical in every detail with those of the albite-schists of the Scottish Highlands.[1]

Undulose extinction is rare in the Penmynydd Zone. The quartz of the white venous augen is in some cases coarsely granoblastic like ordinary vein-quartz, in others nemablastic, and then usually contains a few large plates of muscovite. Many of them have milky bands of minute cavities. No felspar has been found in these white ones. There are, however, augen composed of coarsely crystallised pink potassium-felspar with a varying proportion of quartz. The felspar was kindly determined, some years ago, by Dr. Teall, using Szabo's method.

Quartz is therefore found in these rocks in three conditions: (1) that of the granoblastic body, (2) that of certain finely granoblastic pinkish, twisted, augen, (3) that of the stout venous augen (Plate XI).

[1] Clough and Teall. 'Geology of Cowal' (*Mem. Geol. Surv.*), pp. 39, 299, plates vi, vii.

The following analyses have been made of typical Penmynydd mica-schists. One of a rhyolite has been added for comparison, and they will be discussed on pp. 122—7.

	I.	II.	III.	IV.	V.
SiO_2	70·35	—	67·42	73·48	73·51
TiO_2	not det.	—	not det.	0·29	—
Al_2O_3	15·16	—	17·51	14·79	14·42
Fe_2O_3	0·53	—	1·71	0·03	0·46
FeO	4·31	—	2·27	1·04	1·49
MnO	none	—	—	trace	trace
CaO	1·23	—	2·22	0·53	1·26
MgO	1·89	—	1·32	0·43	0·33
K_2O	2·27	2·63	2·53	4·24	4·29
Na_2O	2·98	2·51	3·76	4·40	4·03
H_2O (at 110°)	0·14	—	1·06	0·81	—
H_2O (above 110°) ...	1·06				0·04
SO_3	none	—	none	0·03	—
P_2O_5	none	—	none	0·02	0·04
	99·92	—	99·80	100·09	100·23

I. Well foliated muscovite-biotite-schist. Porth Nobla, south side [E. 9900]. Anal. J. O. Hughes.

II. Garnetiferous mica-schist. North-east end of Llyn Hendref, Gwalchmai [E. 9993]. Anal. J. O. Hughes.

III. Typical Penmynydd mica-schist. 300 yards north-north-east of Braint Farm, at 200-foot contour [E. 9912]. Anal. J. O. Hughes.

IV. Foliated quartz-albite-rock, with broken phenocrysts of microcline, and a little white mica, epidote, sphene and garnet. 100 yards east-south-east of Graig-fawr, Holland Arms, about two feet from north-west margin of boss (Fig. 10) [E. 8486]. Anal. P. Holland. *Quart. Journ. Geol. Soc.*, 1902, p. 666.

V. Rhyolitic obsidian. Medicine Lake. Anal. *U.S. Geol. Surv.*

Quartz-Schists.

These are white, foliated, glistening with mica, and saccharoid on cross-fracture. They are simple homœoblastic schists, composed of quartz, with a varying proportion, sometimes very small, of white mica. No felspar has been seen. Some of them have the aspect of quartzites, but show no clastic grains.

The Limestones.

The limestones are grey or cream-coloured in tint, some are mottled, some have thin dark seams. Most of them bear some resemblance to the grey Gwna limestones, but even the finest are slightly foliated, which is due to trains of tolerably well-formed flakes of mica, lying in a granoblastic base of carbonate, in which are a few small grains of quartz. The carbonate of the grey type is calcite, of the cream-coloured ones dolomite.

A series of slides taken across the limestone of Trecastell, which is a good deal more altered, show that it graduates through calc-mica-schist into mica-schist. A few limestones of the zone are far more highly crystalline, and may be described as gneissose marbles or cipolini. The Bodwrog marble, perhaps the most beautiful rock in the Island, is composed of snow-white granular calcite, with parallel flakes of well-formed white mica and some rounded grains of quartz. The marble of Erddreiniog is grey, and composed also of granular calcite, but with abundant accessories, including quartz, chlorite, iron-ores, white micas, albite and oligoclase, tourmaline, zircon, sphene, rutile, and anatase. Most of them are anhedral, but some of the anatase (identified by Dr. Thomas) has its characteristic form. These two rocks have been analysed, as follows :—

	I.	II.
Residues insol. in HCl	4·96	23·30
Al_2O_3 ... ... Fe_2O_3	2·01	6·66
CaO	50·14	37·32
MgO	0·15	0·69
CO_2	42·29	30·42
	99·55	98·39
Percentage $CaCO_3$ ...	89·54	66·64

I. 767 yards east of Bodwrog Church. Second band of limestone from west. [E. 10057]. Anal. J. O. Hughes.

II. Quarry by wall, south of wood, about half a mile north-north-east of Erddreiniog. [E. 10080—81, 11396]. Anal. J. O. Hughes.

In No. I. it would seem as if some silicate must have yielded a little to the acid, and its SiO_2 and Al_2O_3 have come down with other elements of the rock. Both rocks differ greatly from the cipolini of the Lewisian Gneiss of Scotland ('Geol. North-West Highlands.' *Mem. Geol. Survey*, p. 82), as well as from the ophicalcites of the Mona Complex. The absence of magnesium is remarkable.

Graphite-Schist.

Where the black schists occur within the Penmynydd Zone they are far more highly crystalline, being thoroughly lepidoblastic. Some varieties are lustrous, others dull and sooty on the foliation-surface, but all yield a black streak, one that adjoins the Bodwrog marble yielding a very strong black streak. A specimen from a little chasm in the cliff south of Porth Tre-castell, 200 yards south-west of the Telegraph Cable Hut [E. 10030] (Plate X, Fig. 6) was examined by Mr. J. O. Hughes, who separated the graphite by destroying the rock with hydric fluoride. It amounted to 0·65 per cent., but much richer ones are now known. The principal minerals are quartz in granoblastic seams (associated with which is a little sodium-felspar), and white mica partly in felted folia, partly in large plates. The graphite is both in dust and in foliated scales. Pyrite and leucoxene are plentiful, so that three opaque minerals are present. The residues left by the hydric fluoride contained many lustrous prisms of rutile, and tourmaline has been found in other specimens. Finally, there is a mica-like mineral with a good pleochroism ruddy-brown to dull olive-green or colourless : $X > Y, Z$, (apparently) ; and optically negative with a varying, sometimes considerable, sometimes very small axial angle. But the bi-refringence is rather low, not much exceeding ·01, while the refractive index considerably exceeds 1·6. It is referred, therefore, to one of the xanthophyllite-chloritoids. It is intergrown with white mica, and sometimes crowded with the rutile needles, as well as minute inclusions. The structure of the rock is highly complex. The graphite and most of the mica lie along the foliation; but the xanthophyllites are in large ragged-sided compound encarsioblasts and their basal cleavage is transverse to that foliation. Through them, however, the graphite seams run on without interruption, so that the encarsioblasts must have developed after the completion of the foliation, and in a solid rock. The little clots of the graphite seams are often frayed out somewhat along the basal cleavage of the xanthophyllite.

Rutiliferous Schists.

The graphite-schist is very rich in rutile; but still more is present in a dull green schist at Bwlch-y-fen [E. 10058], which is chiefly composed of biotite with a feeble brown pleochroism, but now largely chloritised, and some calcite seams with quartz. Iron-ores, pyrite, and apatite are fairly plentiful, and there is a little tourmaline and xanthophyllite. The rutile is chiefly in rather stout prisms that lie along the foliation, unlike the slender needles of the graphite-schist. Analysed in part by Mr. J. O. Hughes, it yielded: $SiO_2 = 42{\cdot}94$, $TiO_2 = 2{\cdot}54$.

The Hornblende-Schists.

The hornblende-schists are heavy, platy, dark-green rocks, often with pistacio-tinted epidotic seams. A few varieties are nearly black, a few quite pale in tint. Their essential minerals are hornblende, epidote, zoisite, albite, sometimes quartz, and occasionally pyrite. Sphene is often plentiful, and the other accessories are a white mica, magnetite, ilmenite, apatite, and occasionally zircon and rutile. The rocks may be fine, but are usually of medium grain, hardly lepidoblastic, but foliated granoblastic schists. The hornblende is in rather long blades, and pleochroic, thus: X, pale straw-colour, Y, brownish-green, Z, blue-green, that of the pale schists being: X, colourless, Y, nearly colourless, Z, pale blue-green. Most of the epidote is normal, some pale with low bi-refringence; but in some of the rocks typical zoisite with delicate blue polarisation-tints is quite abundant, often in long prisms. Granoblastic albite is often an important constituent; it is usually water-clear and untwinned, sometimes disseminated, sometimes in seams which contain also quartz and epidote. A few of the dark rocks contain 'feathery' porphyroblastic hornblende lying in all directions on the foliation-planes. It has the same optical characters as the rest of the hornblende, but is a good deal larger, and is idiomorphic, with the prism and pinacoid well-developed. Oval porphyroblasts of albite-oligoclase, poiciloblastically crowded with inclusions, are occasionally a character; they resemble those in the albite-mica-schists, but their inclusions are much smaller. Some of them are compound, and contain granoblastic quartz. A remarkable schist at Gwalchmai is rich in contemporaneous, granoblastic, pyrite, developed in thin 'schlieren' along the foliation, and therefore a true metamorphic mineral. This unusual rock is also rich in zoisite and rutile, and contains albite porphyroblasts, with some hexagonal hæmatite. The hornblende-schists of the Aethwy Region have many quartz-augen, like those in the mica-schists, some being venous, others nemablastic in texture.

Usually these rocks are well-foliated throughout, but about Holland Arms and Llangaffo there are cores with remains of igneous texture. The hornblende is larger and broader, with pleochroism : *X*, straw-colour ; *Y*, olive-green ; *Z*, blue-green ; their albite is in large broad laths with strong lamellar twinning, and their sphene (which is abundant) is eumorphic. Parallel structure is never absent, but is often very slight, and the rock is here an albite-diorite. The metamorphic process was long, for some of the quartz-augen are cut by old faults that were afterwards healed up by crystallisation ; and a few of the quartz-albite augen south-west of Bwlch-gwyn, though the main foliation bends round them, are themselves a little foliated.

The Glaucophane-Schist.

This remarkable rock is unique in Britain, for glaucophane has not yet been detected anywhere else in the British Isles. Even in Anglesey it is not known outside the Aethwy Region, in which there are 18 masses. It is a dense, heavy schist, very tough, and of a dark steel-blue, sometimes dark lazuli-blue, tint externally, thoroughly foliated, and decidedly but not excessively nemablastic. The body of the rock is very homogeneous, but this is varied by quartz-augen, thin quartzose and epidotic seams, and bright films of white mica tinged with scarlet scales of hæmatite, usually adhering to the quartzose augen. The foliation is rapidly folded, a structure well brought out by the weathering of the thin hard quartzose seams. The structures on the large scale are usually parallel, but knots of epidosite about six inches long are not uncommon, and on the crags that overlook Llyn Llwydiarth the normal schist winds about great phacoidal masses of similar but rather less foliated schist several yards in length. Near the same place are cores with surviving plutonic texture.

The essential minerals are glaucophane and epidote ; the accessories are white mica, quartz, albite, green hornblende, chlorite, zoisite, hæmatite and ilmenite, with a little sphene. Lawsonite has been searched for but not found. In one small quartz-knot at Castellior are a number of prisms of brown tourmaline. The aspect of the rock in thin section, which is now well known from the striking coloured plate (No. 47) in Dr. Teall's 'British Petrography,'[1] is of unusual beauty, nearly two-thirds of it being composed of a continuous foliated weft of clear blue glaucophane, in which float the epidote and all the other minerals.

[1] Photographic plates have been published in Mr. Adye's 'Atlas' and in Grubenmann's 'Kristallinen Schiefer,' Tafel viii.

This weft of glaucophane is composed of slender prisms elongated in the direction of the vertical axis. The basal planes have not been observed, but sections of the rock taken across the foliation show that large numbers of the crystals are idiomorphic in the prismatic zone, the faces (110) meeting at the characteristic angle of 124·2° to 124·4°, being often quite perfect, sometimes combined with (010), and that both prismatic cleavages may be well developed. The refringence and bi-refringence differ but little from those usually obtained. Distinct optical pictures in convergent light are not easy to obtain. The extinction angle is normal, being about 5° in the typical blue glaucophane, but in some crystals of a feebler tint it may rise to 15°. The pleochroism is pronounced, and is: X, very pale straw colour ; Y, lavender-violet ; Z, strong sky-blue. The moderate proportions of aluminium and of water that are present in the rock show that the mineral is not gastaldite, but a true anhydrous glaucophane.

The epidote is partly in granular aggregates, but largely in idiomorphic prisms elongated in the direction of the orthodiagonal, and a good many show the cleavage. It has a high bi-refringence, and is rather strongly coloured, with the characteristic lemon pleochroism. Epidotes of low bi-refringence are less common than in the other basic rocks of the Complex ; but there are a few prisms of true zoisite with blue polarisation-tints. Much of the clear green component that is present is chlorite ; but there is also a green hornblende, which is intimately related to the glaucophane, sometimes eumorphically as a core within it, and graduating into it through a narrow blue-green zone, the angle of extinction sinking as the colour changes from green to blue.

These green minerals are apt to be developed on either side of epidote-aggregates in the direction of the foliation, so as to form with the epidote small compound augen. The thin granoblastic lenticular seams of colourless minerals are largely quartz ; but contain a little water-clear felspar. This has a much lower refractive index in all cases than the quartz, and in some cases undoubtedly lower than 1·536 : it is optically positive ; and sometimes displays lamellar twinning with extinction angles of about 8°. It is therefore albite. Bordering the siliceous seams are often trains of well-formed plates of clear scarlet hæmatite, and there are small schlieren of ilmenite, sometimes passing into hæmatite along their edges. The granules of sphene are very small, and rather rare, and may have been developed from the ilmenite.

In many slides hardly any white mica can be seen, but there is a good deal in the rock as a whole, concentrated, however, into the films alluded to. It is in well-developed plates, often as much as a millimetre in diameter, many of which display a perfect optical picture in convergent light, with an acute bisectrix emerging nearly at right angles to the cleavage, and always optically negative. Some of the plates, however, have undergone much optical distortion, producing undulose extinction and disturbance of the optic axes. When free from this, the axial angle is a wide one. The refractive index and bi-refringence are indistinguishable from those of muscovite. Some flakes of this mica were detached, freed from other minerals, and destroyed by hydric fluoride. The solution was examined spectroscopically, and Mr. J. O. Hughes reports that it displayed the spectrum of sodium strongly, without any trace of the spectrum of potassium. This mica, therefore, is paragonite.

The large epidosite knots consist of granoblastic epidote with short needles of glaucophane, and are quite unfoliated. The quartz-augen are of the same types as those in the green hornblende-schists. Thin quartz veins cut the foliation at right angles, but contain a little glaucophane and are themselves foliated, so that they must belong to an interval in the metamorphism. There are also lenticular bands of granoblastic quartz, with epidote, in which are plates of paragonite and many needles of glaucophane ; and these, though seldom exceeding an inch in thickness, may be allied to some of the siliceous glaucophane-schists analysed by Washington.

The rocks of plutonic aspect occur as phacoids a few yards in length, floating in ordinary glaucophane-schist, compared with which they are rather coarse. They are composed of lenticular tracts of glaucophane (in which is a little green hornblende) inosculating with similar tracts of granoblastic epidote, zoisite, quartz, and albite, with aggregates of sphene. Some of the glaucophane is in broad plates, which may lie in any direction. The rock is a modified and foliated glaucophane-diorite.

The true glaucophane-schist is a rock *sui generis*, and is found in large tracts of its own. But some of the green hornblende-albite schists contain small quantities of a blue-green amphibole with low extinction angles, as well as of real glaucophane, so that intermediate types of rocks certainly exist.

The following analyses will enable this glaucophane-schist to be compared with the hornblende schist and with standards.

	I.	II.	III.	IV.
SiO_2	45·87	47·47	47·859	57·67
TiO_2	not det.	not det.	1·376	—
Al_2O_3	18·80	15·25	15·614	11·07
Fe_2O_3	5·72	8·22	4·921	3·20
FeO	5·44	7·19	7·050	9·68
MnO	trace	trace	0·077	0·06
CaO	11·64	11·32	9·113	0·95
MgO	6·76	5·96	6·328	9·85
K_2O	1·99	0·56	0·822	0·42
Na_2O	2·61	2·11	3·210	6·80
H_2O (at 110°)	0·05	0·04	0·161	0·12
H_2O (above 110°)	1·35	2·13	2·789	0·36
P_2O_5	not det.	—	0·037	—
CO_2	not det.	—	0·696	—
	100·23	100·25	100·053	100·18
Spec. Grav.	2·21	3·77	—	—

I. Hornblende-epidote-albite-schist [E. 9914]. 400 yards west of Sarnfraint Bridge. Anal. J. O. Hughes.

II. Glaucophane-epidote-schist [E. 9829]. Quarry 250 yards east-south-east of Column near Tubular Bridge. Anal. H. S. Washington. *Amer. Journ. Sci.* (1901.)

III. Average of nine basic glaucophane-schists given by Washington. *Op. cit.*, Nos. I—VI, VIII—X.

IV. Glaucophane of Syra. Anal. H. S. Washington. *Op. cit.*

The specific gravity of II is rather above a mean of the specific gravities of glaucophane and epidote. That of I is much lower than a mean of those of green hornblende, epidote, and albite; low even if we suppose a considerable excess of albite, which is visible in some slides. It will be seen that I contains much more potassium and less iron than II. Comparing II and III, the glaucophane-schist of Anglesey is seen to be a tolerably typical example of its class, but rich in ferric iron and in calcium, poor in both alkalies and presumably in titanium, as that was not estimated. In view of the proportions of its alkalies, it is of interest to note, that its amphibole, its felspar, and its mica, being glaucophane, albite, and paragonite, are all sodium species.

Origin of the Glaucophane-schist.

It is usually assumed that glaucophane-rocks, that of Anglesey included, are derived from gabbros or other basic intrusions. In the spring of 1903, however, the present writer, having found that the basic schists of the Gwna Beds (see pp. 76–8) are derived from the spilitic lavas, that amphiboles develop in those schists as they approach the Penmynydd Zone of metamorphism, and that in several places they contain a little glaucophane; began to seek for evidence on the possible derivation of the glaucophane-schist from the lavas. At that time the lavas had not been analysed, but the question at once arose as to what had become of their jaspers in the process. In the course of the summer it was found that the jaspers became bleached at a moderate stage of metamorphism (see p. 88), and the suggestion occurred that the quartz-augen of the glaucophane- and hornblende-schists might represent them. Quartz-augen, it is true, occur also in the mica-schists, but it was found that a skin of hæmatite usually surrounded those in the basic schists, which might represent the discharged iron of the jasper. When the lavas were analysed, it appeared at once that a common origin was possible. In 1911, Dr. Teall, quite independently and without knowing of any of this evidence, suggested, in a letter to the present writer, that glaucophane-schists might be derived from pillow-lavas, asking if there was any field evidence for such a connexion; and in 1912, Mr. J. O. Hughes, independently of both, suggested the connexion on the ground of the analyses alone[1]. If

[1] Since writing the above, I have obtained a copy of a paper by Rosenbusch "Zur Deutung der Glaukophangesteine" (Ak. Wiss. Berlin, 1898), in which he gives a study of some glauc-amphibole rocks from California regarded by Palache as altered tuffs. He considers them to have been "diabase- or spilite-tuffs," and regards their fragments as diabase- or spilite-lapilli, but speaks with reserve, the nature of the fragments being difficult to determine. It will be remembered that spilitic lavas had not at that time been very closely studied.

the analyses on p. 74 be compared with those on p. 118, it will be seen that the rocks are closely allied in composition, especially in the relations of their alkalies. The difference is chiefly in the ferric iron, a difficulty that may perhaps be surmounted by supposing that the original of the glaucophane-schist had become hæmatised at an early stage of its history, a change that is known (see pp. 73–4) to have affected the Gwna spilites very widely.

Garth Ferry.—Now, in the basic mass that ranges south-westward from Garth Ferry, a rather dull glaucophane-epidote-schist [E. 9526] is quarried in the steep wood above the road. Its glaucophane is pale, but has the usual characters. Followed across the streamlet to the south-west, glaucophane diminishes, the rock becomes duller, and at the end of the crag in the wood (called Coed Berclas on the six-inch map) has become a chlorite-epidote-albite-schist [E. 11088] with traces of igneous texture, which differs in no way from those that are known to be derived from the spilitic lavas and albite-diabases. There can be no doubt of its continuity with the glaucophane-schist, for though exposure is not absolutely continuous, the crag feature is, and the basic rock is accompanied all along by a thin band of peculiar greenish mica-schist which can be distinguished from the rest of the Gwna Green-schist.

Yr-allt.—The basic band that ranges along the road at Pedair-groeslon and Yr-allt is, as far south as Yr-allt, a green chlorite-epidote-schist rich in ternary albite (p. 367), but at its southern end a good blue glaucophane-schist appears. The two types are not seen in continuity, though they lie on the same line of strike. A little to the north-east of Yr-allt, however, the green chlorite-epidote-albite-schist contains [E. 6092] a number of crystals of almost idiomorphic glaucophane. The prism-cleavages are unusually well developed, and the pleochroism is pronounced and perfectly characteristic. The band lies in a zone of progressive anamorphism, on its eastern side being Gwna mélange with lenticular grits, on its west Gwna Green-schist with larger micas than usual, but with typical nemablastic pencilling; 50 to 150 yards beyond which the Penmynydd mica-schist comes on. The continuity, therefore, of the two basic types need not be doubted. We have in the rock E. 6092 an evident passage-type, in which glaucophane is beginning to develop, albite and chlorite nevertheless remaining in large quantity. The size and idiomorphism of the glaucophane, however, are an unexpected feature in such a type.

Llaniestyn.—At the farm by Llaniestyn Church is a dull chlorite-epidote-schist [E. 9691] with fine pale amphiboles, in which are large deformed phenocrysts of albite and oligoclase that still retain lamellar twinning, and evidently once a lava. In the same large basic mass, south-east of Ty-du, a fine glaucophane-schist strikes towards this lava.

Llandysilio.—A little glaucophane is also found in the chlorite-epidote-albite-schist [E. 10208 and analysis] in the Gwna Beds on the shore east-south-east of Llandysilio Church islet, which lies in the same anamorphic zone as the rock of Yr-allt.

Inferences.—There can be little doubt, therefore, that these four imperfect glaucophane-schists are modifications of the spilitic lavas of the Gwna Beds. Were no other evidence forthcoming, there would be no hesitation in identifying the perfect ones of the Penmynydd Zone with the same lavas, though it would be unwise to lay stress on an identification of their quartz-augen with the Gwna jaspers. Their occasional phacoidal structure, and especially their large knots of epidosite, are certainly reminiscent of the ellipsoids of the lavas. No quartzite or limestone has been found with them, so the original rock is probably not the Llanddwyn spilite, but may be the Engan spilite (pp. 76–8), with which no quartzite or limestone are associated. The cores of glaucophane-diorite and zoisite-amphibolite might easily have been derived from the small associated sills of albite-diabase.

On the other hand, we have seen that the glaucophane-schist is linked by intermediate mineralogical types to the green hornblende-schists, and that some at any rate of those must be intrusive, as they have cores with good plutonic texture. From the presence of cores of green hornblende in some crystals of glaucophane, it has been inferred that the blue has been produced from the green amphibole. But the glaucophane of Garth Ferry has developed in a rock that must have been pyroxenic without any development of green amphibole as an intermediary. Whichever the origin of the typical glaucophane-schist, it must have been produced either from a hornblende-albite or an augite-albite rock ; most of the elements of the albite going to the production of epidote, the sodium being transferred to the ferromagnesian mineral so as to produce glaucophane, and a little albite remaining over in a reconstituted form.

Dr. Teall points out to me that the higher density of glaucophane-schist implies that it was pressure that determined whether the sodium should enter into albite or into glaucophane. Now, in the Penmynydd Zone the hornblende-albite-schist and glaucophane-schist occur side by side, and there is not the slightest evidence of any greater pressure in or around the latter. Under dynamo-metamorphism, the outer portions of a deep-seated albite-diorite containing 1·99 per cent. of K_2O would tend to produce a green hornblende-schist with some reconstituted albite ; while a spilitic lava, having consolidated originally under low pressures, would, when passing into an amphibolitic schist of some kind (as it could not fail to do), tend to transfer its sodium to the high-pressure mineral, and give rise to a glaucophane-schist. The uniformly fine texture of the glaucophane-schist over large areas also points to a fine rock as its origin, for basic intrusions of such size could hardly fail to show coarser centres, whereas the glaucophane-diorites referred to are known only in one place and are quite small.

It therefore seems probable that much of the glaucophane-schist has been produced from the spilitic lavas themselves ; but it must also be admitted that parts of it may represent the intrusive portions (not very deep-seated) of the same magma, which had consolidated at still lower levels as coarse albite-diorite, now partly transformed into albite-epidote-hornblende-schist.

Banded Marginal Rocks.

Along the margins both of the hornblende- and the glaucophane-schist the mica-schist often assumes an unusually compact and flaggy structure. This material, which contains very little mica (sometimes none at all), is rich in albite, usually also in epidote, sometimes in zoisite as well. It is a typical homœoblastic quartz-albite-epidote rock. About Holland Arms and elsewhere long narrow lenticular strips of it occur as inclusions in the hornblende-schists. They lie along the foliation planes, and such foliation as they themselves possess is conformable to that. In many places, especially on Mynydd Llwydiarth, this material alternates rapidly with both the amphibolitic schists along the junctions, so that there is a zone of interfelting, sometimes forty yards in width. On the crags north-east of Tyn-y-mynydd (' west ') this is so pronounced as to give rise to what might be called strong banded gneisses, but that they have not the coarse granitoid texture that is usually implied by that term. In one crag of hornblende-schist nine feet wide, seven acid bands were counted, contrasting strongly with the dark ones. But both acid and basic bands may be so thin as to be little more than films. In these finely banded rocks the white seams are granoblastic albite and quartz with a few garnets, the dark seams chiefly straight prisms of hornblende with many of blue-polarising zoisite (some of which have cores of epidote), some iron-ores, and rutile. Often the junctions are perfectly sharp ; at other times there is a narrow zone of passage that is probably a reaction-rim between the acid and the basic matter.

Now, whatever the origin of the mica-schists, it is evident that this compact modification depends on the presence of the basic schists. We have seen that some of the latter contain coarse dioritic centres. There is therefore presumptive evidence that these were intrusive into the original material of the mica-schist, that the inclusions are xenoliths, and that the banding is due to rolling out of thin branching sheets at the margin of a basic sill. The richness in albite of the compact acid rock, and its texture, are suggestive of its having been an adinole, a kind of material that is known to possess great powers of resistance, and thus to retain its compactness under dynamic metamorphism. That this material is found on the margin of the glaucophane-schist of Llyn Llwydiarth points to that particular mass having been intrusive, and it is the one in which the cores of glaucophane-diorite occur.

Origin of the Penmynydd Mica-schists.

Survivals of Original Textures.

Remains of original structures have been found at four places only; and as in three cases these are igneous, in one sedimentary, it is evident that the problem is not a simple one. The field relations also indicate that the rocks must have had a heterogeneous origin.

Holland Arms.—In the Aethwy Region, at a craggy knob 100 feet in width, about 100 yards east-south-east of Graig-fawr, Holland Arms (Fig. 10), close to the margin of the mica-schists, are some 30 yards of a compact, fresh, grey, light-weathering rock with a conchoidal fracture. Most of it has a foliation (across which, however, it breaks quite readily), and it passes on the south-east into normal mica-schist. North-westwards this foliation rapidly diminishes, and, just at the margin of the knob, disappears altogether. At this point the rock [E. 8485] (a slide cut by Dr. Callaway) is a granular aggregate of alkali-felspars and quartz, with a little epidote and sphene, the felspar being albite, with (apparently) some oligoclase, orthoclase not having been identified, though certainly present.

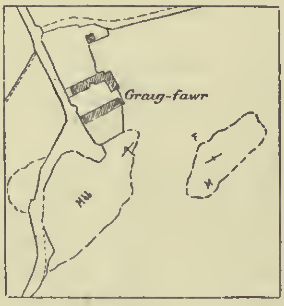


Fig. 10.
The Felsitic Survival.
Scale—1 : 5.000.
F=Felsite. M=Mica-schist.
Mhb=Hornblende-schist.

This rock [E. 8485] is essentially a felsite. But it is not unmodified, for the mosaic is granoblastic rather than felsitic, and some larger albites, which appear to have been phenocrysts, have lost their idiomorphic outlines. From this point, for 35 feet to the south-east, the surface of the knob is clear and bare, and Dr. Callaway had sliced a series of eight more specimens [E. 8486—93] taken from it at short intervals. Of the first of these [E. 8486], taken at a point two feet from E. 8485,[1] he had an analysis made (p. 112). Dr. Teall, when visiting the spot with the present writer in 1911, also took a series of four slides [E. 9170—73] at intervals across the knob. The combined series demonstrate a steady passage from unfoliated felsite into mica-schist. The body of the rocks is composed of granoblastic albite and quartz, with many minute grains of epidote, sphene, and garnet, foliation being imparted by an increasing proportion of white mica, a little brown mica developing as well. The quartz and albite show signs of strain and fracture. In the midst of this ground mass lie lenticular coarse-grained aggregates of microcline, also showing signs of strain, which probably represent broken-down phenocrysts of a

[1] The specimen from which E. 8485 itself was cut had unfortunately been lost some time before when sent for analysis.

potassium-felspar. That these are absent from E. 8485 is probably a mere accident of slicing.[1] The felspar of small pegmatitic knots which begin to develop is also microcline. Now potassium-felspars have not been observed in the normal, micaceous Penmynydd schist; and it is noteworthy that even in this knob microcline decreases as muscovite increases. Comparing the analysis of E. 8486 with that of a typical rhyolite, it becomes evident that it, and consequently the mica-schist of at any rate the immediate vicinity, must be derived from an albite-felsite in which were phenocrysts of orthoclase or microcline, and that the muscovite of the schist is derived from the latter, while the albite survives the reconstruction.

Gaerwen.—This conclusion is confirmed by finding that a compact, unfoliated, rock, near Gaerwen Junction [E. 9480], whose matrix closely resembles E. 8485, contains, as well as microclines, rudely rhombic pseudomorphs about two millimetres in length. They are now composed of granoblastic albite and quartz, and may be regarded as albitised and silicified phenocrysts of orthoclase.

Ynysoedd Duon (1).—The other cases are on the coast of the Middle Region at Ynysoedd Duon. Some 200 yards to the south of the southern islet, on the north cliffs of a chasm, are massive cream-coloured bands composed of a crypto-crystalline mosaic full of broken phenocrysts of albite, quartz, and micro-perthite. The rock, though crushed, is not much reconstructed, and is undoubtedly a sodium-felsite [E. 9184]. It therefore appears that felsitic igneous rocks enter into the composition of the mica-schists in the Middle as well as in the Aethwy Region.

There is no direct evidence as to whether this felsitic material be intrusive or effusive. The included acid strips in the hornblende-schists might be (and have been) regarded as intrusive veins. But they have no transgressive junctions, and there is nothing to prevent their being regarded as xenoliths, as suggested on p. 121. And, as no cores with plutonic texture have been discovered in the felsitic mica-schist, whereas cores of the kind survive within the basic schists, it would appear probable that the latter are intrusive in the former, the intrusions being anterior to the dynamic metamorphism.

Ynysoedd Duon (2).—About 100 yards to the south of the southern islet of Ynysoedd Duon, a flaggy mica-schist appears on the low cliffs, upon whose weathered faces are little grains of clastic quartz, and in thin section [E. 11086] it proves to be a blasto-psammitic schist crowded with fragments of albite and quartz now partially incorporated like those in the Green-Mica-schists of the New Harbour Group, and in about the same stage of metamorphism. But it is very rich in albite, and may be in part of pyroclastic origin. Sedimentary matter was therefore present among the original materials of these rocks.

[1] The rocks recall externally and microscopically the halleflintas of Üto, Sweden; but in those rocks the mosaic is coarser and rounder in grain, with more brown mica, while their phenocrysts are almost wholly quartz.

Marginal Phenomena.

Let us now consider the field relations of the zone. Its mica-schists adjoin the Gwna Beds along many miles of boundary, not only of the main masses but of outliers and inliers ; and except where basic rocks come against the line, the Gwna material is invariably the Gwna Green-schist, which has been shown (pp. 67—9) to be sedimentary in origin. We have already seen that clastic structures disappear as we pass from the Gwna Grits to the Gwna Green-schist. If, further, from a tract of Gwna Green-schist we pass into a tract of the Penmynydd Zone, we find, first, that there is perfect conformity between the foliation planes ; next, that the character of the schistosity remains the same, except that nemablastic texture disappears ; and thirdly, that there is a rapid rise in metamorphism. As the margin is approached, chlorite begins to disappear, green (and sometimes brown) mica to develop ; white mica to increase in quantity and very greatly in size and individualisation of the flakes ; epidote, zoisite, apatite, sphene, and garnet appearing when the junction line is reached. Small porphyroblastic albites develop locally, and the texture of the body rises from crypto- to granoblastic. When basic schists are present, green and blue amphiboles take the place of chlorite. That the change is not catamorphic but anamorphic is shown by the characters of the minerals along the junction. The crystals of the Penmynydd Zone are not cataclastically broken down. The bladed amphiboles of the basic schists, for example, are not crushed as we follow them back towards the Gwna tracts, they diminish in size, and in the zone of passage are slender, but perfect, actinolitic needles. These changes can be observed anywhere along the boundaries. But there is perfect exposure of the junction itself at five places at least, and in each case there is an uninterrupted passage.

Aberffraw.—One of these is on the Aberffraw coast, where the main boundary runs out to sea 833 yards south by east from the island church, and has been examined by Dr. Horne and Mr. Clough, with the writer. It is at a deep chasm, in which there is probably a fault, but the junction is not in this chasm, it is at the brow of its northern cliff. At one place there is a small crush, but it is insignificant, and passing obliquely into the cliff, leaves the passage visible on either side of it. Typical quartzose Gwna Green-schist passes into typical Penmynydd mica-schist, the structures on the large scale remaining unchanged. In the bay north-east of Braich Lwyd is an inlying strip of Penmynydd mica-schist, with limestone and graphite-schist. A little west of the cove at the nook of this bay a buttress runs out eastward from the cliff, and on it is another exposure of the junction, which is again a passage from Gwna schist with grit and jasper to siliceous mica-schist with small surviving clastic grains. Slices taken from close to the boundary show that the Gwna schist is unusually micaceous, the Penmynydd schist less so than usual, but still perceptibly better crystallised than the other.

Mynydd Llwydiarth.—The third and best exposure is in Mynydd Llwydiarth. North-east of the 'h' is a cottage, called on the six-inch maps (Fig. 11) Hafod Leucu, by which a footpath passes eastwards through a gap in crags. If we walk 130 yards east along this path, and then turn south for 50 yards, we find a crag facing east, on which is seen the junction. To its west is typical Penmynydd mica-schist with great sills of hornblende-schist. To its east is equally typical Gwna Green-schist, with innumerable lenticles of chlorite-epidote-schist. The Gwna schist has lost all clastic grains, but is very siliceous, full of nemablastic augen of quartz, and silky with sericitic mica. This type can be followed as far as the crag's foot (the fault that comes northward having passed eastward away from the boundary) where it is still the same, though its micas are becoming slightly larger. Then in a yard or two of bare crag, there is a rapid increase in their size, they become distinctly individualised, the nemablastic texture is replaced by granoblastic, the rock becomes saccharoid, and at the crag's brow is typical Penmynydd mica-schist. The section was visited by Dr. Teall with the writer in 1911.

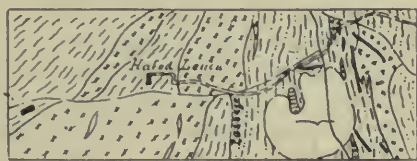


FIG. 11.
POSITION OF PASSAGE IN MYNYDD LLWYDIARTH.
From the six-inch maps.
Dashes and dots=Gwna Green-schist.
Dashes=Penmynydd Mica-schist.
Crosses=Basic rocks. Dykes also shown.

The Strait.—The fourth is on the Menai cliffs between Glyn-y-garth and Craig-y-don, where the Gwna Green-schist develops locally higher crystalline types than usual (pp. 360—1) and passes imperceptibly into mica-schist that if found in a tract of the Penmynydd schists would not be separated from them.

Llanddona.—A fifth is at Wern, Llanddona, where a large glaucophane-schist occurs among the Gwna Beds. Approaching this from the south, it is found that the Gwna rocks, there very siliceous, begin to develop larger micas, until close to the glaucophane-rock they might be treated as Penmynydd schists. There is no change either of structure or material, but only of crystalline condition. Along its margins, therefore, it is certain that the Penmynydd mica-schist has been derived from rocks of sedimentary origin.

An Horizon within the Zone.

Further, we have seen that in the Middle Region a quartz schist, a crystalline limestone, and a graphitic schist are found within the zone. Now these rocks do not occur in a merely sporadic manner; they are members of a tripartite group, of which, according to the accidents of thrusting and erosion (pp. 192—4, 343—4), one, two, or all three may be found together. But it will be remembered that a quartzite, a limestone, and a graphitic phyllite are found as a similar group within the Gwna Beds. There they graduate by change of composition into the adjacent phyllites, and here they likewise graduate into the mica-schist.

Chemical Composition and Inferences.

In both regions, therefore, it is certain that the Penmynydd mica-schists must be derived in part from felsitic igneous material, in part from the sedimentary material of the Gwna Beds.

When once, however, we leave the margins of undoubted felsite and undoubted sediment, and pass out into the country of highly anamorphic schist, no criterion has yet been found for separating, in the field, schist of the one origin from schist of the other. Yet, pending such discovery, some idea may be arrived at of the general nature of that country. Consider the analyses (p. 112). No. IV corresponds so closely with No. V. that there can be no doubt of its being a true rhyolitic rock, its alkalies being high even for a rhyolite. But in the others, while they approach the composition of a rhyolite, there is a marked falling off in alkalies, though these are still not much below the rhyolitic average. There is an increase both in calcium and magnesium, and a very serious increase in iron, especially in ferrous iron, the proportions of all three elements exceeding those characteristic of rhyolitic rocks. That these great tracts of schists were produced from uniform felsitic sheets is therefore impossible. Comparing the analyses with those on p. 70, it will be seen that in proportion as they depart from the composition of a felsite they approach that of the Gwna Green-schists. If, however, we exclude Nos. IV and V of the Gwna Group, which are exceptionally micaceous, we find that in the Penmynydd Zone there is a decided increase of potassium. Now the passages from Gwna Green-schist described above, although undoubtedly continuous, are curiously rapid, the change coming on in the course of a few yards, and the new type reaching its average degree of development within a quarter of a mile. That progressive metamorphism should produce this result without any concurrent change in the original material seems impossible, and accordingly we find an increase of white mica, which must mean an increase of potassium. Dynamo-metamorphism, indeed, could not have produced continuous passages between the products of sediment and those of solid felsite along miles of junction that must, in such case, have been originally well defined. Pyroclastic matter, however, may mingle with sediment in any proportion. If, therefore, we suppose the Penmynydd mica-schists to be composed of rhyolitic dust and tuff, with rhyolitic lavas on some horizons and bands of sediment on others, all the phenomena they present can be reconciled.

The occasional survivals of igneous and clastic structures might be expected in specially resistant beds. The analysis of column IV would be that of a pure flow of rhyolitic lava ; those of I and

II representing rhyolitic tuffs with admixtures of sediment. The compact quartz-albite-epidote rocks could be regarded as modified adinoles produced from fine ashy sediment in aureoles around and xenoliths in the basic intrusions. The zones of passage at the junction with the Gwna Green-schists find an explanation when regarded as zones of alternation where (as in the well-known ashy grits of Snowdon) felsitic tuff and ashy sediment were mingling, and (assuming the Penmynydd schists to be the older) explosions of rhyolitic dust were gradually ceasing to mingle with the sediments. A passage of this kind is, in fact, visible at the junction of the Fydlyn group (see p. 90) with the Gwna Beds of the north-west; and it is a rapid one. Such a zone of passage, when subjected to crystalline reconstruction, would show an abnormally rapid progressive metamorphism, for the alkaline volcanic rocks would recrystallise much more readily than would the sediments, and, if rich in potassium, would at once yield an abundance of muscovite, so that there would be a rapid passage from a dull sericitic schist into a lustrous mica-schist, which is the characteristic feature of the zone in question.

The Coedana Granite and the Zone.

Further evidence as to the origin, and also as to the age of the Penmynydd metamorphism is obtained along the edges of the Coedana granite. From Coedana to Gwalchmai the two rocks come together without any intervening zone of hornfels, two small granites lie along the junction of hornfels and mica-schist on either side of Ty-croes, and at Gwalchmai village one lies within the mica-schist. Now when the granite is exposed close to the Penmynydd Zone it is intensely sheared, and fine granoblastic matter like that of the mica-schist appears within it; while thin seams of granitoid matter are to be found within adjacent mica-schist that shows no sign of cataclastic deformation or thermal alteration. There are no transgressive junctions, and sometimes the granite fades off into mica-schist. It is certain, therefore, that the granite is involved in the Penmynydd metamorphism. To some extent it has been incorporated, but the evidence points to this being merely marginal, and that there has been no bodily transformation of granite into mica-schist. West of Bodwrog Church, not only is the transition too sudden, but the schist is a quartz-schist, far too siliceous to represent the granite, and the junction is evidently an old intrusive margin sheared and recrystallised. In a slide from Bodwrog Church [E. 8484] the junctions of a half-inch sill are still quite sharp on one side, though incorporation has begun in other parts of it. Finally, the outer margin of the hornfels, as may be seen on the coast near Porth Nobla (pp. 332, 342) assumes gradually the structures of the Penmynydd Zone. The Penmynydd metamorphism is therefore subsequent to the intrusion and consolidation of the Coedana granite.

Conclusions.

From the foregoing evidence it is clear that the Penmynydd rocks are a metamorphic, not a stratigraphic zone ; and that the original rocks involved are partly sedimentary, partly volcanic, the latter being both effusive and pyroclastic ; partly also, though to a small extent only, plutonic. The great body of alkaline mica-schist must be derived from felsitic lavas and tuffs, and there is good reason to suppose that these belong to the Fydlyn Group. The sedimentary material is undoubtedly that of the Gwna Group, and includes its alternating grits and phyllites, as well as its quartzite, limestone, carbonaceous-phyllite division. The basic schists are derived, there can be little doubt, from the Gwna spilitic suite, whose effusive and intrusive members seem both to be represented. The Coedana granite is also involved, but only to a small extent, along the margins. All these rocks are converted into holocrystalline schists of different kinds, the glaucophane-schist being a special feature of the zone. The metamorphism is later than the intrusion and consolidation of the Coedana granite.

THE GNEISSES.

These are coarse, granitoid in texture, and more deep-seated and plutonic in aspect than the other foliated rocks of the Complex. The term as here used includes basic rocks which will be called hornblende-gneiss, and biotite-gneiss or gneiss proper, which will be termed briefly 'the Gneiss.'

Hornblende-Gneiss.

This term will be used in precisely the same sense as it is on p. 42 of the Memoir on the North-West Highlands of Scotland ; that is to say, it will include not only well-banded rocks and rudely-banded rocks, but also what might be called foliated, and even unfoliated, diorite. As it is, however, doubtful whether the original material had the chemical composition of a diorite, that word will be employed for local description, only, and not for the formation as a whole. Nearly all are dark, heavy, rocks, the banded gneisses having a totally different aspect from that of the hornblende-schists of the Penmynydd Zone. Four principal types may be recognised : a coarse, dark, massive rock of dioritic aspect (Plate XII, Fig. 4) sometimes unfoliated, but usually with a rude foliation ; secondly, a rock of similar texture, but of much lighter tint ; thirdly, a dark, granoblastic gneiss, usually well, but sometimes rudely banded, and of medium grain (Plate XII, Fig. 1) ; and fourthly, a similar gneiss, but finer, harder, and lighter in tint. The third is perhaps the most widespread, though the first must nearly equal it : the second and fourth are not so plentiful. But this classification is merely of leading types; innumerable gradations exist, so that neither words, drawings, nor photographs can convey any adequate picture of the constantly varying character of the gneiss. For example, on a boss 230 yards east-south-east of Pen-yr-orsedd, five types were noted in only a yard or two, from coarse light material, through normal gneiss of the third type, into a hornblende-rock almost black, all interdigitating along a rude foliation-banding. In this variety of composition the hornblende-gneisses of the Mona Complex recall the amphibolitic members of the Lewisian Gneiss of Scotland, to which they are closely related in other characters, to be described below.

The minerals identified are hornblende, felspar, biotite, quartz, epidote, zoisite, sphene, ilmenite, magnetite, pyroxene, apatite, zircon, rutile, garnet, pyrite, orthite, chlorite, leucoxene, and natrolite.

The only essential minerals that are always present are hornblende and felspar. But biotite, quartz, epidote, and even sphene, rise in one variety or another to the rank of essentials. Thus, we have hornblende-felspar rocks, hornblende-felspar-quartz rocks, hornblende-felspar-quartz-biotite rocks, hornblende-felspar-sphene rocks, and hornblende-felspar-epidote rocks.

All the felspar that yields definite optical reactions is albite. Much, however, is turbid, and oligoclase is probably present, for some crystals with ill-preserved lamellation appear to extinguish at very low angles; but albite is undoubtedly the dominant felspar. It is partly twinned, partly simple, and in all the types occurs in the isodiametric interlocking grains characteristic of plutonic products.

Different varieties of hornblende are found to characterise different types of rock, with pleochroism:

> X, Pale straw-colour; Y, pale brownish-green; Z, bluish-green.
> X, Straw-colour; Y, brownish-green; Z, deep-green.
> X, Colourless; Y, pale brownish-green; Z, pale-green.

The first variety is usual in the rocks of dioritic aspect; the second in the dark bands that make up the bulk of the banded gneiss: the third (which has the unusual absorption Y slightly $> Z > X$) in the lighter bands with biotite and quartz. All these hornblendes have a broad, short habit, never bladed or acicular, and though usually a little longer in the direction of the vertical axis, may have their greatest dimension transverse to the prism. They are never eumorphic, but a slight tendency to development of the prism faces may be noticed, and the cleavages are strong. There is no reason to doubt the original nature of all these hornblendes, but slender needles of secondary actinolite are found in albite near Holland Arms. The biotite has been brown, but is often much chloritised, the pleochroism, where it survives, being pronounced but moderate.

The quartz occurs as rounded grains included in the albite and hornblende, or as a mosaic with the albite.

Epidotes are very abundant in some of the rocks. In the Middle Region they are clear pistazite with the usual pleochroism, and some of them may be original, that is, products of the metamorphism, but others that are found in veins must be later, though probably not much later. A few dark-brown grains that appear to be biaxial are probably orthite. In the Holland Arms district an epidote that is dusky with minute inclusions is an important constituent. Its crystals are often elongated, sometimes along the orthodiagonal, but sometimes along the traces of the principal cleavage, which is presumably basal, and are scarcely pleochroic. Nearly all of them have a high bi-refringence, but sometimes they vary towards zoisite. Some of the large albites of this area are crowded with sheaves of slender prismatic epidote and of true zoisite disposed often with great regularity. This must be regarded as a stage of saussuritisation, but spaces of clear albite remain which retain their optical integrity. It is in these felspars that the needles of actinolite are found. In others the albite has been wholly replaced by granular zoisite. The large dusky epidotes are often found in contact with the sheaves of slender epidote after albite, but the boundaries are sharp. Most of the Holland Arms and Gaerwen slides are old and thick, but these rocks offer interesting studies in saussuritisation.

Sphene is remarkably abundant as an accessory, and as above stated, is sometimes an essential. It also attains unusual dimensions, one or two crystals being as much as 2·5 millimetres in length (Plate XII, Fig. 2). Usually it is in irregular grains, but these large crystals, though anhedral, are elongated precisely in the direction of the prismatic cleavage, which is strongly developed. They are deeply embayed by the hornblende and albite, and contain inclusions of leucoxene. The smaller sphenes may be colourless, but these large ones are brown, with the usual pleochroism.

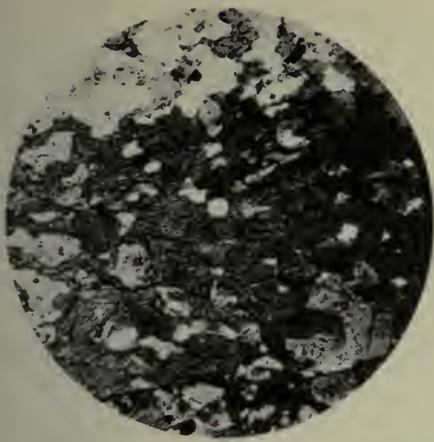
Ilmenite, often leucoxenised, appears to be more plentiful than magnetite.

A pale-green pyroxene is occasionally found in the Middle Region, but in small quantity. It is anhedral, does not form cores to the hornblende, and both minerals appear to be independent and original. It is of interest to note that it is found in the well-banded gneissoid facies.

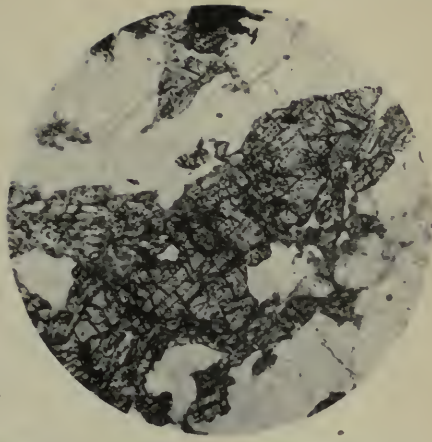
Apatite, in short hexagonal prisms, is remarkably abundant. The remaining accessories are never plentiful, garnet being rare.

Pegmatite, and Textures.

Pegmatite (Plate XIII) (using the term in the wide sense in which it is used in the Memoir on the North-west Highlands of Scotland, for graphic structures have not been observed) is, in the form of veins, lenticular knots, and thin seams, a most important constituent of the hornblende-gneisses, and is intimately bound up with their history. All its felspars, however, are sodium-felspars. Out of 14 pegmatites that were examined the felspar of nine was albite, of four, albite-oligoclase, and of one, oligoclase. They are therefore essentially sodium- or



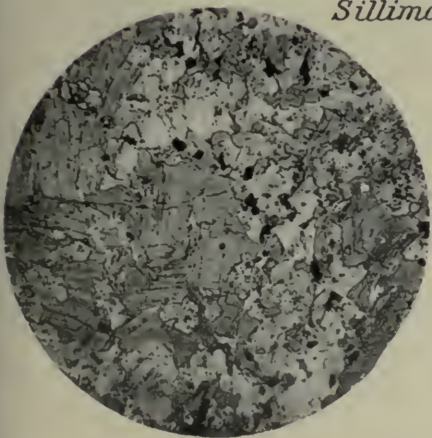
1. Hornblende-gneiss.



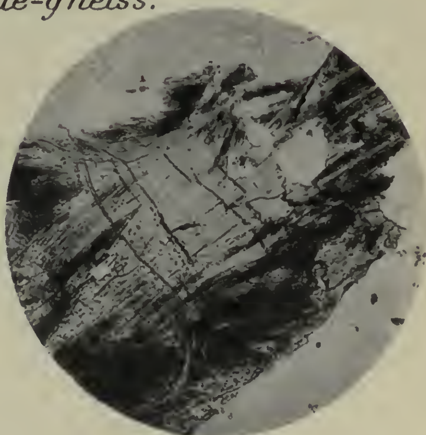
2. Sphene in Gneiss.

3.

Sillimanite-gneiss.



4. Diorite in Gneiss.



5. Sillimanite-gneiss.

Huth coll.

albite-pegmatites. Nor are they very acid, for quartz is in smaller quantity than felspar, and there is often a little hornblende and chloritised biotite. Some are composed of nearly pure albite in crystals an inch or so in length with exquisite lamellar twinning. An interesting feature is that the gneiss is almost invariably darker at its junction with them; even when a vein cuts across a number of bands each band is darker when it comes against the vein, and they are often sheathed with biotite or edged with a zone of large hornblendes which are deep-green for rays vibrating parallel to *Z*, like the hornblendes of the banded gneiss. Their composition is of great importance, for it points to the inference that they are not to be regarded as apophyses of the Coedana granite. That is a mixed albite- and orthoclase-rock, and it is extremely unlikely that its apophyses should be sub-acid albite-pegmatites. Albite, on the other hand, is the felspar of the hornblende-gneisses themselves, and it is therefore more probable that the pegmatites are products of magmatic differentiation from the original of the hornblende-gneiss itself.

The unbanded rocks, which are commonly quartzless, are typically granitoid in texture. The banded rocks are granoblastic, rather coarse in grain, though less so than the unbanded, and the darker ones are also often quartzless. The finest are the lighter bands with quartz and biotite. All are veined by and interbanded with pegmatite.

Biotite gneisses without hornblende are also present, but they will be discussed further on, as they may be foreign to the group.

Development.

The development of the hornblende-gneiss can best be studied in the Middle Region, between Treban alluvium and Llandrygarn Church. The most primitive type, which is seen in many places, appears to be a massive, mottled rock (Plate XII, Fig. 4) full of rudely oval dark bodies, about three millimetres in diameter, in a grey matrix. It is a hornblende-albite rock with a good scattering of ilmenite and apatite. The dark bodies are not phenocrysts, but groups of broad green hornblende, and the matrix is granitoid albite with smaller hornblendes. The structure is not normally igneous, and suggests that segregation has already set in. In rock of this kind, 160 yards south-south-west of Llandrygarn Church, a rude nodular structure has arisen, black nodules being surrounded by shells of the mottled matter. At the 'T' of 'Pandy Treban' drawing-out of the mottled matter has begun, and in the midst of this, rude black clots isolated by tracts of granular albite are beginning to be drawn out also (Fig. 12). In many places, as at the south end of Werthyr alluvium, tracts of partly drawn-out mottled matter

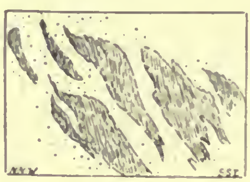


FIG. 12.
HORNBLENDE-GNEISS IN GRANULAR ALBITE.
North boss on east margin of Werthyr alluvium. × ½.

(in which, however, the cleavage of the large hornblendes may be encarsioblastic) begin to be isolated by streams of granoblastic gneiss like that of the banded rocks. With the growth of these there is a transition to the granoblastic banded gneiss itself.

For the sake of simplicity the pegmatites have been, so far, ignored. But they appear at quite an early stage, and take part in the process throughout. Their first appearance is in the nodular rock of Llandrygarn, throughout a large part of which the black nodules are isolated, not merely by the mottled hornblende-rock, but by veins and shells of pegmatite. Close by, at the farm next the church, this aggregate has been drawn out into a gneiss with short, rudely lenticular banding. Various further stages may be seen to the west of Clegir-mawr until we reach the perfect banded gneisses, with pegmatite seams, well seen on Craig-yr-allor, between Clegir-mawr and Treban. The banding has, in the meantime, become still more accentuated by the development of the finer granoblastic type with biotite and quartz, which may be supposed to have originated from reaction between drawn-out quartz-albite-pegmatite and normal hornblende-gneiss. As a few large plates of biotite may be found in the unfoliated rocks, there seem to be two generations of that mineral. The banded gneiss thus consists of granoblastic hornblende-albite rocks, rich in sphene, and of various shades of darkness, with the finer biotite-quartz bands, the banding being accentuated by innumerable seams of pegmatite, the whole complex being folded. But the production of pegmatite had by no means come to an end. Short, stout knots of it (as well as of pure quartz) appear between the bands of the gneiss (Figs. 13, 14, 15) probably

FIG. 13.
SIX-INCH KNOT OF ALBITE-PEGMATITE IN HORNBLENDE-GNEISS.
200 yards north-north-west of Craig-yr-allor.

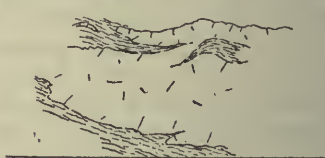


FIG. 14. FIG. 15.
SIX-INCH AND FOUR-FOOT SILLS OF ALBITE-PEGMATITE IN HORNBLENDE-GNEISS.
West and north-west of Clegir-mawr.

produced at a late stage of the process. And after the banding was complete, great sills and veins of it were introduced, cutting across the banding, isolating sub-angular blocks of gneiss, turning some of them round, and producing what may be called plutonic breccias of the most perfect kind. By an unfortunate oversight some of these best sections were not photographed, but the annexed drawings (Figs. 16, 17, 18) will convey an idea of them. Pegmatites have also come in along, and 'healed up' small faults in the banded gneiss, thus giving an insight into the long duration of the process.

[Face page 132.

Albite-pegmatite in hornblende-gneiss. Clegir-mawr, Gwalchmai.

Comparisons.

To readers who are familiar with the Lewisian Gneiss of Scotland the basic parts of that great formation will doubtless have been recalled by the foregoing description. The resemblance is indeed remarkable. The rocks correspond to those of Group III. of the scheme given on p. 43 of the Memoir on the North-West Highlands, and the gneisses correspond so closely in microscopic structure that the figures on Plate XLII of that memoir might represent the granoblastic types found in Anglesey. In both cases quartzless rocks form a large portion of the mass ; and in both also a little pyroxene accompanies the hornblende and stands in the same relation to it. The principal points of difference are first, that the peridotic and pyroxenic rocks of the Lewisian Groups I. and II. have not been found in the Mona Complex ; and, secondly, that the basic gneisses of this Complex are sodium-gneisses, the felspars both of hornblende-rocks and pegmatites being either albite itself or falling within the limits Ab—Ab_5An_1. As an appendage to their sodium-content[1] they are also titanium-gneisses, being unusually rich in ilmenite and sphene, and contain besides a large quantity of apatite. The structures visible in the field, especially the relations of basic to pegmatitic matter, are the same in both cases. Indeed, all the phenomena illustrated in Plates VI to XIV of the Memoir on the North-West Highlands, and discussed by Dr. Teall in its fifth chapter, can be seen, on a smaller scale, in Anglesey. That they should be displayed on a smaller scale is to be expected, for perhaps the most remarkable circumstance of the parallel is that, whereas the plates quoted are selected from a tract 60 miles in length, the corresponding stages in Anglesey are all to be found between Treban alluvium and Llandrygarn Church, a space of rather less than two square miles.

FIG. 16.

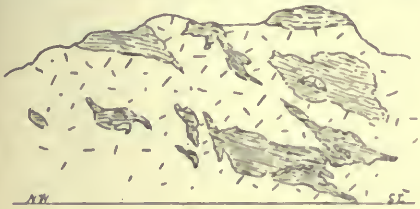


FIG. 17.

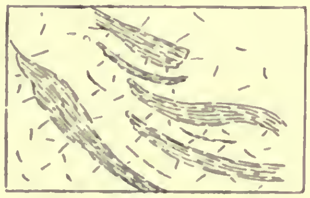


FIG. 18.

COARSE ALBITE-PEGMATITE ISOLATING HORNBLENDE-GNEISS.
Heights: (16) 1 ft. 6 in. (17) 2 ft. (18) 1 ft. 6 in.
High boss, 200 yards north-west of road-fork at Clegir-mawr.

GRANITOID BIOTITE-GNEISS OR GNEISS PROPER.

This is the most deep-seated member of the Mona Complex, being a combination of a granitoid with a foliated element itself highly crystalline.

[1] See Thomas and Jones, *Quart. Journ. Geol. Soc.*, 1912, p. 389.

The Granitoid Component.

The minerals are quartz, felspar, biotite, and white mica, with a little sphene, apatite, and zircon, but these accessories are in small quantity. The quartz is of the type usual in granites. The biotite, which is in fair-sized flakes, has been brown, but is commonly chloritised with separation of leucoxenised ilmenite, showing that it was titaniferous. There is more of it than of the white mica, but not very much of either. The dominant felspar is albite. No potassium-felspar has been detected. Dr. Teall, after examining the ground with the writer, compared the felspar of four of the granitoid bands of Henblâs with four specimens of the Coedana granite. All of the latter contained orthoclase (p. 91), the former only albite with a possible inclination to oligoclase. In a series, also, of many slides and powders taken from the Middle Region, from the Nebo and Gader Inliers, and from Mynachdy, the writer has found that albite is general, but that some of the rocks contain a considerable proportion of oligoclase. No porphyritic felspar is known. The rocks may therefore be described as albite-granites containing in some places oligoclase. Whether the white mica be muscovite or paragonite has not yet been determined. The structure is typically granitoid, and of coarse to medium grain. The rocks differ, therefore, from the Coedana granite both in structure and in composition. Not only are phenocrysts absent, but so is orthoclase, all their felspar being of sodium or sodio-calcium species. The magmas were evidently different.

The Foliated Component

includes mica-gneisses of three types and also some crystalline limestones.

Mica-gneisses.—The minerals identified in the mica-gneiss are quartz, felspars, biotite, chlorite, muscovite, hornblende, magnetite, ilmenite, sphene, leucoxene, rutile, sillimanite, garnet, idocrase, tourmaline, zircon, apatite, graphite, epidote, and talc.

The quartz is often in rather large grains, and though usually clear may be so crowded with minute inclusions as to be hardly less turbid in aspect than the decomposing felspar. The dominant felspar is probably albite or albite-oligoclase, but these rocks differ from all the rest of the Mona Complex in the importance of oligoclase. It is present in many of them alongside of albite, in a good number is the principal, and in some appears to be the only felspar. Both it and albite are often in large grains, with or without lamellar twinning, intergrown granoblastically with the quartz. Potassium-felspar has been found only once, and that where (p. 323) there is reason to suspect an apophysis of the Coedana granite.

The biotite, often in large flakes, though much chloritised, is frequently well preserved, and is deep-brown in basal plates. It has a stronger pleochroism than the other micas of the Complex, being pale straw for rays vibrating at right angles to, very deep-brown, sometimes reddish-brown, for rays vibrating parallel to, the

Micaceous gneiss with knots of albite-granite. Coast of the Gader Inlier at the Fox's Den.

[Face page 131.

base. As it is also very nearly uniaxial in most cases examined, and is (see analysis No. I, p. 137) rich in FeO, it is evidently a haughtonite. The gneisses of the Nebo and other northern inliers are brilliant with a large white mica, which is almost uniaxial, and is a bleached biotite. Parts of the crystals are occasionally still brown and pleochroic, the bleaching having proceeded along the cleavage, so as to simulate intergrowths of muscovite. The bleaching is accompanied by separation of clots of iron-ore and needles of rutile. But the biotite retains its optical properties, especially its high, negative, bi-refringence.

The true white-mica, which from the analyses (p. 137) must be regarded as muscovite, varies a good deal in axial angle. Both micas develop the basal planes well, those of the biotite nearly always lying along the foliation; but the muscovite is occasionally in stellate groups. They are often intergrown, but the muscovite sometimes pierces the biotite [E. 9935] at a high angle to its cleavage planes. Whether hornblende is to be regarded as a mineral of these rocks is not quite certain, for it is possible that those in which it is found belong really to the group described above, though there are cases in which it is hardly in excess of a biotite of the type just mentioned. The chlorite is probably always a pseudomorph of biotite. It is generally crowded with leucoxene, and sometimes with needles of rutile, showing that the biotite, as in other sodium rocks mentioned in this chapter, is highly titaniferous. Rutile occurs also as an independent mineral. How much of the dark iron-ore is magnetite is uncertain, but reflected light so often reveals a faint brown tint or a passage into leucoxene that ilmenite is almost certainly in excess. Some sphene is usually present, sometimes in the characteristic double wedge, and sometimes in large grains, though never attaining the size of those found in the hornblende-gneiss. Zircon is frequent, but tourmaline rare. Apatite, in broad hexagonal prisms of considerable size, is often extremely abundant, usually in the quartz-felspar mosaic. Garnet is far more generally present and far more abundant than appears at first sight, for, owing to its bad state of preservation it eludes observation in the field, retreating into cavities and weathering to a dull rusty tint. But there are seams in which it makes up nearly half the rock. It was of a good rose-colour when fresh, and never euhedral, but occurring in large embayed porphyroblasts (which at Gwyndy are nearly half an inch in diameter) often crowded with inclusions of quartz, biotite, and other minerals. A wholly fresh garnet is hardly to be seen, the mineral having always a mesh-work structure like that of olivine, along which it is traversed by canals of pseudomorphic products most of which are green; and sometimes it is completely pseudomorphed. The principal product is a chlorite, but there is also quartz, and a colourless fissile substance which, from its high bi-refringence and low refractive index, appears to be talc [E. 10838].

In some of the gneisses of the Nebo Inlier, on the northern side of Porth Helygen, there are, as well as rose-coloured garnets, abundant porphyroblasts, about four millimetres in diameter, of a clear, glassy, grass-green mineral, which weather into hollows. Those cut through in thin section are unfortunately in very bad condition, but show signs of a pair of cleavages at right angles unlike the curved cracks of garnet. The mineral has a high refractive index and low bi-refringence, and, so far as can be made out (though no good optical figure has been obtained), seems to be uniaxial. From the powder of a better preserved crystal Dr. Thomas considers that it is almost certainly idocrase. Graphite also occurs on the same coast, and being partly foliated with the gneiss, may be original. It was determined chemically on a specimen from Rhosmynach-isaf by Mr. J. O. Hughes.

Sillimanite.—After the quartz, felspars, and biotite, this is the most abundant mineral of the gneisses, and is undoubtedly the most significant in regard to their nature and origin. It is rare in the most highly granitoid portions, but in some of the coarse lepidoblastic parts is extremely abundant, imparting to them, indeed, a nemablastic texture. The richest localities are the coast of the Nebo Inlier [E. 9527—9, 9534] (Plate XII, Figs. 3, 5) and the valley south-east of Llechcynfarwydd Church. There are three modes of occurrence—in quartz as 'faserkiesel,' in biotite, and alone. The crystals are the usual slender needles. They generally taper, but here and there the basal plane may be detected, and sometimes traces of the prism-faces. Cross-jointing is often seen, and it may extend across bundles containing many crystals. Some of the sillimanite of the coast east of Llanwenllwyfo Church [E. 9529] is pleochroic. This is imperceptible in single needles, but can be observed in parallel bundles of them, the effect being thus intensified. The absorption is $Z > (Y, X)$, and the tints are Z, moderate olive-green ; (Y, X), pale straw-colour. The stability of the mineral is strikingly illustrated where the gneiss is decomposed, it and the quartz being sometimes the only components that retain their optical characters. Where occurring in quartz, it forms dense aggregates of faserkiesel, easily recognisable on the rugged weathered surface by its fibrous texture and its tint of pale foam-green. Sometimes such an aggregate crowds the whole of a quartz-grain, while the adjacent grains contain none at all ; sometimes the aggregate decreases in density, the surrounding grains being pierced by innumerable separate single needles. Occasionally, a long delicate needle of sillimanite may be seen to pass from one grain of quartz into another that has a different optical orientation. In the biotite, it may also occur in aggregates, but for the most part lies along the cleavage-planes, disposed in three systems that intersect at angles of 60°, so as to enclose equilateral triangles (like the rutile figured by Rosenbusch, *Micr. Phys.*, Plate XX, Fig. 5), and so presumably parallel to the rays of the pressure-figure. But the mineral occurs also in tracts of its own, close bundles of needles, in which no binding quartz or biotite can be detected. Little ones are plentiful in thin sections ; but on the coast east of Llanwenllwyfo

Church, on the foliation-surfaces of brown biotite gneiss, are oval tracts an inch in length of clear sea-green sillimanite. Fragments from the cleanest parts of these, teased out, are seen under the microscope to be composed of pure sillimanite. For the most part it is nemablastically foliated, but may also be found in stellate groups.

Limestone.—A massive grey crystalline limestone occurs at several places in the Nebo Inlier. Its carbonate is nearly all calcite, but it is rich in silicates and heavy minerals. Conspicuous among these is brown sphene, often in double wedges, sometimes pseudomorphed in leucoxene. Albite in large grains is abundant, and there is a little quartz. In some of the slides [E. 10568] a colourless pyroxene is plentiful. It is always anhedral, but the prismatic cleavages are very well developed, and some of the crystals have a diallagic striation. A pale green hornblende, which is present, appears to be derived from it; and there is a brown mica with a rather wide axial angie. Apatite and zoisite also occur. There are a good many serpentinous pseudomorphs after a stout prismatic mineral [E. 10265] with rude pyramidal terminations, which Dr. Teall refers to forsterite, as they have the habit assumed by that mineral in the Glenelg and other limestones. One contains a small fresh core which extinguishes parallel to the major axis of the pseudomorph, thus confirming Dr. Teall's view. The abundance of calcite is therefore assignable to de-dolomitisation. Some anhedral grains of an isotropic mineral with a faint brown-rose colour and high refractive index are seen in one slide [E. 204]. Unfortunately it was not possible to compare their refractive index with the pyroxene. But as they are all perfectly fresh, which the garnets of the gneisses are never known to be, they are referred provisionally to spinel, on account of their associations. The minerals of this limestone are therefore :—calcite, albite, quartz, apatite, zoisite, sphene, leucoxene, pyroxene, hornblende, chlorite, biotite, serpentine, forsterite, and spinel.

Chemical Analyses.

The following analyses have been made by Mr. J. O. Hughes.

	I.	II.		III.
SiO_2	54·01	68·09	Residues insol. in HCl...	37·60
Al_2O_3	21·19	17·44	Al_2O_3	2·44
Fe_2O_3	1·43	4·81	Fe_2O_3	3·07
FeO	10·27	—	CaO	29·21
CaO	1·08	—	MgO	2·22
MgO	1·74	—	CO_2	25·60
K_2O	3·94	—	H_2O	not det.
Na_2O	1·83	—	—	—
H_2O (at 110°) ...	0·60	—	—	—
H_2O (above 110°)	2·71	—	—	—
S	0·24	—	—	—
	99·04	—	—	100·14
			Percentage $CaCO_3$	52·16

I. Albite-biotite-sillimanite-garnet-gneiss, 617 yards east-south-east of Llechcynfarwydd Church (at 'yd'), in angle between road and farm lane of Tyddyn-gyrfa (six-inch map) [E. 9939].

II. Albite-muscovite-biotite-gneiss, with a little sillimanite and garnet [E. 9887 and AP. 79] 217 yards north-north-east of Old Windmill (and 63 yards north-west of Graig-fach, six-inch map), Holland Arms.

III. Forsterite-limestone [E. 10266], 170-260 yards north-east of Rhos-mynach-isaf, at contour. Nebo Inlier.

The high percentages of Al_2O_3 and of FeO in No. I will at once be noticed.

Nature and Relations of the Components of the Gneiss.

These components may be roughly classified as follows :

A. Fine hard siliceous bands.
B. Coarser granular biotite-gneiss.
C. Coarse flaky biotite-gneiss.
D. Crystalline limestone.
E. Granite or pegmatite.

Of these, D is rare, and A never present in large quantity. B and C make up the great body of the gneiss, in so far as it is tolerably free from granitoid matter. The hard bands (A) are composed of quartz, albite, and a little biotite. The texture is always finely granoblastic, but some of the rounded quartz weathers very much like clastic grains. The second type (B) is also granoblastic, but rather coarsely so, and its quartz and felspar are often elongated along the foliation, the albite in large grains with lamellar twinning. Short, wavy, lenticular micaceous seams occur in it, and by increase of these it may pass into the third type (C). This, though often extremely micaceous, with biotites that may be four or five millimetres in diameter, is hardly lepidoblastic, coarse granoblastic felspar and quartz generally making up a large part of it, and the biotite being often in good thick plates. Its structure is typically lenticular and its foliation undulose. It is in this rock that oligoclase tends to exceed albite, and that sillimanite and all the more unusual minerals are apt to be found. The prevalent types may thus be briefly described as albite-biotite-gneisses, oligoclase-albite-biotite-gneisses, oligoclase-albite-biotite-sillimanite-, and oligoclase-albite-biotite-sillimanite-garnet-gneisses.

Origin of the Foliated Components.

Before describing the way in which they are modified by the granitoid element (E), it will be well to consider the probable nature of the original materials. The first (A) is highly siliceous, more so in many cases than any known igneous rock. The second (B) is quartzo-felspathic, and might have been derived either from an albite-granite or from an albite-grit, albite-arkose, or albite-tuff. The third (C) closely resembles many rocks of the Scottish Highlands that are certainly pelitic sediments, such as the wavy mica-schist of Suisgill, Sutherland, described by the present writer.[1]

[1] *Quart. Journ. Geol. Soc.*, 1896, p. 643.

From the analysis No. I (p. 137), it is seen to be highly aluminous. No igneous rock, save some of exceptional composition that differ totally from it in their other components, contains anything like such a percentage of aluminium. But the specimen analysed was collected in the year 1901, and many examples of the type that have since been found contain far more sillimanite, and also more garnet, some being, indeed, mainly composed of quartz, sillimanite, and garnet, or of quartz, sillimanite, and biotite. The percentage of Al_2O_3 in specimens lately collected must exceed 30·00. Even the specimen analysed,[1] and still more so those just mentioned, could not have been derived from anything but pelitic sediments. And the mineral sillimanite itself is now well established to be a characteristic of such sediments when subjected to a high grade of thermo-metamorphism. If such, however, be the origin of type C, then types A and B, which graduate into it, must be regarded as psammitic sediments, siliceous and felspathic respectively; and type D, the crystalline limestone, may reasonably be looked upon as an impure calcareous deposit. The balance of evidence, therefore, is at least in favour of regarding the non-granitoid elements of the gneiss as of sedimentary origin.

Relations of the Granitoid Element.

Now the granitoid component is related to the foregoing components in seven different modes, arranged here in order of intimacy, the degree of intimacy reached in the last three being very high, and in the last the highest yet known in the study of gneissose rocks. They are: (1) Veining; (2) Flooding and Isolating; (3) Banding; (4) Lenticular Interfelting; (5) Permeation; (6) Granitoid Gneiss; (7) Gneissoid Granite. But it must be understood that these modes are not sharply separable; they merge gradually into one another, more than one being present in most portions of the gneiss.

(1) *Veining*, in the sense of granitoid strings of small width cutting the Gneisses at high angles, is quite subordinate. (2) *Flooding and Isolating* by well-defined streams and sills of granite or pegmatite with sharp edges (the usual relation of the Coedana granite to the hornfels) is also subordinate. Good examples, however, are to be seen at Llandrygarn (Figs. 19, 20), where the included and split fragments of albite-biotite-gneiss retain the dip and strike of the invaded mass. (3) *Banding*. This is displayed on a grand scale at Henblâs (Plate XV), where an oligoclase-albite-biotite-gneiss of types B and C, with some hard siliceous beds of type A and also some thin hornblende-gneisses, is injected *lit par lit* by conspicuous white and pale-salmon-tinted albite-granite. The dips are low, and the phenomena are exposed on clear escarpments. Alternation is rapid, the chief granites being about six

[1] The percentage of iron, especially of FeO (evidently derived from haughtonite) is remarkable, but there must be quite as much in the Suisgill mica-schists.

inches, the lesser ones about one inch thick, at intervals varying from six to twelve inches. The margins of the granite, which is usually but not always unfoliated, are for the most part sharp, but

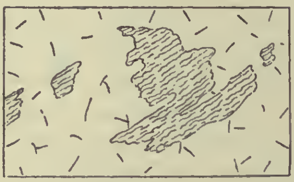


Fig. 19.

Fig. 20.

Inclusions (up to two feet in length) of Gneiss in Albite-granite.
About 330 yards east-north-east of Llandrygarn Church.

there is not the least sign of a chilled selvage. Here and there a little nebulosity can be seen at a margin. Whatever the origin of the granite, the relations locally are those of injection, for though most of the bands are thoroughly conformable, yet here and there they can be seen to truncate the foliation of the gneiss at a low angle and to send off tongues. There is also *lit par lit* injection of more than one phase, for at one place a 12-inch granite band (Fig. 21) turns round a little, and truncates a number of thinner granite bands. Some of the larger bands are double, with a thin film of gneiss between, and some contain thin lenticular inclusions, thus linking this to the preceding mode. Regular interbanding, though so pronounced at Henblâs, is on the whole not common in the gneissose areas. (4) *Lenticular Interfelting*, in varying degrees,

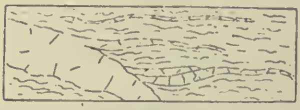


Fig. 21.
One-foot Granitoid band cutting thin Granitoid bands
North-east of Henblâs.

Fig. 22.
Granites in Gneiss.
Coast of the Gader Inlier.
Height, about three feet.

Fig. 23.
Granite in Gneiss.
Coast of the Gader Inlier.
Height, about two feet.

is the most widespread of all the modes. Stout, knotty lenticles a foot or more in length are well seen on the coast of the Gader Inlier (Plate XIV, and Figs. 22, 23). A moderate stage of intimacy is well seen at Tyddyn-gyrfa, where the sillimanite-garnet-gneiss that was analysed contains a large number of seams of rather coarse

The Banded Gneisses. Henblâs, Llandrygarn.

[Face page 140.

pegmatoid matter a foot or so in length, which may swell out in the middle to an inch or more in thickness. Often they do not thin off steadily, but by a succession of smaller and smaller expansions. Even where moderately developed, this mode is more intimate than that of the banding, for the pegmatites are often split and apt to be bordered by thinner ones, thus tending to graduate into the gneiss. As they increase in number this effect is greatly intensified, for they take one another's places by overlapping *en échelon*, until a stage is reached where pegmatites of varying thickness occupy as much space as the intervening gneiss (Fig. 24). The lenticular masses then begin to anastomose, thus transgressing the foliation of the gneiss, and isolating it as lenticular inclusions, the relations being, however, far more intimate than in mode No. 2. The micaceous C type seems more susceptible of this mode than the others are, but at Gwyndy crags the B and A types are present as well, the whole complex rolling gently about, with here and there a good sharp fold. Granitoid and gneissoid materials now begin to pass into each other, partly by rapid alternations of thinner and thinner seams, partly by fraying-out of the ends of biotitic folia into albite-pegmatite or granite (Fig. 25). But the dark biotitic rock is being at the same time prepared, as it were, for such passages, for spots of albite and little quartz-albite augen are now appearing within it, making it quite ready to graduate into foliated albite-granite either along or across the strike. (5) *Permeation.* Along the sides of a complex of this kind graduation will take place, through ranges of closely overlapping lenticles of both dark and light-coloured matter (themselves ill-defined both on their flanks and at their ends) into vague mixed types very difficult to describe in words, in which there is no banding, but cloudy lenticular tracts of granitoid matter inextricably confused with biotitic gneiss, itself cloudy with innumerable albites. No name but that of permeation-tracts can be given to the products of this mode, in which the union of the igneous and the other element is well-nigh complete, if not complete, and the proportions of the two are balanced. (6) *Granitoid Gneiss.* Yet the proportion of granite may still increase, the product being a well-foliated gneiss, but a granitoid one, composed of undulating lenticular films (Fig. 26) of biotitic matter,

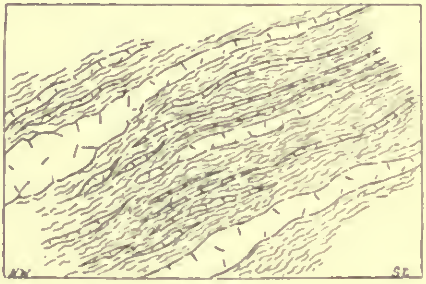


Fig. 24.
Gneiss with lenticular Albite-granites.
Gwyndy Crags. Height, two feet.

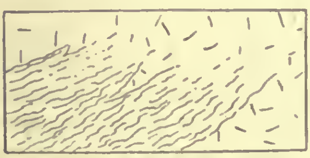


Fig. 25.
Passage of Gneiss into Albite-granite.
Gwyndy Crags.

themselves all cloudy with albites, graduating in all directions into granitic streams with elongated elements of quartz and albite, in and among which they float. (7) *Gneissoid Granite*, the final term, is an albite-granite with a foliation that is due to the presence of thin impersistent films of biotitic gneiss full of small albite spots, dying off at last into mere trains of biotite, floating in a stream of granite.

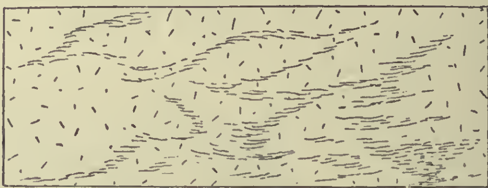


FIG. 26.—FILMS OF GNEISS IN GRANITE.
Coast of the Gader Inlier.
Plan 18 inches long.

The less intimate modes (1) to (4) can be well studied on the coast of the Nebo Inlier, all the modes (the banding at Henblâs, the fourth mode at the crags that overlook the road just south-east of Gwyndy), in the Middle Region, and the advanced modes (5) to (7) at the same crags, and on the great sea-cliffs of the Gader Inlier.

Comparisons and Conclusions.

The phenomena of these granitoid gneisses must, like those of the hornblende-gneiss, have recalled to the reader certain districts in the Scottish Highlands. But the parallel in this case is not so much with the Lewisian gneiss (except, to some extent, the district between Cape Wrath and Laxford[1]) as with the Forfarshire country described by Mr. Barrow,[2] and the parts of Eastern Sutherland described by Dr. Horne and the present writer,[3] whose description has been extended by Dr. Crampton and others in the Annual Summaries of the Geological Survey from 1909 onwards. The behaviour of the granites is the same throughout, but the parallel with Eastern Sutherland is much more complete than with Forfarshire, for the great orthoclase pegmatites and the zones of kyanite and staurolite have not been identified in Sutherland or Anglesey. The resemblance to Eastern Sutherland, indeed, is extremely close. There are certain differences. Independent foliation in the granite, rare but present in Eastern Sutherland (*op. cit.*, p. 644, Fig. 3), has not been found in the Mona Complex. Orthoclase appears to be absent from both the gneiss and its granites in the Mona Complex, nor is the granite ever porphyritic, and albite is its dominant felspar instead of oligoclase. The felspars of

[1] 'Geology of the North-West Highlands' (*Mem. Geol. Surv.*), pp. 103—125.
[2] *Quart. Journ. Geol. Soc.*, 1893, p. 330.
[3] *Quart. Journ. Geol. Soc.*, 1896, p. 633 (on work ending in 1895).

the pelitic-gneiss itself, however, do not present the same contrast, for oligoclase is abundant in the Mona gneisses, though there is, indeed, more albite than had been identified in Sutherland by 1895. Anglesey is, however, greatly inferior to Sutherland with regard to the state of preservation of the rocks, which are often so decomposed that no freshly fractured surfaces can be obtained, although the structures are beautifully displayed upon the weathered crags. In every other particular the parallel is complete. In both cases there are the same types of original material, siliceo-psammitic, felspatho-psammitic, pelitic, and calcareous, and they have undergone the same types of anamorphism. Sillimanite and garnet are abundant in both, but the development of sillimanite is greater in the Mona Complex than in Sutherland, and approaches that of Forfarshire specimens collected by Mr. Barrow. Finally, every mode of the relations of the granite (save independent foliation) that is known in Sutherland is perfectly reproduced in the Mona Complex. But the development in Anglesey is not, in this case, a 'miniature,' as is that of the hornblende-gneiss; for it is found in four separate inliers—the Middle Region, Gader, Nebo, and Mynachdy, and the gneiss of Holland Arms indicates an extension to the Aethwy Region, suggesting a development co-extensive, at the very least, with that of Anglesey itself, and probably (see p. 252) very much larger. Granitisation, indeed, of this kind, is far from being a mere marginal phenomenon; it is doubtless regional.

FOLIATION.

The varying developments of this have been described under the head of the petrology of the different members of the Mona Complex. In crystalline character there is the widest possible range, embracing almost all grades, from the faintest signs of anamorphic reconstruction to the permeation-structures of the deep-seated granitoid gneisses and gneissoid granites. Of the various types of crystalloblastic[1] texture, the leading ones, granoblastic, lepidoblastic, and nemablastic, are all widely developed; and of the special types, the poikiloblastic, diablastic, porphyroblastic, and encarsioblastic, are often to be seen. Of relict- or palimpsest-structures, the igneous rocks in various stages of incorporation yield blastogranitic, blastophitic, and blastoporphyric; and the sedimentary rocks in like manner the blastopsephitic, blastopsammitic, and blastopelitic textures, corresponding ones being yielded

[1] The terminology of Grubenmann wears, it must be confessed, a somewhat ponderous, not to say grim-visaged aspect! Yet it is the only one that has been devised as a systematic expression of the textures of the crystalline schists, and has therefore been adopted in this book. We may hope that a petrologist who is also a classical scholar may some day devise one that is a little less formidable.

by the pyroclastic rocks. What may, perhaps, be called blasto-venous textures result from the incorporation of the quartz and quartz-albite venous sills.

The various grades of anamorphic reconstruction are distributed in an involved and, apparently, capricious manner, but really according to definite laws. Those laws cannot, however, be discussed with advantage until after discussion of the tectonics and the stratigraphy. They will, therefore, be found on pp. 237—241.

GENERAL MINERAL CHARACTERS OF THE MONA COMPLEX.

A short study of its minerals will serve to bring out certain characters that attach to the Complex considered as a whole, some of which are common to its igneous and to its sedimentary members, and have influenced the subsequent history of the whole region. Comparisons and contrasts with other foliated complices will doubtless be suggested by them.

The minerals identified are as follows:—quartz; the felspars orthoclase, microcline, albite, albite-oligoclase, oligoclase, andesine-labradorite, and labradorite; the micas muscovite, paragonite, sericite, green biotite, biotite, and haughtonite; the amphiboles dark-green hornblende, blue-green hornblende, pale hornblende and actinolite, tremolite, asbestos, and glaucophane; the pyroxenes enstatite, augite, diallage, colourless and green diopside; serpentine, chrysotile, bastite, antigorite, brucite, and talc; the chlorites penninite, clinochlore, and delessite; the carbonates calcite, dolomite, and rhodochrosite; the iron-ores pyrite, magnetite, picotite, chromite, hæmatite, and ilmenite; the other titanium minerals perofskite, sphene, leucoxene, rutile, and anatase; the epidotes pistazite, pale epidote, orthite (?), and piedmontite; zoisite; natrolite; tourmaline, xanthophyllite-chloritoid, andalusite, sillimanite; zircon, apatite, graphite, axinite, forsterite, spinel, garnet, and idocrase.

The Felspars.—Now, the most salient fact in the composition of the Mona Complex is the extraordinary predominance of albite-felspar. Orthoclase is hardly known outside the Coedana granite and its hornfelses; microcline outside the less altered parts of the Penmynydd mica-schists; andesine-labradorite is known only in the basic intrusions of Caerau; labradorite only in a few cores of the albite-diabases; oligoclase is a component of the biotite-gneisses. In all these rocks, moreover, there is also an abundance of albite, especially in the Gneisses. But in every other member of the Complex, acid or basic, igneous or sedimentary, original or metamorphic, which contains a felspar at all, the felspar is albite. And as many of the grits and mica-schists are highly felspathic, the quantity of albite must be enormous ; and the Complex must therefore be in great measure a sodium-complex. Idiomorphic albite is known only in the undeformed parts of the spilitic lavas and their suite. The long history of some of the felspars is shown by the fact that the albite of the spilitic suite can often be seen to be secondary after a basic felspar which has decomposed, and that therefore, where reconstructed in anamorphic schists, it has become a ternary albite. Some degree of decomposition is commonly found in the felspars of the Complex, and it is usually of the micaceous type rather than the kaolinous. Its disposal in the grains is of interest. In the granites and in all the Gneisses it proceeds inwards from the periphery, so that fresh felspar tends to survive as cores in the interior. In the blastopsammitic schists the reverse is the case, the core being full of decomposition-products and the margin fresh though in optical continuity. (Fig. 27 and E. 10131, 10151, and others.) The decomposition in this case would therefore seem to belong to that remote period of weathering that preceded the deposition of the sediment ; and the reconstitution of the margin to the period of metamorphism, during which alkaline solutions must have been permeating the rock. Sometimes (Fig. 27 and Plate II, Fig. 2) there is a ring of decomposition-products, which would seem to mark the inward limit of old weathering, so that an old fresh core is now in optical union with a reconstituted fresh periphery.

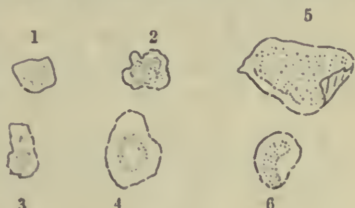


FIG. 27.
REJUVENATED ALBITES.
1, 2, 3, 4 from E. 10151.
5, 6 „ E. 10131.

The Micas.—The white-micas of the Complex also reflect its alkaline composition, but in a different way. In several cases, where the only abundant alkali-minerals are a felspar and a mica, it has been possible to show (pp. 45, 49, 112, 135) that the mica must be muscovite, because analysis of the rock reveals a considerable proportion of potassium, which cannot have been yielded by the felspar, that being albite. In some of the Penmynydd mica-schists it can be further shown that this muscovite is a product of the reconstruction of microcline, for that felspar disappears as the muscovite develops. Albite is evidently far more stable than orthoclase under dynamic metamorphism, and reconstructs itself as new albite. Yet paragonite has been produced. It has been proved in the glaucophane-epidote-schist, a rock in which there is still a little albite, and is probably much more plentiful elsewhere than is as yet known. In the clastic schists, the decomposition-products of the felspars are now largely represented by minute flakes of a white mica, which, as the felspar is albite, may be safely regarded as paragonite. Paragonite in this form is widely diffused throughout the Complex. Very likely much of the 'sericite' may be paragonite, but the contact-micas of the hornfels must be chiefly muscovite. Brown biotite seems to be nearly confined to the Penmynydd mica-schists (where it is not abundant), the granites, the hornblende-gneisses, and the biotite-gneisses. In the last it has been shown to be haughtonite. It is often chloritised, and the great separation of leucoxene and rutile that then takes place shows that it was highly titaniferous. Its remarkable bleaching in the biotite-gneisses, where it often simulates a muscovite, has been described. A much more unusual mica is the grass-green biotite of the New Harbour Beds, of which a chemical analysis is much to be desired. It shows a tendency, in the South Stack Series, to development along with muscovite in compound encarsioblasts.

The Amphiboles.—The strongly coloured amphiboles belong essentially to the Penmynydd Zone and the Gneisses, those of the gneiss having a stronger pleochroism and a broader habit. Pale green ones appear in the contact-aureoles of the Coedana granite and the serpentine, still paler ones in the schistose gabbro, and the colourless calcareous tremolite is essentially the amphibole of the ophicalcites. The great, and for Britain unique, development of glaucophane in the Penmynydd Zone is yet another product of the high sodium-content of the Complex.

Pyroxenes, doubtless plentiful in the original basic rocks, have now a restricted distribution. Augite is known only in the spilitic suite and in the sub-gabbroid sills of Caerau ; enstatite and diallage only in the gabbros, pyroxenites, and some of the serpentines. A little green diopside exists in the hornblende-gneiss, and a colourless diopside is abundant in the fosterite-limestone.

Olivine has not been found unaltered, but its products, among which is talc, are abundant in the serpentine-suite. Forsterite has been identified in a cipolino of the gneiss.

Iron-ores and Titanium.—Among the iron-ores ; pyrite is known as a mineral of anamorphic foliation, and micaceous hæmatite is quite a character of the Penmynydd Zone, both in acid and in basic schists, but the hæmatite of the jaspers is flocculent. Magnetite is probably not very abundant, for inspection in reflected light reveals that very much, perhaps the greater part of the opaque iron-ore has a brownish tinge, shows frequent alteration into leucoxene, and must therefore be ilmenite. Connected with this is the abundance of sphene in many rocks, especially in the green-mica-schists of Holy Isle, in parts of the Penmynydd Zone, and in the hornblende-gneiss, where it attains to the rank of an essential and develops crystals of unusual size (Plate XII, Fig. 2). Rutile is also, locally, abundant. These facts, together with the titaniferous character of the biotites, point to a high titanium-content in the Complex as a whole, in association with its high sodium-content. Such an association has been elsewhere noticed by Thomas and Jones.[1] In the Mona Complex, however, it is not confined to igneous rocks, but is found even in some of the sediments. During the earlier stages of the

[1] *Quart. Journ. Geol. Soc.*, 1912, p. 389.

deposition of the beds, the titanium was probably concentrated largely in basic igneous matter, becoming disseminated, as time went on, by means of volcanic explosions (see p. 50).

Epidotes are widely distributed, both in igneous and sedimentary material. Some are post-metamorphic, and may be quite recent, but the great majority are true minerals of anamorphism. They are abundant and well crystallised in such rocks as the New Harbour Beds and the Penmynydd mica-schists, the amphibolic schists derived from the spilitic lavas, the hornblende- and especially the glaucophane-schist, in some of the hornblende-gneisses, and in the epidote-hornfelses of the granite and the serpentine ; but on a smaller scale and more poorly crystallised in the less reconstructed rocks like most of the Gwna Beds, from which their anamorphic origin is evident. Typical pistazite graduates into varieties with low bi-refringence, sometimes without loss of the lemon-yellow tint and pleochroism. The discovery of piedmontite in the Green-mica-schists is of great interest, and it is to be hoped that more and better crystals will be found. Zoisite, recognised by its uniform low bi-refringence, and characteristic interference-tints of clear indigo-blue, usually accompanies the epidotes where the rocks are well re-crystallised, whether they be sedimentary or igneous. But it is especially a mineral of the Penmynydd Zone of metamorphism, where it is abundant in some varieties of mica-schist, but still more so in the amphibolites of the Aberffraw coast and the hornblende-schists of Gwalchmai. In these it seems to be always a clino-zoisite with the optic-axial plane transverse to the prism.

Various Accessories.—Zircon is frequent in various rocks, but in moderate quantity. Apatite is abundant in the Penmynydd Zone, and still more in the Gneisses. Spinel has been identified in a limestone of the gneiss. Axinite in a vein in the spilitic lava. Graphite in a thin phyllite and mica-schist of the Gwna Beds and the Penmynydd Zone. Tourmaline (an accessory in many rocks) is especially developed in the hornfels of the Coedana granite, in which andalusite also has been found. Xanthophyllite occurs in the same hornfels, and also in graphite-schist of the adjacent part of the Penmynydd Zone, always as an encarsioblast. Garnet, small and idiomorphic, is found in the Penmynydd Zone ; large, allotriomorphic, and much decomposed, is often abundant in the Gneisses, accompanied sometimes by green idocrase.

Sillimanite is known for certain only in the gneiss (Plate XII, Figs. 3, 5), where it is developed on a great scale in several places.

The Carbonates calcite and dolomite, present everywhere as decomposition-products, form considerable masses of rock in the Gwna Beds, where they are often tinged with rhodochrosite. In the Penmynydd Zone and in the gneiss they are re-crystallised along with high-temperature minerals as cipolini, and the same is the case, also, in the ophicalcites.

Quartz-veins are only a subordinate feature, but venous quartz in lenticular augen is developed on an enormous scale in the Gwna Green-schist and in the Penmynydd Zone.

Green Tint and the Chlorites.—No character of the Mona Complex can be more striking to the most superficial observation than its persistent pale-green colour. The extensive Gwna Beds, the Church Bay Tuffs and Skerries Grits, the Amlwch Beds, the Coeden beds, the New Harbour Beds, and, to a less degree, the South Stack Series, the Penmynydd schists, the Hornfelses, and even the Gneisses and the Coedana granite, are all more or less pervaded by this pale green colouration. Now in all these great formations, except the New Harbour Beds and the South Stack Series, which are coloured by a green biotite, the green colouring matter is a chlorite. Looked upon usually as mere decomposition products, and suffering from somewhat indefinite optical properties, chlorites are apt to receive scant attention from petrologists ; but it is evident that in this complex they must have no small physical significance and be worthy of a closer study. And it soon becomes clear that they have not all been produced in the same manner. Some are decomposition products, but others are true minerals of anamorphism, and are thus respectively products of destruction and of reconstruction. They may be distinguished as 'chlorite of catamorphic dissolution' and 'chlorite of anamorphic evolution.' The first of these can be recognised in the usual way. The chlorite of the undeformed parts of the spilitic lavas is after augite, that of the Gneisses, of the granites, of the hornfels, of the parts of the Penmynydd Zone that adjoin the latter, is for the most part after biotite, partly after hornblende. These, then, are chlorites of dissolution. But consider such a rock as the Gwna Green-schist. It is in a very early stage of reconstruction, minute white mica being the only new mineral that accompanies the chlorite. There is not, nor ever can have been (for in the autoclastic mélange the almost raw material is still preserved to us), any crystalline mineral after which this chlorite can be a product of dissolution. The original ferro-magnesian matter was probably a sprinkling of pyroxenic dust or glass of spilite, which would have decomposed very soon after the deposition of the beds. This chlorite was therefore produced in the early stages of dynamic reconstruction, and is a chlorite of anamorphic evolution. So is that of the Amlwch and other northern rocks, only the evolution has proceeded further, so that both it and the white mica are more distinctly crystallised. Consider now the passage from the Gwna Green-schist into the Penmynydd Zone, which we have already seen (pp. 124—6) to be an anamorphic evolution. In the Penmynydd mica-schist we find a chlorite in much larger, better-formed flakes (or rather plates), clear green, intergrown with the muscovite, with no sign of being a pseudomorph after any other mineral. It is a chlorite of evolution, the most perfect known in the Complex. In the most advanced stages of the Penmynydd Zone a biotite appears. Van Hise has expressed the opinion[1] that 'the equations which represent the reactions in the zone of catamorphism are reversible in the zone of anamorphism.' We have, accordingly, a chlorite of dissolution replacing a biotite of evolution, and a chlorite of evolution replaced by a biotite of evolution.

In geological time, however, the chlorite of dissolution is vastly later than that of evolution. Some of it may possibly be as old as the later movements of the Mona Complex, some may be due to Ordovician destructive movements, some may be as late as Tertiary erosion. In the parts of the Pennynydd Zone where biotite is beginning to appear and yet (long afterwards) has become chloritised, chlorites of both origins must occur in the same rock, a conjunction that may be looked for along lines running north-east and south-west through Gaerwen Church and Porth Tre-castell respectively.[2] Most likely these chlorites belong to different species, for certain differences between them appear to be tolerably constant. The chlorites of dissolution tend to be irregularly formed and not cleanly crystallised; to be yellowish-green in tint and rather feebly pleochroic. Their bi-refringence is low, and they frequently polarise in the well-known blue, with occasionally the lavender hues. Their axial angle is commonly very small, though bi-axial ones are not infrequent. For the most part they seem (even when flakes with intergrown muscovites, with whose optic-axial plane their own appears usually to coincide, are excluded), to be optically negative, but the reactions in convergent light are poor. The chlorites of evolution are better and more cleanly crystallised, of a clear, cool-green tint, and with much stronger pleochroism. Their bi-refringence appears to be rather higher, and they often polarise in the peculiar brownish hues. They are usually, though by no means always, distinctly bi-axial, the average axial angle being in any case greater than in the other group. All those examined appear to be optically positive. The chlorites of dissolution, therefore, would appear to be partly pennine, partly prochlorite; but the chlorites of evolution may, with some confidence, be ascribed to clinochlore. The subject, however, needs much further study.

The chief special idiosyncrasies of the Mona Complex are therefore: its high sodium-content, expressed in albite, paragonite, and glaucophane; its high titanium-content, expressed in ilmenite, sphene, leucoxene, and rutile; and its persistent green colour, due chiefly to the great abundance of chlorite of anamorphic evolution.

[1] 'A Treatise on Metamorphism,' p. 369.

[2] A slide from near Gaerwen [E 9919] containing chloritised biotite, contains also a clear green chlorite that seems to be independent.

CHAPTER V.

THE PALÆONTOLOGY OF THE MONA COMPLEX.

ORGANIC remains have been found at six localities near Holyhead: Soldier's Point, cove beyond the Breakwater, western side; Coast, 400 yards east of Porth Namarch; High Moor, about three-eighths of a mile east of the South Stack; the South Stack itself; Henborth, north side; Coast, west-north-west of Gors-goch [Af. 791—2, 3662—98]. All the fossils are from the South Stack Series. Most of them are castings or 'pipes' of annelids, of the types referred by American authors to *Scolithus* and *Planolites*. The 'pipes' of *Scolithus* penetrate the grits at right angles to the bedding; those of *Planolites* lie along the bedding, usually at the partings between the grits and the seams of fine and now highly crystalline mica-schist. A remark of Dr. Peach [1] that castings of this kind 'not only indicate the presence of such animals during the deposition of the beds [the passage refers to the Cambrian quartzites], but also of sufficient organic matter having been mixed with the sand where they occur to furnish nourishment to the worms,' may be recalled here. Dr. Peach (who named these fossils), noting that two specimens from the foot of the cliff on the southern side of the South Stack were remarkably suggestive of organisms of the nature of *Archaeocyathus* or *Archaeoscyphia*, had them submitted to Dr. G. J. Hinde, who says, 'They are too far gone for positive determination, but I incline to agree with Dr. Peach's suggestion that they may belong to the same group as *Archaeocyathus*.'

All these fossils have suffered more or less deformation along the foliation-planes, but their state of preservation is remarkable when it is remembered that the finer beds, in contact with which many of them have been found, are now in the condition of beautifully crystalline and minutely corrugated mica-schist. *Scolithus* occurs chiefly in the massive beds of the Stack Moor part of the series, in some of which it is abundant; *Planolites* chiefly in the more thin-bedded Llwyn portion. The forms referred to *Archaeocyathus* are from the Llwyn division, but close to the Stack Moor beds. In view of the probable high antiquity of the rocks, the existence of these fossils is of great interest, but they are far from being sufficiently definite for purposes of correlation.

[1] 'Geological Structure of the North-West Highlands of Scotland,' p. 372.

Castings of annelids have been found also in the Gwna grits at Bonc Twni cove, Bodorgan. Others lie upon the bedding-planes of the Tyfry grits north of Ffynnon Sais, Llanddwyn. It has been seen that there are strong reasons (pp. 86—8) for supposing the jaspers of the Complex to be altered radiolarian cherts. Search has accordingly been made both in the nodular and bedded varieties, especially at Llanddwyn and Amlwch. Some small objects that may be organic were found at Llanddwyn [Af. 790], but they were undeterminable. Also, all slides of the jaspers containing anything that might possibly be an organism were submitted to Dr. Hinde, but with the same result. A jasper from Llanddwyn [E. 10095] with beautiful radiating structures about an inch in diameter, somewhat reminiscent of Walcot's *Atikokamia*, was compared by Dr. Hinde with a specimen of that form lately given by Dr. Horne to the Royal Scottish Museum, but he writes, 'The Mona Complex specimen appears to me inorganic. It is unlike any specimen of the *Archaeocyathus* group which has come under my notice up to the present.'

Oldhamia, too, has been looked for, especially in the purple phyllites, but a structure that had been referred to it proved to be of dynamic origin. Some bodies in the limestone of Bryn-maethlu resemble foraminifera, but no organic structure is to be seen under the microscope. Nor has anything been found in the oolitic limestones of the northern coast, yet it is difficult to believe that such rocks as these will prove to be totally barren.

CHAPTER VI.

THE SUCCESSION IN THE MONA COMPLEX.

Introductory.

Local successions can be made out in the several isolated regions and inliers of the Mona Complex, but these must all be brought into harmony before a general succession throughout the Complex can be established. Now the scheme of colours and symbols that has been adopted on the one-inch map for the various sub-divisions of the Complex has been applied throughout, the New Harbour Beds of Holyhead, for example, being coloured and lettered with the Amlwch Beds, the Church Bay Tuffs with the Skerries Grits, and so on. But, from the foregoing petrological description, it will already have appeared that the same colour and letter has been applied in several cases to formations that differ considerably in character ; that the scheme, in fact, implies a number of correlations. These have, indeed, been incidentally alluded to in the petrological descriptions. Evidence for them will now be given.[1] A general scheme of the succession will, then, be put forward, with brief accounts of the sections upon which it is founded.

Correlations within the Complex.

Such fossils as have been found in the Mona Complex, though of great interest, cannot yet be utilised for purposes of correlation ; and correlations of unfossiliferous rocks may, even when they are comparatively undisturbed, be vitiated by change of facies. Where disturbance is great, and metamorphism has set in, the risk is still greater ; and, therefore, the correlations which will now be set forth are put forward with reserve. The geographical extent of the exposed portions of the Complex, however, is not large, hardly affording space for change of facies so great as to prevent recognition. And, what is much more important, though moderate changes of facies must be admitted, yet the greater subdivisions of the Complex contain members with persisting characters, by whose presence the identity of the changing members can be recognised.

[1] Attention is drawn to the fact that the validity of these correlations, while affecting, of course, the colour- and symbol-scheme, does not in any way affect the maps as such. The lines laid down upon them are completely independent of these correlations.

Holyhead Quartzite and South Stack Series.—The quartzite of Rhoscolyn has the same characters as that of Holyhead, and stands in the same relation to the South Stack Series. The South Stack Series itself undergoes no change of consequence all over Holy Isle, and is easily recognisable, the only local variation being that the beds adjacent to the Quartzite are less massive at Rhoscolyn than they are above the South Stack. In the Coeden Beds, identified with this series, there is a change of facies, but it is not great. The grits are rather thinner, usually darker, and weather cream-colour instead of white; but there is a great deal of a peculiar fine bluish-green grit, which is very prevalent [E. 9313—4] in the South Stack Series. Like that series, they are free from volcanic bands. Certainly they cannot be identified with the Skerries Grits, which, only half-a-mile away, are coarse, massive, and ashy, so that specimens can be distinguished at a glance. In short, they resemble the South Stack Series more nearly than any other group in the Complex, with differences easily explicable by a slight change of facies, so that the decision rests with the stratigraphy, and will be considered below.

The New Harbour Group.—The Amlwch Beds differ from the New Harbour Beds of Holy Isle chiefly in the sharp individualisation of their thin grits, which are also rather coarser. But there are persisting beds common to the two. The spilitic lavas of the Amlwch Beds are of precisely the same type as those of the New Harbour Beds, and the associated jaspery phyllites and pale bedded jaspers are indistinguishable in the two series. Thus three members of marked character pass on unchanged, and it is therefore inferred that the Amlwch Beds are a northern facies of the New Harbour Group. In confirmation of this it is to be noted that the Lynas alternating beds of the north correspond in character to the Soldier's Point beds of Holy Isle and the west, the latter becoming still more like them at the Garn Inlier, while the Bodelwyn beds of the north approach the character of the fine Celyn beds of Holy Isle. Further, that it is in the Soldier's Point and Lynas beds that the spilitic lavas and jaspers occur in the two regions respectively. And finally, that the relative positions of the sub-groups are as follows:—

South Stack Series (Llwyn Beds)	... ...	Coeden Beds
{ Celyn Beds	—Pelitic...	—Bodelwyn Beds }
{ Soldier's Point Beds	—Psammitic (with lavas and jaspers)	—Lynas Beds }
Church Bay Tuffs	... ...	Skerries Grits

thus confirming the correlation in a remarkable manner, and showing that the change of facies is less than at first sight appears. This correlation is of great importance, as, once established, it adds weight to the evidence for all the other identifications of groups in the Northern Region.

The Skerries Group.—The Skerries Grits resemble the Church Bay Tuffs, with part of which they are correlated, in that their matrix is a pyroclastic porcellanous epidosite of the same nature as that which often makes up the body of the latter; in which, when grits occur (as on the Rhos-y-cryman coast) they are of thorough Skerries type. An extraordinary massiveness, with occasional impersistent bedding, is a marked character of both. Most important, however, is the fact that both of them contain fragments of the same peculiar felsitic and granitoid micropegmatites, which are developed on such a great scale at The Skerries, indicating that both drew their materials from the same supply. It is therefore inferred that the Skerries Grits are a northern, gritty facies of part of the Church Bay Tuffs; and, as their quartz (see p. 59) is largely pyroclastic, the difference is less than appears at first sight. In the Trwyn Bychan band, Church Bay types act as a matrix to the part of the Skerries Grits with which they alternate. Reasons have already (p. 62) been given for referring the Tyfry Grits to the Skerries Group, in which case they must be regarded as an eastern facies of the Church Bay Tuffs. The pyroclastic nature of some of the hornfels of the Coedana granite has already been dwelt upon; and the field-aspect of the crypto-crystalline variety often recalls that of the Church Bay Tuffs. Thin short basic bands occur in both (see pp. 94, 284, 334). Where least altered, the porcellanous epidosite of those tuffs is constantly suggested, and there is the same rare and impersistent bedding. The hornfels as a whole cannot possibly represent any of the well-stratified members of the Complex, and so the massive Church Bay Tuff is the only member which it can represent, a conclusion confirmed by its relations to the rocks of Bodafon.

The Gwna Group.—The identification of the Gwna Beds in the several districts, in spite of the disruption and deformation they have undergone, presents but little difficulty. The autoclastic mélange and green-schist have essentially the same characters all the way from Garth Ferry to Carmel Head and from Llanddwyn to the Corwas Inlier. In the Gynfor district there is but little volcanic matter, but as that is plentiful at Carmel Head and Wylfa there is no real northern facies. Now it is true that sediments like those of the Amlwch Beds could furnish a mélange and green-schist which might be confused with those of the Gwna Beds, so that reliance on the characters of these rocks alone might lead to erroneous correlations. The Gwna Beds, however, contain a quartzite, a limestone, a graphitic phyllite, and nodular jaspers which are peculiar to themselves, with spilitic lavas and tuffs that are unlike the spilitic lavas of the Amlwch series. Of the special members, only the jaspery phyllites could be confused; and the associated jaspers are quite unlike in the two cases. All or some of these characteristic members are found in every one of the Gwna districts, and it is they that sustain the correlation. All of them are present in the Middle Region, and the quartzite is never absent anywhere. In the Corwas Inlier it and the green-schist are the only members. In the Aethwy Region the lavas and jaspers are finely developed. At Gynfor they are on a very small scale, but the quartzite, limestone, and black phyllite attain their maximum. The Bodafon quartzite is assigned to this horizon, because (apart from its staining) it has all the usual characters of the Gwna quartzite, and differs widely from that of Holyhead, the only other quartzite of the Island, whose associates are totally absent at Bodafon, while the Bodafon Moor beds are certainly of Gwna type. Although there is no northern Gwna facies, there are western and eastern facies, parted by a line, or group of lines (which are not laid down on the maps), running up Gwna Vale, and thence east of Mynydd Bodafon to Llaneilian. In the western facies the limestones are grey, with graphitic phyllites, the quartzite rather thick, and the spilitic lavas very thin. In the eastern facies the graphitic phyllite is absent, and many of the limestones are manganous and full of spilitic lapilli ; while the lavas are vastly thicker, appearing on two horizons (the Engan and the Llanddwyn spilites), with one of which there are spilitic tuffs. The alternating grits and phyllites (now largely autoclastic mélange) also thicken enormously. Thus : the western facies is dominantly sedimentary and relatively thin as a whole ; the eastern facies contains a great volcanic development and is very thick. No transitional facies appear even along the parting line. That line is also the parting between the Church Bay Tuffs and Tyfry Beds, which are southern and eastern facies of the Skerries Group.

The Fydlyn Group, in anything like its original condition, is known only at the Fydlyn Inlier. No other facies has as yet been detected, though there is reason to suspect (see p. 233) that it thickens greatly in a south-easterly direction.

The Penmynydd Zone of Metamorphism.—Evidence as to the horizon of the recognisable parts of the Penmynydd Zone has already been given in considering the origin of its rocks. The sedimentary component is undoubtedly the Gwna Group. A suggestion was thrown out on p. 127 that the felsitic element (always largely, sometimes wholly, sodic) might represent the Fydlyn rocks. Good evidence for that suggestion will presently appear.

The Gneisses.—With regard to the mutual relations of the gneisses, there need be no hesitation in regarding those of all the several inliers as essentially one and the same formation or metamorphic zone. The same albite-granites, and the same albite-oligoclase-biotite-gneisses, with the type-mineral sillimanite, are common to them all.

The Coedana granite, with its porphyritic orthoclase and hornfels-alteration, is regarded as distinct—a later intrusion from a potassic magma.

Order of Succession.

Evidence as to the order of succession of the greater clastic subdivisions of the Complex is to be found in its western tracts to the south of the Carmel Head thrust-plane, untroubled by any change of facies. But the link between the Skerries and New Harbour

Groups is much better exposed in the Northern Region, so that if the correlations just now made have been correctly made, the chain of evidence is complete. In which direction that succession should be read, which, that is to say, is its true order chronologically, will be considered further on.

The key to the succession is in Holy Isle.

Holyhead Quartzite and South Stack Series.—By the road along the south side of Holyhead Mountain, on each side of the word 'Reservoirs,' felspathic massive grits with seams of mica-schist of the same type as those of the great cliffs that look down upon the South Stack, rise from below the Holyhead Quartzite and graduate up into it. On the high moor to the east of the Stack two small outliers of white quartzite rest, infolded, upon the South Stack Series (Fig. 28). At and west of Ynys Wellt point the South Stack Series graduates imperceptibly into the quartzite. On the cliffs of Rhoscolyn (Folding-Plate II) the quartzite is seen six times to rest upon or be folded into the South Stack Series, the junction being

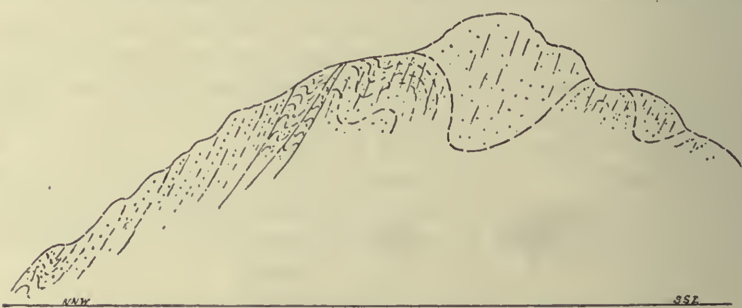


FIG. 28.—INFOLDED OUTLIER OF HOLYHEAD QUARTZITE ON THE SOUTH STACK MOOR.

At the 500-foot contour. Height of section, 60 feet.

conformable to the bedding of that series. At Rhoscolyn Head the change is so gradual that the line drawn is really arbitrary. In the chasm 200 yards to the south-east of the Head the junction (rather sharper) is clearly seen on the face of a great cliff. The South Stack Series and the Holyhead Quartzite are therefore adjacent members of the succession.

South Stack Series and New Harbour Beds.—The South Stack Series (and always its Llwyn member) is also seen, at a number of places, in relation to the Green-mica-schists, and the junction is clearly exposed at three sections near Stryd; at the large 'H' to the west-south-west (Cae-allt-wen crag of six-inch map); by the dyke on the Porth Dafarch road; at and east of Bodwradd; by the Lifeboat Station, Rhoscolyn; in Borth Wen; and at three sections on the curve thence to Pentre-iago. At all these sections there is a rapid but unbroken change from the one type of sedimentation to the other. Further, at all of them (except the northern Stryd section, which is not quite deep enough—see p. 266), and at some ten places more, where, without actual exposure of the junction, the two series are seen close together, a little albitic basic band (Figs. 29, 30, 31), usually from

FIG. 29.—SPILITIC TUFF AND PASSAGE BEDS.
Crag at small farm (Cae-allt-wen) north of 'H' of 'Holy.'
Scale, 24 inches = one mile. SSS = South Stack Series. ST = Spilitic Tuff.

six to twelve inches thick, is found. It is not at the junction, but about a yard within the Green-mica-schists, graduating into them, and is undoubtedly a basic tuff. At Borth Wen, Rhoscolyn, it thickens out to several yards, and assumes the characters of the spilitic lavas of the group, but thins rapidly to six inches when followed round the curve. At more than twenty places, therefore, a thin spilitic tuff is found within the Green-mica-schists, always about a yard from the junction with the South Stack Series. That junction, consequently, must be regarded as a true horizon.

FIG. 30.
SPILITIC TUFF AND PASSAGE BEDS.
500 yards north of west of Bodwradd.
(Llwyn Beds taken in on pitch immediately to north-east.)
Height, about 20 feet.

But if the South Stack Series be adjacent to the quartzite on the one hand, and to the New Harbour Beds on the other, they must lie between those two, which they can actually be seen to do between Rhoscolyn Hill and the Lifeboat Station, so that the succession in Holy Isle is :

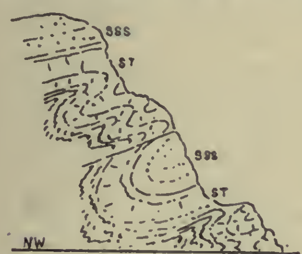


FIG. 31.
SPILITIC TUFF (ST), PASSAGE-BEDS, AND SOUTH STACK SERIES (SSS),
At Lifeboat Cove, Rhoscolyn.
Height, about 30 feet.

Holyhead Quartzite.
South Stack Series.
New Harbour Group.

New Harbour and Skerries Groups. At Porth-y-defaid the New Harbour Beds are succeeded by the main mass of the Church Bay Tuffs ; but there is evidently a rupture, for Gwna Beds are brought against the same line inland, and a (later) dislocation is actually visible on the low foreshore. Yet on the north side of this there is a 50-foot band of green-mica-schist, finer than that to the south, but, like it, containing thin seams of jaspery phyllite. It would appear, therefore, that the dislocation is dying out seawards and that the margin of the New Harbour Beds just escapes upon its further side. This band is highly epidotic, and graduates in clear exposures into the Church Bay Tuffs, which also contain thin purple seams for a few yards more. At their northern end close to Yr-ogo-goch (though the New Harbour Beds do not appear) the tuffs contain many thin bands of pale bedded jaspers and green grits like those found at the margin of the New Harbour Group. Bands of the tuff, somewhat metamorphosed but easy of recognition, alternate with the New Harbour Beds (there also containing purple phyllites) at Brwynog. A few yards east of Llanddeusant Church a massive epidositic tuff of Church Bay type appears among, and graduates into, the Green-mica-schists; and a very fine one with wriggling veinlets like those of Llanrhyddlad behaves in the same way on the coast at Penial. Whether these be nips of the main tuffs is not known, but even if not, they show that explosions of the same kind were taking place during the deposition of that part of the New Harbour Group. At the Garn, typical Church Bay Tuff, highly sheared, succeeds the Green-mica-schist all across the inlier (Folding-Plate IX). The actual junction is not laid bare by any one section, and as the change, where it occurs, is a little more rapid than would be expected at a passage, there may be a small rupture. Only a small one, however, for the approach to the change is quite gradual, both rocks passing into a fine crypto-crystalline platy schist of intermediate character. In the New Harbour Beds, a few yards from the line, is a band resembling the tuff, also a thin basic schist with bedded pale jaspers; and similar jasper occurs also in the tuffs for a few yards close by, thus indicating a natural junction. None of these sections, taken by itself, furnishes a demonstration, but taken together they leave no serious doubt that the New Harbour Beds are adjacent to the Church Bay Tuffs.

Passing to the Northern Region, it will be found that the relations between the Amlwch Beds and Skerries Grits are absolutely clear. On the rugged western cliffs of Bull Bay thin hard bands begin to appear in the southern part of the massive Skerries Grits, and increase in numbers until there is a perfectly gradual passage by change of material, into the Amlwch Beds. Indeed, the position chosen for the boundary is arbitrary, and intermediate types are found all along the line to the westward, inland. Thin jaspery phyllites, which occur in the gritty tuffs to the north of the junction, also knit the groups. At the east end of the Middle Mouse a massive purple-green pebbly tuff, intermediate between the Tyfry and the Skerries types, graduates by alternations into flaggy Amlwch Beds. A similar tuff appears among the Amlwch Beds, and displays the same relations, at Porth-y-gwartheg.

Along the southern side of the main outcrop of the Skerries Grits, especially at the ‘a’ of ‘Llanfechell,’ at Bwlch, and at Pen-yr-orsedd, the Amlwch Beds alternate with them for a few yards. But the finest section of all is where the same line runs out to sea at Llanrhwydrys Church. It should be visited at low water. Just beyond a small fault and a dyke is a cliff at whose foot the Amlwch Beds, typical thin hard grits with phyllites, dip under massive ashy Skerries Grits with little acid fragments. In the cliff itself thin fine beds occur among the coarse massive ones, both being impersistent, and the junctions being sometimes irregular and quite unsheared. There is a clear passage from the Amlwch to the Skerries Group. Indirect evidence of the stratigraphical unity of the two groups is found at Amlwch, on the cliffs 300 yards east of the end of the path that comes from the Coastguard Station, where the flaggy Amlwch Beds themselves are pebbly. Their junction with the Skerries Grits of the East Mouse cannot be many yards away beneath the sea. But the pebble contents of the Amlwch Beds are the same as that found upon the Mouse; indicating that, for some time, they were drawing their materials from the same source. If, then, the Amlwch Beds be rightly correlated with the Green-mica-schists of Holyhead, no doubt can remain that the Skerries Group and the New Harbour Group are adjacent members of the succession. On the western cliffs of Bull Bay the Skerries Grits are seen to lie between the Amlwch Beds and the Church Bay Tuffs.

Skerries and Gwna Groups.—That the Gwna Beds adjoin the Skerries Group is clear on both sides of the Carmel Head thrust-plane. At Brwynog, Rhyd-wyn and Gareg-lwyd to the south, and at Mynachdy, Caerau, and Llyn Llygeirian to the north of it, epidositic ashy matter of Church Bay and Skerries type is inextricably involved with Gwna Green-schist. At the south end of Porth Swtan the junction is exposed. The foreshore west of the '73' level is composed of typical Church Bay Tuff, in which are small fragments of a pink felsite. At the foot of the cliff close by, where the roadway comes down to the beach, the body of the rock is identical with the decomposed parts of the tuff and, like it, homogeneous, with fresh portions that are good epidosites. In this material the first Gwna quartzites appear, above them foliation sets in, with broken banding, and the whole passes rapidly into decomposing Gwna mélange with many small quartzites, but still ashy between them in places. On the headland south of Porth-yr-hwch (Folding-Plate X) a clear passage is again seen from one group to the other. A few thin short bands of hard fine siliceous grit appear in the tuff, then these increase in number, and in a few yards the rock becomes a typical Gwna mélange, in which, a little distance to the south, are quartzites, limestones and spilites. Inland, on the same line, a passage of the same kind is to be seen in the ravine a little west of Pant-yr-eglwys alluvium. All along that line and along the lines of junction to the north-west and north of Llanrhyddlad Church intermediate types are met with, and the boundaries laid down upon the maps are more or less arbitrary. At the Garn Inlier (Folding-Plate IX) the Church Bay Tuffs are succeeded by Gwna mélange, and the junction is well exposed on the escarpment a little way below the summit. Just as at Porth-yr-hwch, fine siliceous grits begin to appear in the previously homogeneous tuff. These grow more numerous; and, the heterogeneous mass at once breaking up under the shearing stresses, we pass in a few yards into Gwna mélange, in which lenticular quartzites then appear. Its matrix is still ashy even at the crest of the escarpment. The same junction is well seen at Hell's Mouth, both on the reefs at the beach and in a rocky chasm a few yards east of them. There is a vertical shear-plane in the chasm, but it is not the boundary, for it lies within the Gwna Beds. In the green tuff, here unusually schistose, a few small autoclasts of pale Gwna grit begin to appear, and then increase in numbers across a width varying from two or three feet to several yards, until the rock has become a typical autoclastic mélange chiefly composed of grit, with here and there a calcareous phacoid. But, though the grits are pale grey, the schistose matrix of the mélange is at first green and full of the fine reconstructed pyroclastic matter of the tuffs, like the usual Gwna mélange further south. There is therefore a passage, as at the other sections.

Such are the best sections across this junction. They leave no doubt that the Gwna lies next to the Skerries Group in the succession, graduating into it. Gwna mélange (pp. 354—6) appears within the Tyfry Beds in the Pentraeth Inliers, and their shear-cleavage is one with the foliation of that mélange, while purple beds like those common in them are incorporated into Gwna Green-schist at Bryn-gwallen. On the shore of the Aethwy Region to the north-east of Garth Ferry (p. 359) the Gwna grits contain fragments of keratophyres like those in the Tyfry grits, and of albite-quartz-felsites and albitic hypabyssal rocks like those of The Skerries. In the Dingle at Llangefni the grits of the mélange contain deformed pebbles an inch and a half in length which are identical with the hypabyssal albitic boulders of The Skerries, demonstrating that the Gwna Beds were then drawing their materials from the same source as did the Skerries conglomerates.

Passage-beds, intermediate in character between Skerries and Gwna type, are well seen about Nant-newydd, Llangefni. At Llangristiolus, 160 yards east of the late dyke and 60 yards north of the footpath to Llan-fawr, is a craglet escarpment that shows bedding well. At its foot are ashy grits with green partings, in which are purple seams just as in the undoubted Tyfry Beds a few yards to the south. At its brow the grits become siliceous and thinner, and at once break down into lenticular mélange with small quartzites. There is a clear passage from the Tyfry to the Gwna Beds by thinning of the beds and by decrease of pyroclastic matter. The same is the case in the railway cuttings at Bodorgan and on the coast near Twyn-y-parc. On the craggy brow south of Porth-ro there is a passage from Tyfry to Gwna phyllite. The Tyfry Beds, therefore, stand in the same relation to the Gwna Beds as do the Skerries Beds with which they are correlated.

At Mynydd Bodafon the massive hornfels graduates into the beds (themselves converted into hornfels) that 'underlie' the Bodafon quartzite. Here also, then, The Skerries and Gwna Groups adjoin and alternate with each other; thus confirming, moreover, the identifications of the hornfels and the Bodafon quartzite with members of those groups.

Gwna and Fydlyn Groups.—At Fydlyn the gritty felsitic tuffs alternate for a few yards with Gwna Beds (Fig. 32), and are twice seen to graduate into the Gwna mélange between there and Trwyn Crewyn. The Fydlyn rocks are therefore closely linked with the Gwna Group. As they are not seen at the junction with the Church Bay Tuffs they must lie on that side of the group which is remote from the Skerries Beds.

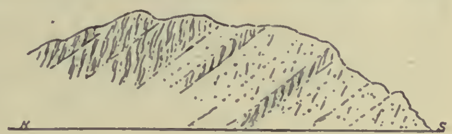


FIG. 32.

PASSAGE FROM FYDLYN TO GWNA BEDS.
About 10 feet high.
Brow of Fydlyn Cliff.

The Coeden Beds.—The position of the Coeden Beds may now be considered with advantage. It has been shown that they are more nearly related lithologically to the Llwyn part of the South Stack Series than to any other member of the Complex, and that they cannot be identified with the Skerries Grits. Along their northern margin they adjoin the Amlwch Beds, and are knit with them by a zone of rapid alternation, so that they undoubtedly succeed the Amlwch Beds in the direction away from the Skerries Grits. That, further south, is precisely the position of the South Stack Series relatively to the New Harbour Beds and Church Bay Tuffs. Those two groups, however, are identified with the Amlwch Beds and Skerries Grits. The Coeden beds, therefore, may be with confidence regarded as a facies of the South Stack Series.

Correlating, then, the Northern Region with the remainder of the Complex, we have

THE BEDDED SUCCESSION.

South.	*North.*
Holyhead Quartzite.	
South Stack Series.	Coeden Beds.
New Harbour Beds.	Amlwch Beds.
Church Bay Tuffs.	{ Skerries Grits. Church Bay Tuffs.
Gwna Beds.	Gwna Beds.
Fydlyn Group.	

It will be seen that the correlations made on lithological grounds are sustained in every case by the positions of the beds in the respective orders of succession. The foregoing members constitute that portion of the Complex which will be referred to as 'The Bedded Succession.'

The Penmynydd Zone is not, indeed, a stratigraphical horizon. But we have seen (pp. 122–6) that its rocks are partly a crystalline condition of the Gwna Beds, partly altered felsite and felsitic tuff. These acid volcanic rocks, therefore, adjoined the Gwna Beds in the succession, but no such rocks are found at the junctions with the Skerries Group, or in that group itself. No facies of that group found in the Middle or Aethwy Regions could have yielded such a product as the Penmynydd acid mica-schists of those regions. The Fydlyn rocks, however, could ; and we have seen that they adjoin, and that their felsitic tuffs graduate into, the Gwna sediments on their other side. The felsitic parts of the Penmynydd schists may, therefore, be correlated with the Fydlyn rocks.

Position of the Gneisses.—The position of the Gneisses remains to be considered, but our knowledge is unsatisfactory, for there are no sections displaying their original relations to any rocks of known horizons. The Nebo Inlier and those about Llanerchymedd and Bryngwran are completely isolated by Ordovician rocks. But they all lie on one great curving zone of strike, and as the small inliers are manifestly one with the great gneiss of the Middle Region, it is clear that a continuous floor of gneiss must range beneath the Ordovician rocks all through the central parts of Anglesey. The gneiss of the Gader Inlier is faulted, on the cliffs, against Gwna mélange full of lenticular grits in a slightly anamorphic matrix. The rocks are in totally different crystalline conditions, and a passage is impossible. At Mynachdy, north of the 'h' and below the drive, Gwna phyllite and quartzite are seen only about nine inches from gneiss, but there is no change in the Gwna rocks, and the junction must be a rupture. The gneiss of the Middle Region is isolated from the remainder of the Complex by the great Coedana granite. At Gwyndy it is seen very close to two of the hornfelses of that granite (which are believed to be modifications of the Church Bay Tuffs), but the change of type is abrupt and the junctions not exposed. On the Holyhead road, between Caerglaw and the ninth mile-post, gneiss and mica-hornfels strike at one another, and a passage is suggested. But again the rocks of the nearest exposures are contrasted, on the north being thorough gneiss, on the south being thorough hornfels ; and as the hornfels is a little crushed in the crag that overlooks the road, there is doubtless a fault running east and west, as is indicated by the features. At Holland Arms, on the edge of the high wood, south of the 're' of 'Pentre,' there is a 30-yard band of coarse micaceous gneiss along the edge of the basic ones. Just outside the wood, close to the gneiss, is a hard siliceous rock with large micas which appears to be an unusual modification of the Penmynydd schists, but it is poorly exposed and the junctions are not seen. All the known junctions are therefore either faulted, thrust, or hopelessly obscure. It is to be noted, however, that wherever gneisses appear the adjacent member of the Complex in their immediate neighbourhood is either the Gwna Beds, the Gwna-ward portions of the Skerries Group (of which the hornfels appears to be a modification), or the Penmynydd schists ; never any member of the Holyhead Group. Whatever their true relations, then, they may with confidence be placed at the Gwna-ward end of the succession. And as the Fydlyn and Gwna rocks are interbedded at their junction, the Gneisses must be placed at the extreme end beyond the Fydlyn Group.

Tabular Statements of the Succession.

The successions in the several regions and inliers are therefore as follows. And the general succession in the Complex may be taken to be as in the table given on p. 164.

Local Successions.

Holy Isle.

Holyhead Quartzite
South Stack Series
New Harbour Beds

Western Region.

New Harbour Beds
Church Bay Tuffs
Gwna Beds (W.)

Fydlyn Inlier.

Church Bay Tuffs
Gwna Beds (W.)
Fydlyn Beds

Gader Inlier.

Gwna Beds
Gneiss

Garn Inlier.

New Harbour Beds
Church Bay Tuffs
Gwna Beds (W.)

Corwas Inlier.

New Harbour Beds
(Church Bay Tuffs ?)
Gwna Beds

Northern Region.

Coeden Beds
Amlwch Beds
Skerries Grits
Church Bay Tuffs
Gwna Beds (W.)
Gneiss

Deri Inlier.

Penmynydd Zone (Gwna)

Nebo and Llanerchymedd, &c., Inliers.

Gneiss

Middle Region.

Tyfry Beds
Gwna Beds (E.)
Penmynydd Zone (Gwna W.)
" " (Fydlyn)
Gneiss

Pentraeth Inliers.

Tyfry Beds
Gwna Beds (E.)
Penmynydd Zone (Fydlyn)

Aethwy Region.

Tyfry Beds
Gwna Beds (E.)
Penmynydd Zone (Fydlyn)
Gneiss

No reason has been given, so far, for placing the Holyhead Quartzite towards the top, and the Fydlyn Group towards the bottom of the table. The reasons will be given on pp. 165—6. The reasons for placing the Plutonic Intrusions above the Bedded Succession will be found on p. 167. The Penmynydd Zone has been included in the table because of its great importance in the Complex. But it is included, not as a stratigraphic but as a metamorphic zone, and the reason for placing it at the top will be found on p. 167.

THE GENERAL SUCCESSION.

	GROUP NAME.	SOUTHERN FACIES	NORTHERN FACIES	WESTERN FACIES	EASTERN FACIES	
	PENMYNYDD ZONE OF METAMORPHISM -	Correlated in part with Fydlyn and Gwna Groups.				Mica-schist, quartz-schist, limestone, graphite-schist, hornblende-schist, glaucophane-schist.
	PLUTONIC INTRUSIONS	—	—	—	—	Coedana granite, diorite, serpentine-suite.
THE BEDDED SUCCESSION. / HOLYHEAD GROUP	HOLYHEAD QUARTZITE	—	—	—	—	Massive quartzite.
THE BEDDED SUCCESSION. / HOLYHEAD GROUP	SOUTH STACK SERIES	South Stack Series 2. Stack Moor Beds 1. Llwyn Beds	1. Coeden Beds	—	—	Massive schistose grits with partings of mica-schist. Thin-bedded ditto, ditto.
THE BEDDED SUCCESSION. / HOLYHEAD GROUP	NEW HARBOUR GROUP	New Harbour Beds 2. Celyn Beds 1. Soldier'sPointBeds	Amlwch Beds 2. Bodelwyn Beds 1. Lynas Beds	—	—	Thin tuff-schist. Fissile green-mica-schist. Gritty green-mica-schist, with bedded jasper, jaspery phyllite, and spilitic lava.
THE BEDDED SUCCESSION.	SKERRIES GROUP -	Church Bay Tuffs	Skerries Grits Church Bay Tuffs	—	Tyfry Beds	Massive tuffs, and ashy grits and conglomerates. Bedded ashy grits in east.
THE BEDDED SUCCESSION.	GWNA GROUP - -	—	—	Gwna Beds Attenuated and chiefly sedimentary.	Gwna Beds Thick and with much volcanic matter. Black phyllite absent.	Alternating grit and phyllite, autoclastic mélange, and green-schist. Quartzite, limestone, graphitic phyllite, jasper, jaspery phyllite. Spilitic lava, tuff, and albite-diabase, often passing into chlorite-epidote-schists.
THE BEDDED SUCCESSION.	FYDLYN GROUP - -	—	—	—	—	Acid lavas and tuffs with thin sediments. All schistose.
	THE GNEISSES - -	—	—	—	—	Basic and acid gneiss with granitoid matter.

Chronological Order of the Succession.

There seems no doubt that this is the real succession in the Complex. But nothing in the succession itself, or in the field-relations of its members, affords any evidence as to its true chronological order, except the circumstance that the Gneisses, its most deep-seated member, are found at the Fydlyn-ward end, which suggests that in that direction the lower and older beds may be at least expected. The state of alteration of the clastic members proves nothing, for, although the Gwna Beds usually display a low grade of alteration and the Holyhead Group a high one, yet in the Penmynydd Zone the Gwna Beds are as highly crystalline as anything at Holyhead.

There is, however, one piece of evidence that is of great weight, if, indeed, it be not conclusive. As well as their boulders of unknown igneous rocks, the conglomerates on The Skerries have yielded some pebbles of white quartzite and scarlet jasper. The quartzite is fine, unfoliated, and not of Holyhead but of thorough Gwna type. The jasper is unmistakable; it is the type known only in the spilitic lavas and limestones of the Gwna Group. Smaller fragments of the same quartzite and jasper are also found here and there in the Skerries Grits upon the mainland of Anglesey. There can be no doubt, therefore, that the Skerries Grits are later than the Gwna Beds. But, if any member of a given succession can be shown to be later than any other member, that carries with it the chronological order of the whole of that succession. The Fydlyn rocks, then, will be taken to be the lowest, the Holyhead Quartzite the highest member of the sedimentary and volcanic series of the Complex; the Gneisses the lowest member of the whole Complex.

There is confirmatory evidence. Fragments of quartzite of Gwna type are found in the Church Bay Tuffs, the Amlwch Beds, and the Green-mica-schists of Holyhead; and small fragments of scarlet jasper in the South Stack Series and the Holyhead Quartzite. No fragments indicating a contrary succession are known.

It will be well to tabulate the composite (and a few simple) fragments that have been found in the Complex altogether.[1] The following members of the succession have yielded the fragments that are enumerated in the right-hand column:—

HOLYHEAD QUARTZITE. Jasper, granoblastic rocks, mica-schist, Gwna quartzite (?).

[1] These fragments may be seen in the following (among other) slides and specimens:—
In Holyhead Quartzite, E. 10128.
" South Stack Series, E. 10131, 10135, 10137, 10570.
" New Harbour Beds, E. 10150, 10156.
" Amlwch Beds, uncut specimens.
" Church Bay Tuffs, E. 10370, and specimens.
" Trwyn Bychan Tuffs, E. 10513, 11251.
" Skerries Grits on Main Island, E. 10384, and specimens.
" " " East and Middle Mouse, E. 9319—24, 10511, and specimens.
" " " The Skerries, E. 10579—98, and specimens.
" Tyfry Grits, E. 9839, 10009, 10074, 10116—19, 10198—200, 11250.
" Gwna Grits, E. 10105, 11038, 11196, 11249.
" Gwna Quartzite, E. 9801, 9954, 10196.

SOUTH STACK SERIES.	Jasper, Gwna quartzite, schistose grit, hypabyssal albite-rocks, granoblastic rocks, mica-schist, blue quartz, tourmaline-mica-schist, granite, gneiss.
NEW HARBOUR BEDS.	Gwna quartzite, granite.
AMLWCH BEDS.	Gwna quartzite, green grit, pegmatitic felsite.
CHURCH BAY TUFFS AND SKERRIES GRITS.	Pegmatitic felsite, pegmatitic albite-granite, Gwna quartzite, Gwna jasper, green grit, purple grit and mudstone, keratophyre and spilite, schistose grit, granoblastic rocks with mica, mica-schist. *Fragments within these pebbles.*—Spilite and keratophyre, granoblastic rocks, mica-schist.
TYFRY GRITS.	Albite-trachyte, keratophyre, spilite, quartz-felsite, tourmaline-mica-schist, gneiss (?).
GWNA GRITS.	Keratophyre, albite-quartz-felsite, hypabyssal albite-rocks, micropegmatite, granite, schistose grit, quartz-schist, mica-schist.
GWNA QUARTZITE.	Spilite, granoblastic rocks with mica, mica-schist, tourmaline.

The green grits and the purple grits and mudstones may be from the Gwna Beds, and the keratophyres and albite-trachytes are doubtless from unexposed parts of the Gwna spilite-magma. The pebbles of the Skerries Grits (unless detached and brought into those beds by volcanic explosions) imply some degree of unconformity between the Skerries and the Gwna Groups. South of the Carmel Head thrust-plane the two groups appear too closely knit for this to be admissible. It is true that the Tyfry Beds appear to rest, sometimes on the spilite-limestone group, sometimes on other Gwna sediments, but there is too much disturbance in those regions for unconformity to be affirmed with confidence. In the Northern Region a break (masked by deformation) is admissible, but it is probably quite a local one, such as may easily occur in volcanic districts. Not a single fragment that can be recognised as from the Gwna rocks displays the slightest foliation or deformation of its own. All the evidence, whether of pebbles or of junction-sections, indicates that, at the time when the Skerries Beds began to be laid down, the Gwna rocks had not been affected by any regional metamorphism. Incidentally, the pebbles reveal the interesting fact that the Gwna sands and cherts must have been quartzitised and jasperised at a very early period, long before that of the regional metamorphism of the Complex.

Turning to the other pebbles, the great igneous boulders of The Skerries indicate that acid hypabyssal rocks were then undergoing erosion, and from the size of the boulders it is clear that they were exposed to waste at some place very near The Skerries. The less deep-seated of them had been exposed somewhat earlier, small fragments of such being found in Gwna grits. They must be of great antiquity: but they cannot be *in situ* anywhere in Anglesey, and their source remains unknown. The Skerries conglomerates, coarse though they be, represent only a local platform of erosion ; and, of the Gwna sediments, even the coarsest are but grits. The true base of the whole clastic series of the Complex must therefore be lower down, and it still eludes us.

Chronology of the Plutonic Intrusions.

The Coedana Granite is injected into the Gwna rocks and Skerries Group, the Serpentine-suite into the New Harbour Beds. But it has been further shown that the thermal alteration induced had in each case been preceded by some degree of deformation, and in the case of the Coedana granite by folding, though the intrusive rocks themselves underwent afterwards both deformation and anamorphic reconstruction. The plutonic intrusions can therefore be assigned to an interval or intervals in the great earth-movements of the Complex. Some light will be thrown (see pp. 208, 211, 277) on the dates of these intervals by the tectonic relations of the intrusions.

As the *Serpentine-suite* have suffered more deformation than the Coedana granite, their foliation being locally folded and their tremolite-schists highly anamorphic, it is reasonable to suppose that they are somewhat older. The Plutonic sequence would thus be : Peridotite, Pyroxenite, Gabbro, Granite.

The Penmynydd Zone of Metamorphism we have seen to be later than the intrusion of the Coedana granite.

The Relations of the Gneisses to the Bedded Succession.

A question that still remains over is that of the true relations of the Gneisses. It appears, from the evidence that has just been given, that they must, as far as mere position is concerned, be placed below the Fydlyn and Gwna rocks, and thus at the bottom of the whole succession. Is their metamorphism, however, the same as that which has affected all the rest of the rocks of the Complex ; or are they portions of an ancient gneissic floor, whose metamorphism was produced before the deposition of any of the members of that succession ? A conclusive answer cannot as yet be given to this question, but some evidence is available, and that on both sides will now be set forth.

Their proximity to the Coedana granite in the Middle Region certainly suggests that they are genetically connected with it, and that their metamorphism is, like that of the Penmynydd Zone, a part of the regional metamorphism of the whole Complex. We have seen, however, that the felspars of the two rocks are different, and that the granitoid element of the gneiss cannot be the Coedana granite. And as the Coedana hornfels is a far less deep-seated product than the gneiss, the two cannot have been produced in the same thermal zone. The diorite of Llangaffo cutting (see p. 99) appears to have been an intrusion into

Fydlyn or Gwna rocks now converted into Penmynydd mica-schist, but it is very doubtful whether it can be identified with the basic portions of the gneiss. No boulders of the Gneisses have as yet been found in the Skerries conglomerates, nor have any that are undoubtedly from them been found in any member of the succession.

On the other hand, a fragment of a coarse muscovite-biotite-gneiss [E. 10135] has been found in the South Stack Series; another, less certain in character [E. 10200] in the Tyfry grits; large plates of white mica like that of the fragment in E. 10135 are not uncommon in the coarser grits of the Complex, while small granitoid pebbles are occasionally seen, and felspars of granitoid aspect are abundant. The position of the Gneisses below the whole known sedimentary series points, it would seem, to their being an ancient floor. In the Middle and Aethwy Regions, their strike is often north-westerly, as if it were a survival of the effects of movements older than those which (there striking persistently north-east) have incorporated them into the Complex. Moreover, in spite of their lepidoblastic seams, they are seldom sharply folded, as though they were parts of a massive ancient floor that was already comparatively rigid. Their position in the Middle Region is not easy to account for on either hypothesis, and is probably due to an ancient folded thrust-plane, bringing them against the Church Bay Tuffs (see pp. 221, 184), which has been obliterated by the great flood of the Coedana granite. It is noteworthy that, whereas the crystalline condition of the members of the Bedded Succession varies considerably from place to place, that of the Gneisses is always the same. Wherever they appear, whatever the state of the adjacent rocks, the Gneisses are always, and right up to the junctions, the same coarsely and plutonically crystalline products that have been described on pp. 128—143. Their crystallisation appears, therefore, to be independent of that of the Bedded Succession, appears to be their own, and consequently anterior to the deposition of that succession. The strongest evidence yet known as to their age and relations is derived from certain places (pp. 177, 216) (Fig. 94) where the succession is known to be inverted, and where they are found adjacent to the Gwna Beds, overlying them in secondary synclinal nips. Now, at such places, the Gwna Beds are strongly autoclastic and very slightly re-crystallised, but there is a steady progressive metamorphism as we pass from them to the tectonically lower and lower members of the (inverted) succession. The Gwna Beds, that is to say, though just at the lower margin of the zone of fracture, are slightly anamorphic. Yet the gneiss that overlies them is texturally as highly crystalline as it is anywhere. But it is heavily crushed and its coarsely crystalline structures broken down. Though now almost in the same zone of the earth-crust, the Gwna Beds are slightly anamorphic, the Gneisses are wholly and severely catamorphic. It follows that the deep-seated crystalline characters of the Gneisses, their characters, that is to say, as gneisses, must be older than the deposition of the Gwna Beds, and, consequently, older than that of the Fydlyn Beds. There must therefore be an unconformity of the first magnitude between the Gneisses and the remainder of the Complex. But this unconformable junction has never been found. Within the limits of Anglesey, at any rate, it is probably cut out everywhere by thrusting. When the structures of the Complex come to be considered, it will be seen that along such thrust-planes (pp. 204, 209) foliation has developed, masking their nature as disruptions, and that they have been also folded. The balance of evidence, therefore, is in favour of regarding these gneisses as parts of an ancient floor. But the preceding argument, though strong, is indirect, and is not a demonstration.

The Ancient Floor.

That the Bedded Succession of the Mona Complex rests unconformably upon a yet more ancient foliated complex, whose foliation was complete, not only before the Mona metamorphism but before the deposition of the sediments now involved in that, is, however, certain. From the fragments contained in tho Complex here and there, we get, even if the visible Gneisses form no part of that old floor, some dim light as to its nature, and see that it included schistose grits, mica-granulites, mica-schists, and tourmaline-mica-schists, with granitoid and also gneissose rocks.

Note.—In this chapter, attention has been focussed upon the succession of the *main* divisions of the Complex. The relative positions of the *sub-divisions* have been, in several places, implied; but full evidence would have involved detail that might have rendered this chapter too intricate. Where the positions of sub-divisions are known they have been placed in that order in the table on p. 164. The evidence will be found in chapters VIII and X, particularly in chapter X, and on pp. 383—5. In the latter place more precise particulars will also be given with regard to the stratigraphical horizons on which the Penmynydd metamorphism is known to develop.

CHAPTER VII.

THE TECTONICS OF THE MONA COMPLEX.

Introductory.

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

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

THE MAXIMUM PRIMARY STRUCTURES.

Evidence for Inversion.

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

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

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

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

The hade of the North Stack fault is seen at the Bwa Du and at Porth y Post, but a much finer section is that on Holyhead Mountain, at the curve of the Gigorth cliffs. Looking southward from the North Stack Signal Station, the fissure of the fault can be seen high up on the mountain side, a dark chasm, hading to the east about 10° from the vertical (Fig. 33).[1] The chasm can be visited from above. Its walls are very even, and seem from that view-point to hade at 15° or more. It is perhaps 100 feet deep to the steep

Fig. 33.
The North Stack Fault,
Seen from the Signal Station.
Height, 400—500 feet.
HQ=Holyhead Quartzite.
SSS=South Stack Series.

[1] There is a photograph in the Survey collection (No. 1288) that shows this chasm quite clearly. But it was taken late on a summer evening, and would not furnish a satisfactory reproduction for this volume. Fig. 33 is therefore substituted.

scree below, is 10 or 12 feet wide, and filled with breccia from side to side. Further details are given on p. 256. The fault determines the stupendous cliffs of the Quartzite (Plate XVI), and where it crosses the mountain gives rise to a strong line of Quartzite crags, which, seen in profile, are a conspicuous feature for many miles. Its throw is visibly 500 feet, but must really be a considerable multiple of that, as might indeed be expected from its 10 feet of breccia.

The Namarch fault is well seen at Porth Namarch. Its chasm in the main cliff is choked with fallen blocks, but about 34 yards to the north a large buttress of the South Stack Series has been left by the sea against the quartzite wall, and there the fault is clearly exposed, hading east at 12°-15° from the vertical (Plate XVII, and Fig. 34). The massive quartzite presents a smooth face, and

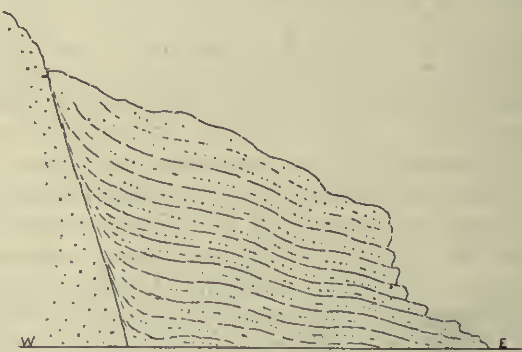


FIG. 34.—THE NAMARCH FAULT
at Porth Namarch.
Height about 50—60 feet.
South Stack Series to the right : Quartzite to the left.

the ends of the beds of the South Stack Series are distinctly dragged up as they sink down eastwards on the fault. There is very little breccia, but a slight schistosity parallel to the hade is induced in the sinking rocks, as if the fault were somewhat compressive, connected with which may be its ability to curve rather unusually in ground-plan. Its throw cannot be less than 720 feet, but must, like that of the North Stack fault, be vastly more than that.

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

The North Stack and the Sea Cliffs of the Holyhead Quartzite. From the South Stack Moor.
Height seen = 582 feet.

[Face page 172.

opposite directions on the two sides of the fault. On the western side the South Stack Series is overlain by the Quartzite ; on the eastern side it is overlain by the New Harbour Beds.

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

These anomalies cannot be reconciled by ordinary isoclinal folding, even though that be on the great scale that is revealed on the western coast, still less by normal folding.[1] They can be reconciled only by postulating very extensive inversions.

The Maximum Primary Folding as Revealed in Holy Isle.

A fundamental point is that both pitch and faults must be combining to bring in higher and higher horizons in a north-easterly direction. Let us first, then, consider the portions that lie to the south-west of the North Stack fault. At the Stack Moor, outliers of the Quartzite rest upon the South Stack Series (Fig. 28). At Rhoscolyn, infolds of the Quartzite are seen several times to rest upon the South Stack Series (Folding-Plate II), from beneath which in turn emerge the New Harbour Beds. So the order on this side of the fault is, all along, the normal one, with the Quartzite uppermost. On the other side of the fault, at Rhoscolyn, the order is, as we have seen, in the opposite direction, the New Harbour Beds resting on the South Stack Series. An explanation, therefore, can be found if we suppose that on the two sides of the fault in the Rhoscolyn area we see parts of two limbs of a great recumbent fold, the limb seen on the north-eastern side being inverted. But the north-eastern side is the downthrow side. The inverted limb, consequently, is the upper limb. The fold composed of these two limbs may be called the *Rhoscolyn Recumbent Fold*. It must have a horizontal amplitude of at any rate seven miles. Holy

[1] As far back as the summer of 1907 I had the advantage of taking my friend Mr. Clough over some sections in Anglesey, and mentioned to him some of the anomalies of the North Stack fault, upon which he replied that it would seem as if there must be inversions and recumbent folds like those then known in the Scottish Highlands. The Cowal Memoir (see, in particular, Figs. 47 and 52 of that work), it will be remembered, appeared in 1897, and Dr. Horne's interpretation of the Fannich folds in 1900. The classic work of Bertrand was published in the years 1883-5, his posthumous essay at the end of 1907 ; Lugeon's great paper in 1901. The remarkable paper by Mr. E. B. Bailey appeared in 1910. To it the reader may be referred for an interesting history of the development of this branch of geology.

Isle affords no evidence of the directions of gape and close, but some evidence is available from elsewhere, which will be given further on (p. 177). Anticipating that evidence, let us assume that it closes to the south-east and gapes to the north-west.

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

A question then arises as to where we pass from the Rhoscolyn to the Holyhead Fold, but it cannot be answered with precision, for the position must be somewhere in the three-mile tract of New Harbour Beds that forms the middle of the Isle, beds that are evidently doubled on themselves. An approximate indication can, however, be given, for though nearly all are Celyn beds, yet, about the alluvial belt that may be called the Tre-Arddur gap, are some flaggy psammitic rocks that are referred to the Soldier's Point horizon, and as these are to be expected in the core of the roll-over, the change of tectonic horizon may be placed in the Tre-Arddur gap. If, however, the roll-over between the two great folds were unbroken, it should take in as its core the whole of the lower part of the Mona succession, whereas nothing appears but New Harbour, and those almost entirely Celyn beds, the Soldier's Point beds being reduced to a small fraction of their normal thickness. We must therefore postulate a powerful rupture at this tectonic horizon, and as the roll-over has closed to the north and its upper limb is rolling southward, the slide is doubtless a thrust, which may be called the Tre-Arddur Thrust-plane. The extent of Celyn beds is indeed remarkable, but when rocks, especially crystalline schists, are powerfully folded, it may often be seen that the more yielding seams are packed and pushed forward in the cores of anticlines to lengths out of all proportion to their

Plate· XVII.

[Face page 174.

The Namarch Fault. Porth Namarch.

thickness, while innumerable minute thrust-planes appear in them, which may cause no rupture in the stronger beds outside (Figs. 43, 44, &c.). The Celyn beds, and even the Soldier's Point beds, being highly pelitic, would behave in this way on an enormous scale when caught in the cores of master-folds, and doubtless this is the cause of the width of their outcrop. An effect of the Tre-Arddur thrust-plane is to reduce to moderate dimensions the thickness of the folding masses towards Holyhead Mountain, and thus enable the faults to bring in more tectonic horizons than they could otherwise. Even as it is, their throws must be measured, not in hundreds but in thousands of feet.

We come now to the Namarch fault. The pitch going on as usual on both sides of it, and the fault itself being a downthrow on the north-east, it is doubly evident that whatever we meet with on that side must be something higher in the Complex than anything yet met with. Yet, instead of the Quartzite, it brings down, against the South Stack Series, New Harbour Beds of Soldier's Point horizon, which must, consequently, be on a higher tectonic horizon than the uninverted Celyn beds of Mynydd Celyn and Tre-fignath. They must be on the upper limb of the Holyhead Fold, and must be inverted. The Holyhead Recumbent Fold gapes to the north-west. A portion of its core is brought up (see pp. 210, 271—2) on a thrust-plane at the Breakwater. The South Stack Beds of this core are those which are brought down against the Quartzite of Holyhead Mountain by the Namarch fault.

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

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

(2) That the evidence admits of a consistent interpretation of this folding, and brings to light the presence of two recumbent master-folds, the Rhoscolyn and the Holyhead Folds, which are successive tectonic horizons.[1]

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

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

[1] For a section through Holy Isle, see Folding-Plate III, which should be read in conjunction with the lower two-thirds of the diagram, Fig. 35, p. 180. For other sections see Folding-Plates I, II, and Chapters VIII, X.

The Maximum Primary Structures on the Main Island.

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

In the Western Region and the Northern Inliers.

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

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

In the Northern Region.

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

Evidence for Directions of Close and Gape.

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

In the Middle Region and its Ancillary Inliers.

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

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

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

In the Aethwy Region.

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

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

Amplitudes, Facies, and Recapitulation.

We thus recognise the existence of three main, or (to adopt an adjective first used in the classification of the thrust-planes of the

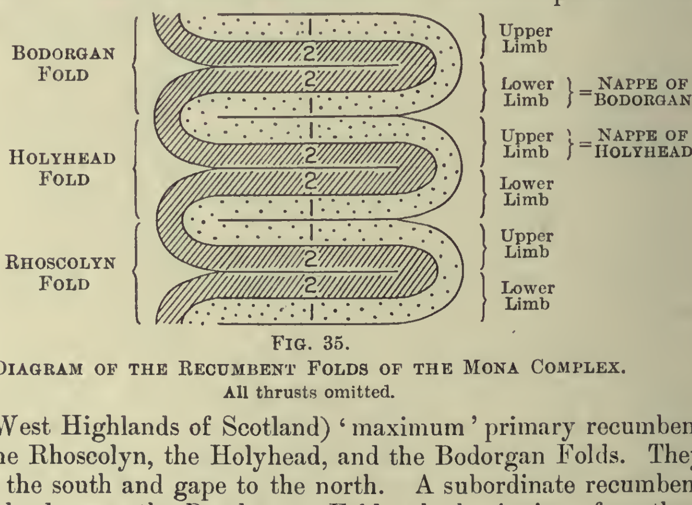


Fig. 35.
Diagram of the Recumbent Folds of the Mona Complex.
All thrusts omitted.

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

Amplitudes.—If the foregoing views be correct, it is possible to arrive at minimum estimates of the horizontal amplitude of these recumbent folds. The fragment that remains of the Rhoscolyn Fold extends from the North Stack (for the islet, as will appear on p. 207, must be placed on that fold) to the south coast of Holy Isle, so that the horizontal amplitude must be at least seven miles. How much further it extends is not known, for the rest of the lower limb has been destroyed by the sea. The Nappe of Holyhead, from where it disappears on the Bodorgan inliers to the north side of the Gader Inlier, is fourteen miles in length. To this must be added the width of the Northern Region, which is more than four miles. But that region has (see Chapter XVIII) been carried southwards on the Carmel Head thrust-plane a distance of at least twenty miles, which must therefore also be added. The total known length of the Nappe of Holyhead is therefore as much as thirty-eight miles. But, as will presently be seen, this measurement is of country that has been driven together by innumerable folds and thrusts at more than one epoch, so that its present can hardly be more than half its original extent. It is probably, therefore, not an excessive estimate to put the real horizontal amplitude of the accessible part[1] of the Holyhead Recumbent Fold at something like sixty miles. The amplitude of the Bodorgan Fold is not known. From the Menai Strait to the furthest outcrops of the Engan spilites at Trefollwyn is about seven miles, but the violent contrast between the two Gwna facies near Bodorgan shows that the same tectonic horizon must extend many miles beyond that; and it may be as extensive as any. Possibly the Gynfor over-roll, regarded as merely subordinate, may really be the beginning of the Bodorgan Fold.

Facies.—An interesting feature is the part played by facies. In the establishment of the correlations between the several members of the succession from region to region, facies presents an obstacle to be overcome. But once overcome, it is the greatest of aids in the interpretation of the structure, at any rate on the main Island,

[1] The true locus of close has never been found, and is doubtless outside Anglesey.

for without it the existence of the third great recumbent fold, the Bodorgan Fold, would never have been suspected ; and the directions of close and gape would have remained unknown. And the manner in which differing facies, on four different horizons, which must originally have been many miles apart, have been brought close together by the combined action of the recumbent folding of the Complex and of the Post-Ordovician Carmel Head thrust-plane, is most remarkable.

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

THE MAJOR, MINOR, AND MINIMUM STRUCTURES.

The Major Secondary Folds.

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

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

FIG. 36.
MAJOR ISOCLINES IN LLWYN BEDS
In the chasm of the dyke.
North cliffs of Henborth.
Height, about 200 feet.

Other Major Folds.

Studies of the major secondary folding in the several regions will be found in Chapters VIII, X; in Folding-Plates I—VIII, X; and in Figs. 91—4, 99, 156—8. Here, therefore, only a few

[1] A remark made on the spot by Dr. Flett, whom I had the advantage of taking there in 1907.

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

Major Thrust-planes.—Among the major secondary thrust-planes, the Bodfardden thrust-plane, driving northwards and waxing eastwards, nearly abolishes pitch in the southern part of the Western Region. In the Northern Region it is not always easy to distinguish the thrusts of the Complex itself from the great Post-Ordovician thrusts. But there is reason to think that the Wig (see p. 216) and Caerau thrust-planes (Folding-Plate V) belong to the major secondary movements of the Complex, and they must both be of great magnitude. They are carried forward by the Carmel Head thrust-plane. Other thrusts have developed along the Bwlch infold of the Skerries Grits. The Trwyn Bychan thrust-plane (Fig. 95) (which is at one place horizontal) and several higher major thrust-planes throw the steep foliation of the massive Church Bay Tuffs into bold sigmoidal curves. In the Middle and Aethwy Regions the highly inclined thrusts that are known may be ancillary not to the secondary but to the primary folds, and their steepness due to their outcrops happening to be on the limbs of the steep secondary anticlines. But some are no doubt secondary thrust-planes, among them that which cuts out the eastern limb (p. 222) of the Bodafon anticline. As (to anticipate) the minor, ternary, thrusts have been 'healed' by crystalline metamorphism, there can be little doubt that the major secondary thrust-planes have been likewise healed, and that they have long become pure foliation-planes.

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

The Minor or Ternary Folding.

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

As the major folds are superimposed upon the maximum recumbent folds, so are the minor superimposed in their turn upon the major folds. But as the major folds are not recumbent, but at tolerably high axial inclinations, the relations are different, are indeed frequently in reverse order, the axial inclination of the minor being often lower than that of the major fold upon which it is imposed. These relations can only be seen in the great sections at the South Stack, on the coasts (especially the south coast) of the Llwyn-y-berth promontory, and at

FIG. 37.
FOLDS OF THE LLWYN BEDS
At one-eighth of a mile west of Porth Dafarch.
Height, 80 feet.

Rhoscolyn. At the South Stack, the great sweeping folds shown as if smooth in Folding-Plate I, are never really smooth, but are perpetually wrinkled all along their course, as seen in the Frontispiece (Plate I). All the wrinkling is isoclinal, and its axes dip at lower angles than those of the major folds, the mutual relations in different parts being admirably seen on the major anticline that is exposed in the chasm that cuts into the Stack on the southern side. Along the southern cliffs of the Llwyn-y-berth promontory (Fig. 37) the general dip of the beds is at high angles to the

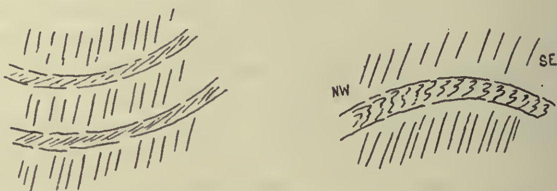


FIG. 38.—FOLIATION IN MASSIVE AND FISSILE BEDS.
Cliff opposite the South Stack.

north-west, sometimes even vertical, what is seen being really a part of the limb of a steep major isocline whose amplitude is greater than the height of the land. But the vertical beds are thrown into a rapid succession of minor isoclines with amplitudes of only a few feet, whose axes dip at angles of 10° to 45°. These are folds of the stronger grits, those of the lepidoblastic partings being more rapid. A remarkable feature of the relation of the minor to the major folds is that whereas at the South Stack

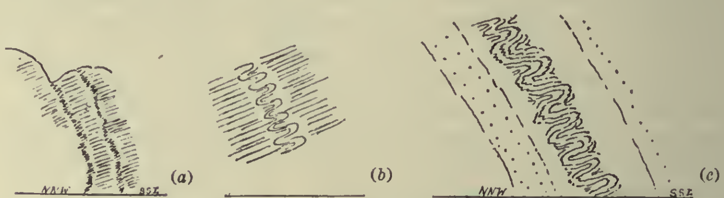


FIG. 39.—MINOR ISOCLINES WITH OVERDRIVE OPPOSITE TO THAT OF MAJOR FOLD. RHOSCOLYN MOUNTAIN (208-foot hill).

(a) Height of cliff, about 100 feet, junction of Quartzite and South Stack Series.
(b) Detail, enlarged.
(c) Similar structures at the fissile seam in the Quartzite.

and at Rhoscolyn, some of the major folds are not purely isoclinal but have limbs that dip to the south-east (Folding-Plates I, II); the minor folds upon those limbs are still isoclinal, retaining (Figs. 38, 39) the same axial inclination as on the isoclinal major folds.

Types of Minor Folding.

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

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

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

FIG. 40.—FOLDING IN AMLWCH BEDS.
Moor, top of Ednyfed Hill, Amlwch Port.
Height, two feet. Isoclines becoming locally symmetrical.

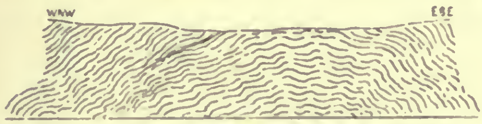
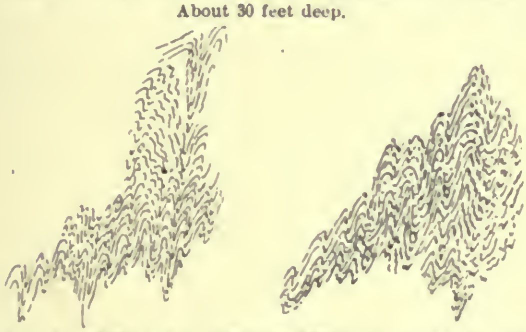


FIG. 41.—SECTION BETWEEN TUNNELS, BODORGAN.
About 30 feet deep.



FIGS. 42 AND 43.—MINOR FOLDING ON VERTICAL AXES IN THE MIDDLE REGION.
Gwna Green-schist, 500 yards south-east by south from Pen-y-graig, or 600 yards north by east from Bryn-yr-odyn.

2. *Isoclinal.*—This (Plates XVIII, XIX, XX, XI, and Figs. 44—53, &c.) is by far the most prevalent. It is universal in Holy Isle, almost universal in the Northern Region, general though less conspicuous in the Western Region, and strongly developed over much of the Aethwy Region. More perfect isoclinal folding than that of the New Harbour Beds of Holy Isle can hardly be imagined (Plate XIX). The fine Celyn beds in particular display it in a wonderful manner. On the rugged moors of Mynydd Celyn, for example, the

FIG. 44.
MINOR ISOCLINES IN SOLDIER'S POINT BEDS.
Upper Road Cutting. Government House.
Three and four inches in amplitude.

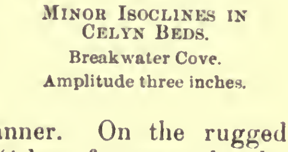


FIG. 45.
MINOR ISOCLINES IN CELYN BEDS.
Breakwater Cove.
Amplitude three inches.

whole mass is folded so thoroughly and so rapidly that one cannot look in any direction without seeing isoclines laid bare in some aspect or other (Fig. 47), and there are dip-sections of great beauty every 10 or 20 yards. The smallest average amplitudes are in these lepidoblastic Celyn beds, where they are usually a few inches: the largest are among flaggy Soldier's Point and Coeden Beds, where they range to 10 feet. The axial inclination is moderate, often about 45°, but tends to be steep in the Coeden beds (Fig. 132, p. 298), and perhaps lowest in the Celyn beds. As a rule there is no great disparity between the length of the limbs,

FIG. 46.
MINOR ISOCLINES AND THRUST IN CELYN BEDS.
Breakwater bosses. Length four inches.

FIG. 47.—MINOR ISOCLINES IN CELYN BEDS, MYNYDD CELYN.
Height about one foot.

but peculiar long straight limbs are seen on the fine sections at Point Lynas (Fig. 52) and about Porth-y-felin, Holyhead (Fig. 53). In the Middle Region, where folding is comparatively

FIG. 48.
MINOR ISOCLINE
of a few feet amplitude, in
LLWYN BEDS.
North-west of Gors-goch.

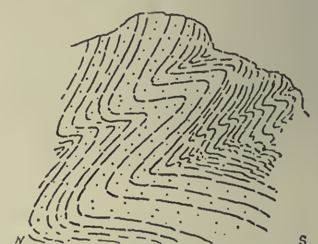


FIG. 49.
FOLDING IN AMLWCH BEDS.
Half-a-mile west of Bryn-eilian.
Height about two feet.

Minor Isoclinal Folding in the New Harbour Beds. Holyhead Breakwater.

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subordinate, a short fold may be seen at intervals of several yards upon steeply dipping folia. In fissile beds the curvature is often very sharp, yet beautifully smooth. There is the usual tendency to

FIG 50.
MINOR ISOCLINES
of two feet amplitude in
HORNBLENDE-SCHIST.
566 yards north-west of Bryn-eryr, Aethwy Region.

FIG. 51.
SHARP TWO-FOOT
ISOCLINE IN
HORNBLENDE-SCHIST.
Gigfran, Mynydd
Llwydiarth.

thinning and thickening in different parts of the fold, lepidoblastic seams becoming extremely attenuated on the limbs and packed into the anticlines to many times their original thickness.

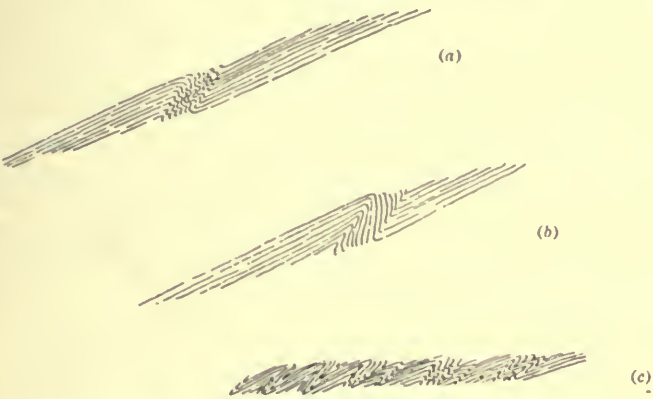


FIG. 52.—STRAIGHT-LIMBED ISOCLINES.
Western Cliffs of Point Lynas.
(a), (b) Limbs 30 to 40 feet in length.
(c) Limbs three feet in length.

The curious foldings of the quartz-seams call for further study, which will need the aid of thin sections, and will throw much light on the metamorphic process. They are not perfectly conformable,

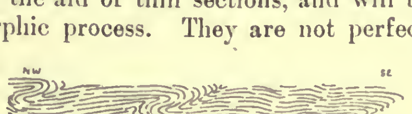


FIG. 53.—FLAT-LIMBED ISOCLINES.
South of Porth-y-felin, Holyhead.

but cut somewhat across the folia while folding with them, and that often very sharply. It is not easy to believe that they could be folded so powerfully without internal reconstruction, yet it is not merely the older ones (now granoblastic and incorporated) that behave in this way, but the later ones that are still venous in texture. It would seem (E. 10154) as if the curvature were due to their following lines of weakness in the already folded rock. But those now granoblastic have evidently been themselves folded. Foliation-planes in the act of rolling over anticlines often show a fine striation, and when a thin sheet of the older granoblastic quartz is present, the striation can be seen to be a local nemablastism, indicating the direction of stretching, but is usually a mere film upon the plane. Now this direction does not seem to be at right angles to the strike, but slightly oblique. On Mynydd Celyn, for example, it is at about 65° to the strike, which is east-north-east to west-south-west, the nemablastic striation running steadily from north-west to south-east. There appears therefore to have been some degree of torsion, yet the strike itself is wonderfully steady.

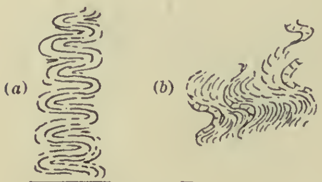


FIG. 54.
A-CLINAL MINOR FOLDING.
(a) Diagrammatic.
(b) Drawn from Nature.
West side of slack, north-west of Ty'n-y-mynydd-east, Mynydd Llwydiarth.

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

FIG. 55.—A-CLINAL MINOR FOLDING.
A little north of Ty'n-y-mynydd-east, Mynydd Llwydiarth.

FIG. 56.—A-CLINAL FOLDING OF HORNBLENDE-SCHIST IN MICA-SCHIST.
West shore of Elusendai alluvium. Penmynydd.
Height one foot.

4. *Polyclinal.*—The fold-axes in this type are both vertical, horizontal, and inclined this way or that way; and all close together, for the folding is extremely rapid; conveying to the eye an impression of confused and irregular crumpling from no particular direction, an impression intensified by a kind of quivering, a lack of decisive and steady sweep in all the curvature (Figs. 57—60). It may be that the 'polyclinal' type (as it may

conveniently be termed) results from isoclines having been, as it were, 'spoilt' by the same lateral oscillation that induced the

FIG. 57.—POLYCLINAL MINOR FOLDING.
300 yards south-west of Ty'n-y-mynydd-east, Mynydd Llwydiarth. East side of slack. Height about two inches.

FIG. 58.—POLYCLINAL MINOR FOLDING.
250 yards south by west from Ty'n-y-mynydd-east. Height one foot.

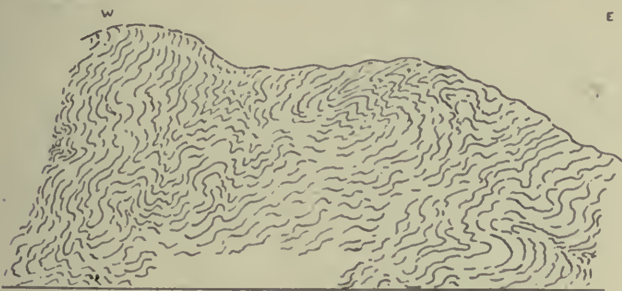


FIG. 59.—POLYCLINAL MINOR FOLDING.
250 yards west of Ty'n-y-mynydd-east, south of dry pool. Height three feet.

a-clinal type upon the vertical dips. The poly-clinal type has as persistent a strike as the isoclinal.

FIG. 60.
DETAIL AT TOP OF FIG. 59.

Pitch.

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

FIG. 61.
PLAN OF FIVE-FOOT FOLDS IN HORNBLENDE-SCHIST.
About 100 yards north-east of Gigfran, Mynydd Llwydiarth.

Thrusting.

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

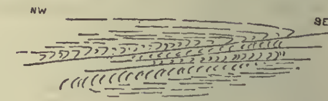


FIG. 62.
MINOR THRUSTS IN THE TRE-ARDDUR ZONE.
Cliffs west of Castell.

FIG. 63.
MINOR THRUSTS IN THE TRE-ARDDUR ZONE.
Foot of crag, south-east of Gareg-fawr.
Height about nine inches.

FIG. 64.
SIGMOIDAL FOLIATION WITH THRUSTS AT ONE-FOOT INTERVALS.
East bluffs of Trwyn Bychan.

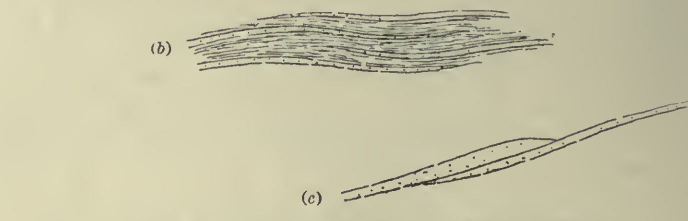


FIG. 65.—STRUCTURES IN THE AMLWCH BEDS.
(a) West-south-west of Graig-ddu. (b) Porth-y-gwartheg.
(c) About 250 yards west-north-west of 'Cave,' Bull Bay.

[Face page 192.

Isoclinal Folding with small-scale Thrusting. Salt Island, Holyhead.

In reality, the simple-seeming flags are riddled with innumerable minor thrusts, but these are at an extremely acute angle to the bedding (Fig. 65), sometimes actually parallel to it, so that the thicker beds are split by thrust-planes up the middle and carried forward parallel to themselves, until presently the thrust-plane curves a little and cuts one of the halves gradually off. A curious modification of the process is shown in Fig. 66, where a thin grit has been stretched and ruptured, pelitic matter filling in the spaces, but without destruction of the general bedding-plane. Another modification, which is frequently seen, is by oblique minor thrusting that causes adjacent beds to interdigitate (Fig. 67), a relation that

FIG. 66.
STRUCTURES IN AMLWCH BEDS.
Porth-y-gwartheg.

FIG. 67.—INCIPIENT LENTICULAR CUTTING.
170 yards north-east of Coast-guard path end, Amlwch. Half natural size.

appears, indeed, on the large scale, and imparts a characteristic form to many outcrops. Doubtless these phenomena are due to attempts to superimpose minor isoclines upon a long limb of some large major isocline, where the impulse was nearly parallel to the general dip. Evidently they are stages of the process that elsewhere produced an autoclastic mélange. But they are not a mélange, for the bedding is far from being destroyed.

Principles of Autoclastic Mélange.—The essential characters of an autoclastic mélange may be said to be the general destruction of original junctions, whether igneous or sedimentary, especially of bedding, and the shearing-down of the more tractable material until it functions as a schistose matrix in which the fragments of the more obdurate rocks float as isolated lenticles or phacoids. Now this condition is general throughout the higher tectonic horizons of the Mona Complex, which, *at that time*, were in the zone of fracture, so that all attempts at minor folding resulted only in thrusts or other ruptures. By the accidents of recumbent folding and erosion, most of the Gwna Beds that are known to us are on those horizons, and are consequently in the

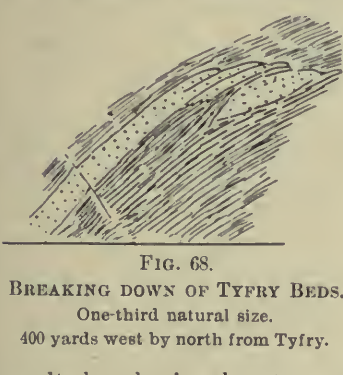


FIG. 68.
BREAKING DOWN OF TYFRY BEDS.
One-third natural size.
400 yards west by north from Tyfry.

condition of mélange, to which they lent themselves readily by reason of their very heterogeneous character. The early stages of development may be seen in the Tyfry Beds of the Pentraeth Inliers (Fig. 68), on Twyn y Parc in the Bodorgan headlands, and especially well at the top of the Fydlyn Group (Fig. 32, p. 161). At the top of that massive deposit the thin alternating beds come on, these are soon stripped into phacoids transversely to the bedding; which rapidly becomes imperceptible, and they thus pass into typical autoclastic mélange. An excellent little section showing perfectly a rapid breakdown of bedding into mélange by shearing nearly parallel to the dip, is to be seen at Llangristiolus, 160 yards east of the late dyke, and 60 yards north of the footpath to Llan-fawr. The characters of the autoclastic phyllite-and-grit mélange have been described on pp. 65—6, for a sketch of it was necessary to a petrological sketch of those sediments, which are hardly known in any other state, as well as to one of the Gwna Green-schist. Here we are concerned with the structure as such, and therefore only with the Autoclastic General Mélange, which includes all the members of the group. It is developed on a great scale in all the Regions except Holy Isle. In the eastern Middle Region, for example, nothing else is to be seen along 11 miles of strike, and in the eastern Aethwy Region it occupies 20 square miles of country. In a country of this kind, the larger masses are found to be arranged as trains of lenticles overlapping *en échelon*. (See the diagram, Fig. 69, as well as

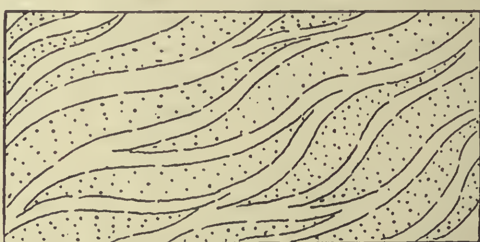
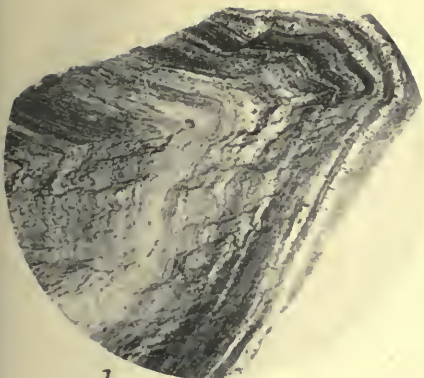


FIG. 69.—DIAGRAM OF AUTOCLASTIC MÉLANGE.

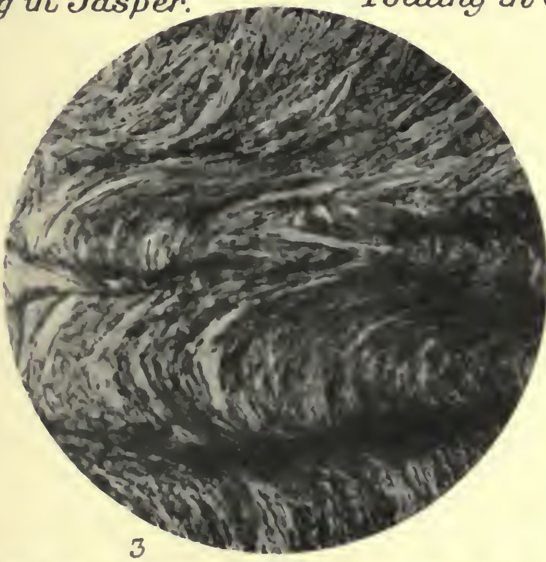
Figs. 4, 5, 165—6, 169, 188, Plates VII, XXII, and the parts of the one-inch map about Pentraeth, Llaniestyn, and elsewhere.) The major axes of the lenticular cores are slightly curved, the form of the line being highly characteristic,—a sigmoidal curve approximating to a straight line. Upon a map, the masses that can be separated out appear as if embedded in a homogeneous and structureless matrix. But this country-rock is itself built up of interdigitating lenticular bodies; and, could we take in the whole region at a glance, it would present itself to us as a mélange of torn and sheared lenticular masses of all sizes, from such as are two or three miles in length to the smallest that the eye can see, of spilitic lava, diabase, quartzite, limestone, jasper, and grit, floating in an

Plate XXI.

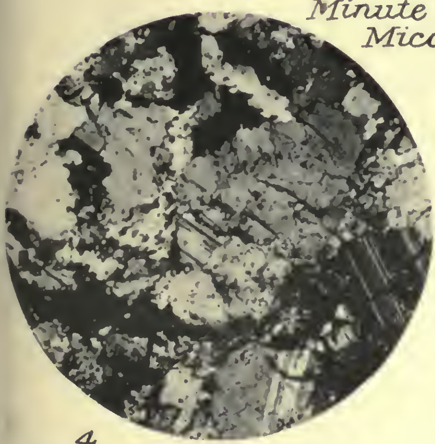


1. Folding in Jasper.

2. Folding in Coeden Beds.



3 Minute folding in Mica-schist.



4.

5.

Granite and Mica-schist pebbles in Harlech Grits.

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undifferentiated but schistose body that is a weft of all the more easily deformable elements, itself pervaded throughout by the same lenticular structure.

THE MINIMUM OR TESSARY FOLDING.

As is the major to the maximum, the minor to the major, so is the minimum related to the minor folding, upon which it is in like manner superimposed. It is perceptible only in the lepidoblastic fissile seams, and appears in the field as a very fine rippling on the brilliant foliation-surfaces. Perhaps it is most highly developed where a lepidoblastic seam, underlying a strong hard band, is packed up to many times its original thickness into the core of an anticline. Like the minor folding to which it is ancillary, it may be symmetrical, isoclinal, a-clinal, or polyclinal, and also pitches with the minor folds. Thrusting may develop on it, especially in connexion with packing, and usually fails to disturb the curve of the minor anticline as developed in the overlying hard band. Thrusting of this kind, when rapidly repeated, is identical with strain-slip-cleavage (Fig. 70). Minimum structures may be recognised even in autoclastic mélange, in the form of a fine augen-structure, usually to be found in the schistose matrix. But the minimum folding can be effectively studied only under the microscope (E. 9828, 10142—3, 10149, 10158, and Plate XXI, Figs. 1, 2, 3) and needs much further study, especially in relation to the crystallisation. In some cases, a curve appears to be accomplished by apposition of mica-plates that are still straight and extinguish separately. But in others no separate extinction has been detected, the shadow sweeping round the curve as the nicols are rotated, so that the mica-crystals appear to be really curved. Yet they show no sign of optical strain, for in the straight limb just outside the anticline, while in optical continuity with the crystals of the curve, their extinction is perfectly normal and parallel. In very finely lepidoblastic seams the amplitude of the folds may be extremely small, needing a one-fifth-inch objective to be made clearly visible. In one such rock from the South Stack Series on the lower limb of the Rhoscolyn Recumbent Fold (Plate XXI, Fig. 3, E. 10158), there are folds that are distinctly recognisable as folds, whose width is barely measureable on the millimetre scale of the stage, and can hardly exceed ·01 millimetre.

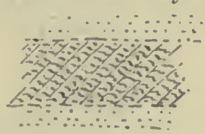

FIG. 70.—STRAIN SLIP.
Quarter of a mile west of Minffordd Windmill.

STRUCTURES OF THE SECOND AND THIRD GENERATIONS.

The Valley Thrust-planes and the Foliation of the Western Region.

The foregoing structures, though classified for convenience sake as from primary to tessary, are all (as has been indicated already) directly related to one another, are all products of one and the same system of dynamic impulse, and the classification may have no chronological significance. There are, however, structures that are the products of an independent impulse or even impulses, and these can be shown to be superimposed upon the original series. The beautiful isoclines of Holy Isle begin to fall off in regularity near Penrhos, and when we cross to the Main Island, the south-eastward impulse is clearly less intense. It will be remembered that we are passing to a higher tectonic horizon. Let us follow the section on the foreshore along the Alaw from Valley Foundry to Gored (Fig. 71). At first, the folding is still truly isoclinal, but

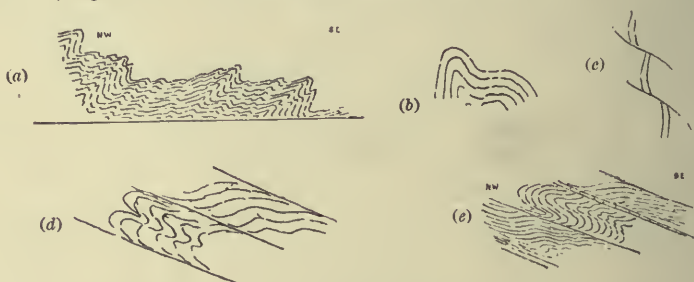

Fig. 71.

Change of Structure along the Estuary of the Alaw.

Amplitudes one foot or less.

Nos. *a* to *e* in order eastwards, from Valley Foundry to Gored Footpath.

the axes are persistently steeper, and the short limbs nearly vertical. Soon some of the axes become vertical, and south-easterly dips appear. The south-eastern limbs of the anticlines then become pinched in places, and small thrusts of about a quarter of an inch develop, with overdrives to the north-west. These increase in both number and intensity, until, at Gored, the banding of the Soldier's Point beds is powerfully overdriven by and violently contorted between them, while the foliation of the lepidoblastic seams is drawn out so as to be nearly parallel to them. The old isoclines have now disappeared, and the south-eastward impulse has been completely overpowered by the new north-westward one. Moreover, the now prevalent south-easterly dip is that of a new foliation, for venous quartz seams which appear along it become granoblastically reconstructed as do the older ones of Holy Isle. The same north-westward thrusting is seen, still better, on a range of crags about two miles to the south-east, which overlook the railway nearly opposite the Church by the Ford, where special dip-arrows indicate the structures. Between the thrust-planes, which may be called 'the Valley Thrust-planes,' the old banding of the Soldier's Point beds is cut into short lengths and sheared into sigmoids (Fig. 72),

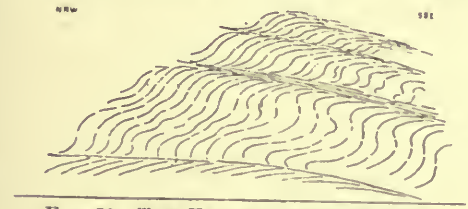

FIG. 72.—THE VALLEY THRUST-PLANES.
Crags above the railway, east and south-east of Llanfair-yn-neubwll Church.

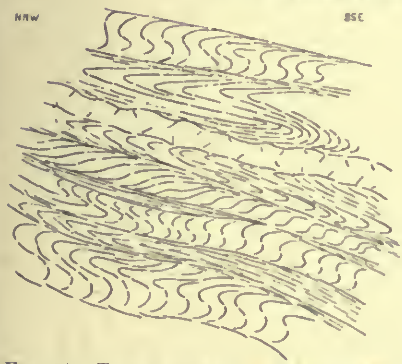

FIG. 73.—THE VALLEY THRUST-PLANES.
Further stage, and with vein-quartz.
Crags above the railway, east and south-east of the same Church.

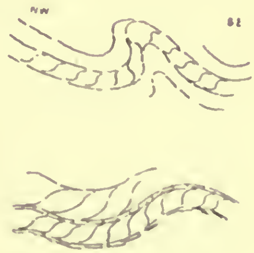

FIG. 74.—UNDULATIONS OF THE VALLEY THRUST-PLANES.

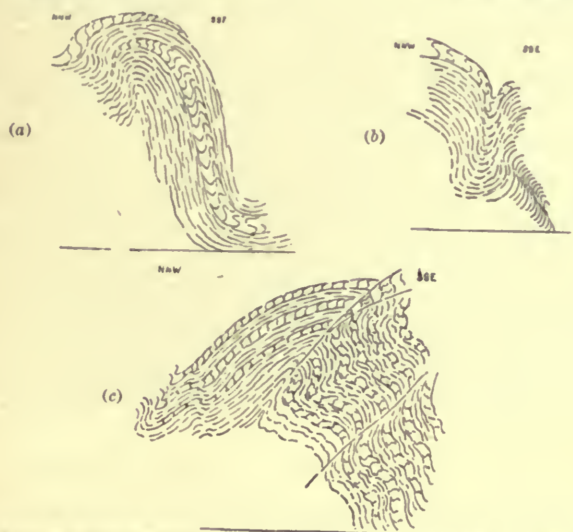

FIG. 75.—THE FOLDING AND THRUSTING OF THE VALLEY THRUST-PLANES.
Amplitudes up to four feet.
Crags above the railway, north-east and east of the Church.

and as these dip to the north-west in most cases, they are to be regarded as parts of the old isoclines that still retain the original inclination. But they soon become violently contorted and overfolded from the south-east (Fig. 73). Sills of venous quartz are introduced along the new planes, and all but the thicker ones become reconstructed granoblastically (like the older quartz of Holy Isle) and some of them even foliated. The new structure is therefore more than a thrusting, or even a strain-slip; it is a new foliation. The thrust-planes then lose their steady dip, and undulate in gentle curves (Fig. 74). These grow sharper, and presently they are thrown into powerful folds (Fig. 75, *a*), round which they carry with them the already twice-folded banding (shown in the figure) of the New Harbour Beds. But the process has been carried yet a step further. Some of the folds into which the Valley thrust-planes are thrown become overdriven into true isoclines, and these now develop strain-zones of their own (Fig. 75, *b*) which can be seen in the act of tearing-out. True thrust-planes then appear, which thrust the Valley thrust-planes themselves, until at last we have sections (Fig. 75, *c*), in which folding is imposed upon folding, thrusting upon thrusting, and each upon the other. In such sections as Fig. 75, *c* it is possible to see, all in the space of a yard or two, no less than three generations of folding and two of thrusting. First, there are the remains of the old isoclines of Holy Isle, then the refolding of the old isoclines, then the Valley thrust-planes, then the folding of the Valley thrust-planes, and finally the thrusting of those thrust-planes.

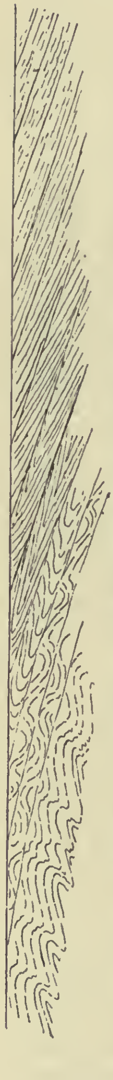

Fig. 76.—Diagram to illustrate the change from the Isoclines of Holy Isle into the Foliation of the Western Region.

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

Relations of the Penmynydd Metamorphism.

We must return to a consideration of the Autoclastic Mélange. Almost everywhere the dips of its divisional planes, though high and often vertical, are very steady. But in the Aethwy Region

Lenticular Quartzites in Autoclastic Mélange, with late basic dyke. Porth Wnol.

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it is violently folded, the folding being in great measure polyclinal. And it is not merely the schistose matrix that has thus given way, but the resistant lenticular phacoidal cores. Lenticular masses of spilitic lava, of limestone, and even of obdurate siliceous grit, have been doubled sharply on themselves (Plate XXIII, Figs. 77, 78, 79). We have already seen (pp. 69, 124—5) that the Gwna Green-schist is but a more schistose and reconstructed condition of the Autoclastic Mélange, and that the adjacent parts of the Penmynydd Zone (though its further parts are acid volcanic matter) are identical with the Gwna Green-schist, being in a more advanced stage of the same process. Now the very same system of folding affects at once the Autoclastic Mélange, the Green-schist, and the Penmynydd schist; and the folding is not due to disturbance after crystallisation, for the most highly folded rocks of the

FIG. 77.—FOLDED PHACOIDS OF GRIT.
300 yards east-north-east of Pedair-groeslon.

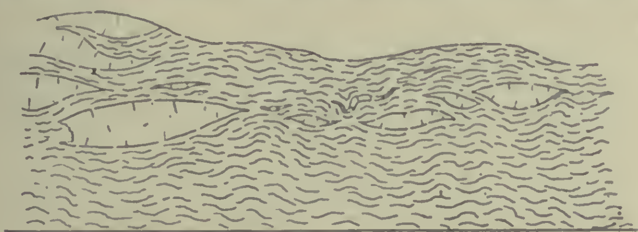


FIG. 78.—LIMESTONES IN GWNA GREEN-SCHIST.
Baron Hill drive, at 'M' of 'Meurig.' Height about 15 feet.

Penmynydd Zone [E. 9828] are completely free from optical strain or other signs of catamorphism, and the western parts of the Autoclastic Mélange are considerably re-crystallised. There is no doubt that the whole group of phenomena is one, and that all of them, from the folding of the Autoclastic Mélange to the crystallisation of the Penmynydd Zone, are stages of one and the same anamorphic process. We obtain a glimpse of a pause in this process. For the small augen of albite-pegmatite in the hornblende-schist are occasionally, though very rarely, a little foliated, showing that they segregated after the principal foliation had been produced, but before it was quite completed. Now it is certain that at the time when the Gwna rocks were broken-down into an autoclast, they must have been in Van Hise's crustal zone of fracture. And it is equally certain that, at the time when the Autoclastic Mélange so produced was intimately folded, its obdurate grit-phacoids doubled on themselves, its matrix converted into fine chloritic mica-schist, and the spilites and albite-diabases converted into actinolitic epidote-chlorite-schists with fresh ternary albite, it

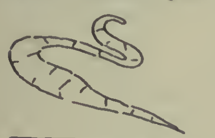


FIG. 79.
FOLDED PHACOID OF LIMESTONE IN FIG. 78.
Longest limb about two feet.

could not have been in the zone of fracture, it was in the zone of flowage. By some means, therefore, the mélange and all its associates must have been brought into a lower zone of the earth-crust than that upon which they lay at first. By what means could this have been accomplished? Cover by deposition of a great load of sediment is evidently excluded, for not only is there no sign of any such unconformable mass, but the period was not one of subsidence and accumulation, but of mountain-building and erosion. Suppose, however, another maximum recumbent fold to have been initiated, and another *nappe de récouvrement* to have rolled over above these rocks, then they would receive heavy cover, would be lowered in tectonic horizon, and be transferred from the zone of fracture to the zone of flowage. We have seen reason to suppose that they are all upon the Nappe of Bodorgan, and on an horizon so high it was difficult to understand how the Penmynydd metamorphism could be produced. On the tectonic horizon where that fold originally lay, such metamorphism would not have been possible. It would be possible by the process now suggested, and in the folding of the Aethwy mélange we have independent evidence that such a process actually took place.[1] That folding, and with it the Penmynydd metamorphism, are therefore to be regarded as later than any of the structures hitherto described.

LATER STRUCTURES.

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

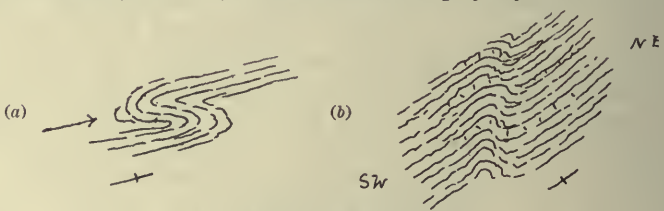
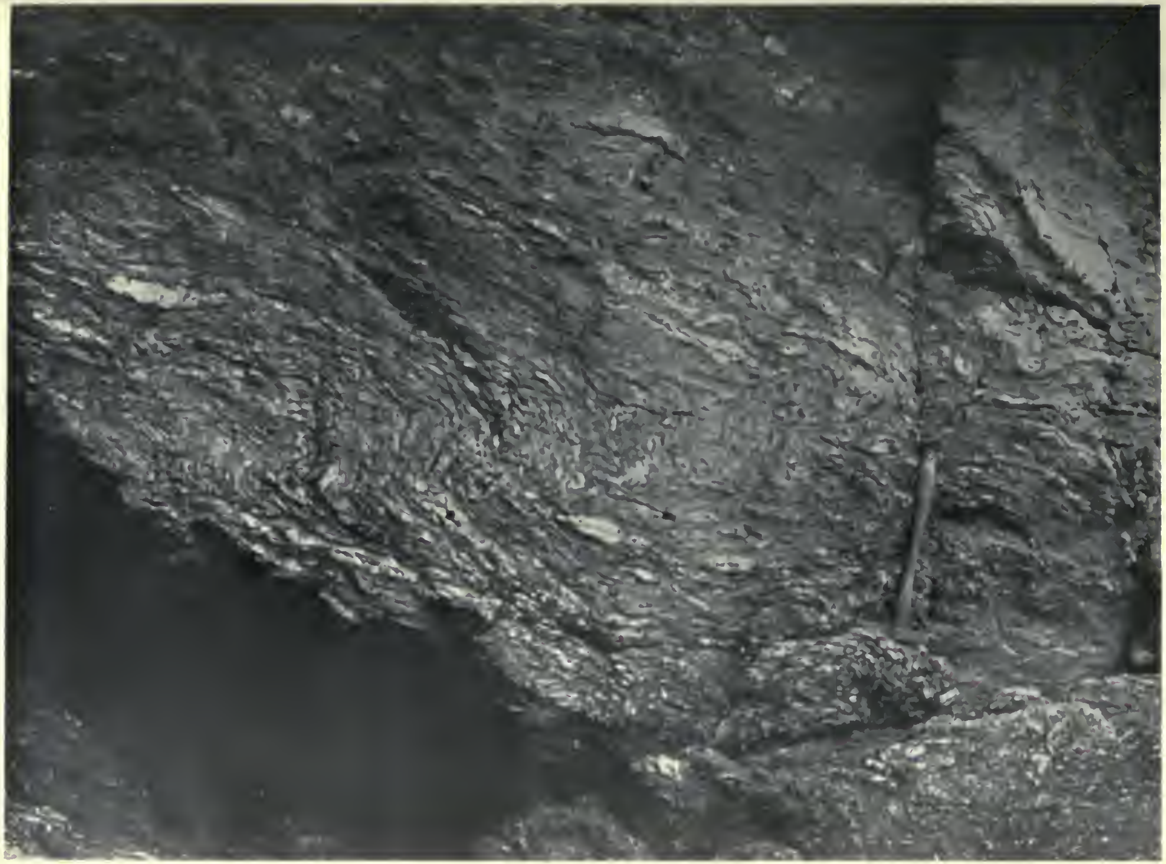


FIG. 80.—CROSS-WRENCHES.
(a) Bodewran. (b) North side of road 550 yards west of Garth Ferry Inn.

These are usually sharp and sudden, but instead of pervading the whole rock, occur only at intervals of a yard or two (Fig 80). The

[1] That the rocks on the Rhoscolyn Fold escaped, under these circumstances, from still higher metamorphism than that which they had already undergone, is probably due to that fold having by this time become incapable of any more movement. The Coedana granite was also absent there. The same explanation may apply to the less altered parts of the Nappe of Holyhead. The condition of the latter must be admitted, however, to be a difficulty—the only serious one that seems to remain in the way of this interpretation of the Complex. But see footnote to page 227.



[Face page 200.

Folding of Autoclastic Mélange. Menai Strait.

movement is nearly always in the horizontal dimension, so that they appear in ground plan as cross-wrenches at angles of about 65° to the strike. The transverse folds impart a peculiar waviness to the general strike, and where combined with polyclinal folding, a confused "gnarling" to the whole system. They often pass into thrusts, along which there is a little deformation, and sometimes a slight development of nemablastic foliation in quartz that is traversed by them.

Final Catamorphic Movements.—Even the latest of the many movements that have been described are in some degree anamorphic. But the Mona Complex is traversed by countless lines of crush along which no re-crystallisation has taken place. Large numbers of these are doubtless Post-Ordovician, and all might have been considered so, but for one piece of interesting and decisive evidence. The Gneisses, and also the Coedana granite, are cut by seams of pale-green mylonite [E. 9944] that resemble in every particular the mylonite of a North-West Highland thrust-plane, though the displacements are small and the seams not often more than one millimetre thick. They are better developed in these granitoid rocks, on account of the abundant felspars, but are to be seen in many others. Now large boulders of gneiss and granite are plentiful in the Ordovician conglomerates at the base of the zone of *Didymograptus extensus*, and some of them contain the seams of mylonite. But when traced outwards, these seams are found to end off sharply at the surface of the boulder, and not to pass out into the conglomerate. Fig. 102 *e* (p. 244) shows a four-foot boulder of basic gneiss with gneiss-granite sheared against it, but the shear-plane (though producing an ancient weathering-bay) does not pass outside the boulder. The conglomerate is cleaved, but the old shear-line lies at about 70° to the strike of the cleavage. These mylonites are therefore Pre-Ordovician, and are to be regarded as produced by the last movements of the Mona Complex. They have not been observed on the lowest tectonic horizons, and are first known on the Nappe of Holyhead.

FOLIAL RELATIONS.

Relations to Bedding, Folding, and Thrusting.

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

FIG. 81.
FOLIATION IN A GRIT.
West of Porth Ruffydd.
Height 30 feet.

The law seems to be that, in the coarse and massive beds, the foliation is parallel to the axial dip of major folds. Thus, at the South Stack, and throughout the Quartzite of Holyhead Mountain, where the major folds are at a high angle and some of them symmetrical about vertical axes, the foliation is vertical or nearly so (Plates I, XVI). There is, however, a slight fan-shaped arrangement with divergence upwards, both in very massive beds on major folds and in the Quartzite considered as a whole. As the axial dip of the major folds lowers and they become isoclinal, the foliation-dip lowers with them (Plate XVIII). On the Llwyn-y-berth promontory, where the land is too low to show the whole sweep of the major folds, its dip is much lower than that of the long limbs; and may not be straight, but within each bed be disposed in sigmoidal curves (Figs. 81, 82), a new series of sigmoids developing in each of such beds. But there are some long limbs to which it is nearly parallel (Fig. 83). On the larger minor folds it also shows a tendency to fan-like divergence (Fig. 84) at the apex of the fold. In the grits, therefore, it behaves very much like an ordinary cleavage, might indeed be called a cleavage-foliation; and as the great mass of the deposit is grit, this foliation determines the conspicuous features of the crags, especially in the Quartzite, over most of which no other structure is perceptible. But in the lepidoblastic bands we meet with a complete exception. Instead of passing directly through them (with perhaps a slight deflection) as does an ordinary cleavage through bands of shale, this structure stops at their margins (Plate I, Frontispiece, and Fig. 37), begins again as usual in the next grit, and leaves them, to all appearance, completely unaffected. Their foliation, which is very fine, seems to be their

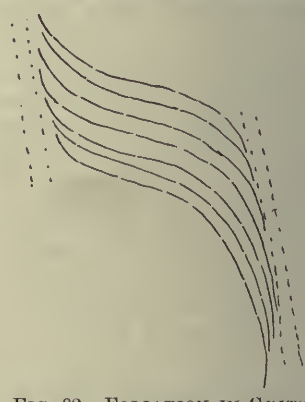


FIG. 82.—FOLIATION IN GRITS OF SOUTH STACK SERIES.
Quarry north of road, Kingsland, Holyhead.

FIG. 83.
FOLIATION IN GRITS.
East of Porth Ruffydd.

Bedding and Foliation in the South Stack Series. Seaward end of the South Stack.

[Face page 202.

own, and is violently folded in sharp isoclines, in which there is no sign whatever of the vertical foliation of the grits. The break, however, is not always complete. On the South Stack (Plate XXIV), the cleavage-foliation passes out into minute thrusts and slides that rupture the sharp corrugations of the fissile partings. Sometimes, again, as it approaches the lepidoblastic seam, the steep straight foliation of a grit will begin to bend, then to fold, sometimes quite sharply, until its ends appear, at the junction, to be in continuity with the contorted foliation of the fissile seam. (Figs. 85, 86). This may possibly mean that the lepidoblastic foliation has been folded by a south-easterly thrust of the upper massive beds along the planes of bedding. But that does not seem to account for the relation shown in Fig. 87. In other cases (Fig. 86, *c*) it bends over at the junction, and a faint cross-foliation at low angles may be discerned within the fissile beds.

FIG. 84.
DIVERGING FOLIATION IN GRIT.
Amplitude about two feet.
Headland west-south-west of Gors-goch.

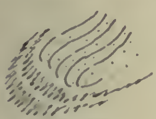


FIG. 85.
PORTH RUFFYDD.
Bending of foliation in fold of bedding.

FIG. 86.—FOLDING OF FOLIATION OF FISSILE BED AT JUNCTION WITH OVERLYING GRIT.
Cliff north-north-east of Maen-y-fran, Rhoscolyn.

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

FIG. 87.
FOLIATIONS IN A TWO-INCH ANTICLINE.
Rhoscolyn.

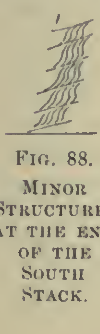


FIG. 88.
MINOR STRUCTURES AT THE END OF THE SOUTH STACK.

Foliation in other parts of the Complex.—Folial relations in other members of the Complex are as follows. In the New Harbour Beds on Holy Isle it follows everywhere the folded bedding, save where it develops along the minute strain-slips in the lepidoblastic seams as they pack into the cores of anticlines, and along the multitudinous minor thrusts that are ancillary to the Tre-Arddur primary thrust-plane. In the New Harbour Beds of the Western Region its development is, as shown, along the Valley thrust-planes; and as these same planes are continued into the Church Bay Tuffs, and from them into the Gwna mélange, there seems (when once we have passed above the Valley tectonic zone) to be no folial break in the whole region. The same is the case at the Fydlyn Inlier, but at the Garn and Corwas Inliers bedding-foliation seems to reappear in places. In the Coeden and Amlwch Beds of the North, it follows folded bedding (save at the places mentioned on p. 202, and at some strain-slips) and then develops along the minor thrusts of the western portion, as it does along the shear-planes of the Gwna mélange below the Caerau thrust-plane. At the passage between the Amlwch Beds and Skerries Grits in Bull Bay a steep foliation can be detected crossing bedding that is at a lower angle. This steep foliation is the only structure to be seen in the massive tuffs of Trwyn Bychan, save the thrust-planes (themselves foliated) that throw it into sigmoidal curves. Such slight foliation as is to be seen in the Gwna rocks of Gynfor coincides with that of the Trwyn Bychan rocks. The massive grits of The Skerries have also a steep foliation cut by lower thrusts, which may be taken to be the same as that of Trwyn Bychan. In the Middle Region (excluding the Gneisses), foliation is only known to follow folded bedding in the Bodafon anticline, where the roll-over of the massive quartzite probably compelled it. Almost everywhere else it is at high angles or vertical, and as the vertical planes of the Gwna mélange are foliation, though of a low order, and there is no break; that of the rest of the rocks, including the Penmynydd Zone and even the hornfels, must be developed along one and the same system of shearing. When folding is to be seen, the folded planes are doubtless the same shearing, thus foreshadowing the conditions of the Aethwy Region. The Pentraeth Inliers repeat the conditions of the Middle Region. In Aethwy, as we have seen, the foliation-planes are without doubt old shear-planes of the same system as those of the Gwna mélange, now rapidly folded. At one or two places about Llangaffo, the folded foliation of the glaucophane-schist is crossed by a second foliation (Fig. 90) (see also Fig. 177, p. 369), but this is rare. In the Llanddwyn Wedge, the low grade

Fig. 89.

Folding of foliated minor Thrust-planes, with truncation of Bedding.

Headland three-sixteenths of a mile east of Clybyddiad.

Height, about two feet.

of foliation that exists is generally vertical, but with violent folding locally. Its relation to that of Aethwy proper is not known. The foliation of the serpentine-suite in Holy Isle, produced during the major folding, is generally parallel to the major thrust-planes. The old foliation of the Coedana granite is not related to any known suite of planes, but its later one belongs to the vertical system of the Middle Region. The foliation of the Gneisses in all the regions is undoubtedly determined by ancient planes of movement, but belonging, apparently, to a system of their own, though locally forced into rude parallelism with later ones.

FIG. 90.
SECOND FOLIATION CROSSING THREE-FOOT ISOCLINE OF GLAUCOPHANE-SCHIST IN MICA-SCHIST.
Farm north-east of Tyddyn-fawd.

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

CHRONOLOGY OF THE FOLIATION.

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

NOTE.—See Note on page 242, and Appendix IX.

CHAPTER VIII.

GENERAL VIEW OF THE MONA COMPLEX.

SKETCHES will first be given of the developments, the condition, and of what are believed to be the structures of the Complex in the several regions and inliers; and then an attempt will be made to unify these into something like a connected picture. But the interpretations put forward in this chapter are for the most part based on the views as to the succession and the tectonics adopted in the preceding chapters, and are therefore subject to the reservations and cautions expressed on pp. 152, 170, 176, 182.

DEVELOPMENTS IN THE SEVERAL REGIONS.

HOLY ISLE.

As the evidence for the existence of the maximum recumbent folding was derived from Holy Isle, the most salient points in its structure had to be described to some extent in Chapter VII, thereby anticipating much of the present summary. Those points, therefore, will be taken for granted now, and only so much added as is necessary to an elucidation of the major secondary folds.

The members of the Complex that are present are the Holyhead Quartzite, the South Stack Series, the thin spilitic tuff at the junction, the New Harbour Beds, and the serpentine-suite of intrusions. Both divisions of the South Stack Series are developed on a great scale, especially at the north end of the Isle; the Stack Moor Beds appearing only at the Stack Moor, the Breakwater coast, and Rhoscolyn. Most of the wide extent of the New Harbour Group south-west of the Namarch fault belongs to the fissile Celyn beds, the Soldier's Point beds having been recognised, so far, only along the Tre-Arddur alluvium; but they occupy nearly the whole of the tract north-east of that fault.

The Isle falls into four structural parts (as shown in the chart, Fig. 100); the lower limb of the Rhoscolyn Fold, south-west of the North Stack fault; the upper inverted limb of the same fold, from Cymyran Bay to Tre-Arddur Bay; the lower limb of the Holyhead Fold, from Tre-Arddur to the North Stack Signal Station; and the Nappe of Holyhead, north-east of the Namarch fault.

The pitch is persistently to the north-east; while both major and minor secondary folding are (save one or two exceptions) isoclinal with a southward overdrive. The major secondary folds are as follows:—

Country South-West of the North Stack fault.—Of prime interest are those which are exposed in the magnificent sea-cliffs that look down upon the South Stack (Plate I, Frontispiece; and Folding-Plate I), for they are the only major folds in the Complex that are visible directly to the eye.[1] They have been described on p. 183. It is interesting to note how the resistance of the massive beds to the southerly impulse raises the axial inclination, and with it the foliation-dip in the grits, locally to 90°. The net effect of the great folds is on the whole synclinal, for the Stack Moor beds descend to sea-level, though the north limb of the syncline has been destroyed by the sea. To that syncline we owe the fortunate preservation of the two little infolded outliers of Quartzite (Fig. 28) on the very crest of the Stack Moor. Probably a steep anticline, followed by a syncline 500 feet deeper, lie beneath Gigorth Bay, for the Llwyn beds just appear at the foot of the south walls of the Bay, so it is likely that the North Stack fault clings to the land, leaving the North Stack itself on its west at the base of another Quartzite infold. With the rise of the Llwyn beds near Pen Las Rock the folding becomes completely isoclinal, the isoclines having a vertical amplitude of more than 200 feet. When Henborth is passed, this diminishes, and about Porth Rhwydan we see the curious phenomenon of nearly vertical beds thrown into many small isoclines with foliation dipping at rather low angles northward (Fig. 36). Judging by the characters of the beds, the net effect of the whole series of isoclines appears to be a gradual rise, but the base never appears, for the sea cuts away this limb from Porth y Post to Rhoscolyn.

The major secondary folds at Rhoscolyn (Folding-Plate II) are isoclinal from Bwa Du to Rhoscolyn Head, and then follows a broad low anticline at Maen y Fran, succeeded by a powerful syncline, isoclinal, but facing sharply northward—the only powerful isocline in the Isle with a northerly overdrive. One of the most remarkable features is that, no matter what be the dip of the massive beds, no matter in which direction the major isoclines be overdriven, the rapid minor isoclines developed in the fissile partings face persistently south-east. Even in the cliffs between Maen y Fran and Rhoscolyn Beacon, where the beds are nearly vertical, the minor isoclines are still arranged as in Fig. 38, showing what an overmastering impulse there was from the north-west. It is, unfortunately, difficult to decide the interesting question

[1] For the means of obtaining access to the Stack, see p. 257.

as to whether *all* these great folds be secondary, or whether, in the north-westward-facing isocline, we have the true closing core of the Rhoscolyn maximum Recumbent Fold itself. In favour of that view is the fact that the minor isoclines ignore its inclination and cross it. Yet they may still be later than, and equally ignore, a major secondary fold. And, further, it is not easy to believe that the throw of the North Stack fault can have diminished so much as the hypothesis requires.

Country between the two Main Faults.—Turning now to the country between the two great faults (Folding-Plate III), the apposition of the Rhoscolyn anticline to that of Maen y Fran suggests that they are on the same secondary major axis, the Rhoscolyn anticline being the roof, brought down by the North Stack fault. But the strong southerly dips are absent, and there is no suggestion of a synclinorial structure. The Rhoscolyn anticline does not seem to be completely isoclinal, but its northern limb is a very gentle dip for some two miles, on which the New Harbour Beds (chiefly of Celyn horizon) are driven together by innumerable minor isoclines and little foliation-thrusts. Into them, after the maximum recumbent, but before the major secondary folding (see pp. 109, 211), was intruded the complicated serpentine-suite. There can be no serious rupture on the south, where the old thermal aureole remains ; but between Cae'r-sais and Porth y Garan the New Harbour Beds are driven over the intrusions on a powerful thrust, which may be called the Garan Thrust-plane, while the intrusive rocks themselves are much deformed, converted into crystalline schists, and their foliation corrugated by the minor folding. Away from the thrust-plane, the resistance they offer gives rise to a considerable deflection of the strike (see Fig. 101, p. 239). The vertical foliation-dips that prevail both in and around the larger intrusions (on the main Island as well as on Holy Isle) point to their being stocks or bosses that rose (before the secondary folding—see pp. 109, 211) almost at right angles to the tectonic horizons established by the recumbent folding.

This upper limb of the Rhoscolyn Recumbent Fold is a northward, the lower limb of the Holyhead Recumbent Fold, a southward over-roll ; and, as the Skerries Group is pinched out, the New Harbour Beds of the two folds being folded on themselves, there must be a powerful thrust at the roll-over. Precisely where the tectonic horizon changes is not yet known, but from the presence of Soldier's Point beds and of innumerable minor thrusts (Figs. 62, 63), it is taken to be about the Tre-Arddur gap. Until, however, the Soldier's Point horizon can be identified with confidence wherever present, greater exactitude cannot be attained. For, not only are New Harbour Beds brought against New Harbour Beds, but the Tre-Arddur thrust itself, being a plane of the primary recumbent folding, must have been powerfully folded by the major secondary, and further corrugated by the ternary minor isoclines, so that it would appear at several places. Besides, there may be more than one thrust at the zone, all similarly folded, thus yielding a multiplicity of thrust outcrops. Finally, being older than the maximum metamorphism, re-crystallisation would have been set up along them, so that they would now appear, not as mylonising ruptures, but as planes of pure foliation, scarcely distinguishable from all the other countless, corrugated, foliation planes.

In any case, we pass, beyond the Tre-Arddur gap, into the lower, uninverted limb of the next great recumbent fold, the Holyhead Fold. Soldier's Point beds can be recognised for about a quarter of a mile, after which they do not reappear upon this limb. The net effect of the incessant isoclines is still a general northward inclination, by virtue of which the major infolds begin, a mile from the gap, to take in the lower part of the South Stack Series, though the pitch confines that series, for a mile and a half, to the eastern side of the tract, until, in the deep infold that begins near Gorllas, it is allowed to reach across to the North Stack fault. An interesting effect of the pitch is the way in which the little spilitic tuff, clinging to the base of the South Stack Series, but always just within the Celyn beds, keeps bending to and fro round the rising ends of the minor isoclines.

To come to the major folds; there is no means of gauging the amplitude of those near Tre-Arddur; but from Gareg-fawr to Llain-goch it is clear that the recumbent limb is thrown into a series of great isoclines that, close to the Namarch fault, must have amplitudes (measured from the pitch-angle) of 1,100 feet in some cases. One anticline, just beyond Stryd, brings up the Celyn beds all the way to the fault. About Capel Gorllas the dip steepens and

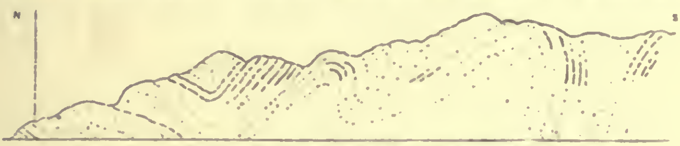


FIG. 91 —MAJOR FOLDS OF THE QUARTZITE ON THE GREAT SEA CLIFFS.

Bedding obscure where lines are dotted. Height, about 500 feet.

steadies, indicating a plunge to a still deeper infold. So steep are the dips, that in the valley beyond the last appearance of the Llwyn beds there is room for a complete outcrop of the Stack Moor beds, whose top is just seen along the roadside at the base of the Quartzite, which is now brought in by this deep infold. The other side of that infold has been destroyed by the sea, but the bedding seen over the great caves near the North Stack suggests that the South Stack Series is once more about to rise. The structures in the Quartzite are very hard to read (Plate XVI), but such bedding as can be made out indicates that it has been packed into the great syncline (which may be called the Mountain syncline) in a succession of folds with amplitudes of more than 700 feet, tentatively shown in Fig. 91, which is the result of a number of re-drawings made in favourable lights. It will be seen that the folds are not persistently isoclinal, the massive Quartzite having offered more resistance than usual to the south-ward impulse.

Country North-east of the Namarch Fault.—The country to the north-east of the Namarch fault is all on the upper, inverted limb of the Holyhead Recumbent Fold (Folding-Plate III), being the first appearance of the vast Nappe of Holyhead; and is composed almost entirely of New Harbour Beds, of Soldier's Point horizon. They are thrown into the most beautiful minor isoclines that are known in the Mona Complex. But at the Breakwater, Celyn beds (in which is the little basic tuff) appear, and are quickly followed, as we cross the cove, by both divisions of the South Stack Series. The Quartzite also appears three times, and is twice visibly intercalated in the Stack Moor beds, in cakes varying from 30 to 270 feet thick. Now it is manifestly impossible that the 30-foot quartzite cake of Porth Namarch can be the continuation of the vast mass of the mountain, against which it is brought by the Namarch fault. Therefore the Breakwater tract cannot be the true core of the Holyhead Recumbent Fold. It is interpreted as a subsidiary recumbent core (Fig. 92), pushed back southward into the gape (which must be multiple) of the Holyhead Recumbent Fold. The amplitude of the Breakwater fold is unknown. It must be full of ruptures, for not only is the Quartzite cut down to thinner and thinner cakes, but the South Stack and Celyn beds are greatly cut down also. These are primary thrusts ancillary to the Breakwater fold itself; they roll over on a major secondary anticline which brings up the Breakwater core from under the Soldier's Point beds of the great Nappe of Holyhead (Fig. 93).

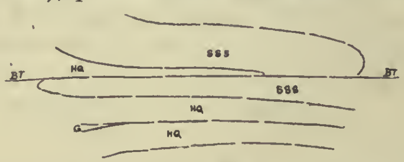


FIG. 92.

DIAGRAM OF RECUMBENT BREAKWATER FOLD.

HQ=Holyhead Quartzite.
SSS=South Stack Series.
BT=Breakwater Thrust-plane.
G=Direction of gape of Holyhead Fold.

FIG. 93.—SECTION ACROSS THE BREAKWATER TRACT.

About three-eighths of a mile east of Porth Namarch. Scale: 24 inches = one mile.

HQ = Holyhead Quartzite.
SMB = Stack Moor Beds.
LB = Llwyn Beds.
CB = Celyn Beds.
SPB = Soldier's Point Beds.
TT = Thrusts.

Holy Isle is therefore a fragment, sculptured out of the cores of two maximum recumbent folds, the Holyhead and the Rhoscolyn

Fold, with the subsidiary Breakwater fold; which are accompanied by folded foliation-thrust-planes ancillary to the recumbent folding, all being thrown into great secondary major isoclines, and the whole mass packed, by a south-eastward impulse, into innumerable minor isoclines, to which minor thrust-planes are in their turn ancillary.

The Western Region.

The members present are the New Harbour Beds, the Church Bay Tuffs, and the Gwna Beds. Of the New Harbour Group, the Soldier's Point beds alone are known to be present, and they contain a fine development of the spilitic lavas and also of the bedded jaspers and jaspery phyllites. The Church Bay Tuffs are nearly undeformed at their northern end, but become schistose to the south. The Gwna Beds consist of typical green-schist and mélange, with strong developments of quartzite, limestone, and graphitic phyllite, and some good ellipsoidal spilites with nodular jasper. Some of the serpentines and their associates also fall within the district. The New Harbour Beds are holocrystalline schists, though less perfect than in Holy Isle (p. 48); but metamorphism falls off rapidly in the other two formations, and almost vanishes in the northern outcrops of the Church Bay Tuffs, whose great homogeneous mass doubtless offered exceptional resistance.

The whole region is regarded as lying on the inverted Nappe of Holyhead (the reasons for which view are given on p. 176), and if so, then the succession must be an inverted one. Whether any part is upon a lower limb depends upon the course of the Namarch fault, but such portion could in no case extend as far as the railway. From Tre-gof creek south-eastward the course of the fault has not been ascertained with precision, as there is evidence of several parallel fractures, which are shown upon the maps. It is most probable, however, that the main fault passes along the Strait of Holy Isle, whose features are evidently determined by faulting. To keep strictly to the channel involves curves near Fadog and Cymyran, and it may pass across the Fadog promontory and east of Cymyran; but as it can be seen to curve pretty sharply at Porth Namarch, such curvature is no serious obstacle. The fault raises important questions concerning the stratigraphical position of the serpentine-suite, for whatever course be assigned it, some of that suite are left on either side, and therefore on different tectonic horizons. Had they been sills injected before the maximum recumbent folding, it is incredible that they could now be grouped as they are. There is, however (pp. 109, 208), independent petrological and other evidence that they were injected at an interval or intervals in the movements. The stratigraphical evidence, therefore, indicates that the intervals were after the maximum folding, and that the intrusions then found their way across different tectonic horizons; but before the major secondary folding and shearing, to which they owe their metamorphism.

It has been shown on pp. 196—8 how, near Valley, the old isoclinal folding of Holy Isle is overpowered by a minor thrusting coming from the opposite direction, upwards from the south-east, and that these new planes are in their turn folded. Now this thrusting is one with the general foliation of the Western Region, which must therefore be later than the isoclines of Holy Isle. Isoclines overdriven from the north-west are seen here and there; but the dominant structure is the new foliation, which has a persistent (though not universal) dip to the south-east, and must be regarded as due to an upward shear from that direction. With it a few true bedding-dips, as on Clegyr-mawr, agree.

The Major Structures.—It will be seen from the map that, if the succession be inverted, the recumbent nappe must be thrown into a broad secondary syncline, the northern secondary limb being truncated by the Yr-ogo-goch fault that brings down the Ordovician rocks (close to which the bedded jaspers suggest that the New Harbour Beds are about to rise); that the syncline must be pitching eastward; and that it must be compound, a number of large anticlines within it bringing up the Church Bay Tuffs. Now, to obtain a correct picture of the structures as a whole depends upon obtaining a true reading of the forms of these major folds, and of their relations to the dominant secondary foliation. The prevalent southerly dip of that raises a presumption that they are isoclines with a northward overdrive. At Clegyr-mawr the bedding of the tuffs dips 20°—30° south-east, to pass below the first nip of Gwna Beds (which, evidently pitching eastward, fails to reach the sea). On both sides of that nip are also south-easterly dips, and the same is the case again in the narrow anticline of Tuff that follows, and in the succeeding Gwna Beds of Foel. That the dips coincide with true dip is shown by the Tuffs on the south limb of the narrow anticline turning round on the sea-cliff to pass below the Foel Gwnas, as well as reappearing to pitch under them on the ebb-reefs of Porth Swtan. It therefore appears that the folds must be isoclinal, with the northward overdrive suspected, and that the secondary foliation is a product of the same stresses. Whether, however, any of their limbs are free from rupture may be doubted, for three reasons. The great homogeneous mass of tuff would not readily lend itself to folding; the Gwna Beds are shattered into mélange; and the tendency to rupture was very strong even about Valley (Figs. 71—75) at a lower tectonic horizon. It is to be supposed that the major folds about Llanrhyddlad are for the most part thrust out along the dominant foliation, except at the sea-ward ends, where, on the rise of the pitch, there would be relief of strain. One such rupture, which may be called the Bodfardden Thrust-plane, is evident upon the maps, for along it the Gwna Beds as well as the Church Bay Tuffs are brought against the New Harbour Beds. It is dynamically connected with the pitch, for as the infold subsided eastwards, it ruptured, and the New Harbour Beds of the southern limb were driven over it. The thrust itself is doubtless a true foliation-plane, and if exposed would probably show no cataclastic structures, for the Gwna Beds and Church Bay Tuffs as they approach it show perceptible progressive metamorphism. Seawards it wanes with the rise of the pitch, and at Porth Defaid must have passed into the New Harbour Beds or died out, for there is a passage into the Tuffs (p. 157) at that place. At Brwynog it must begin to wane again, for the Tuffs reappear. But all their central parts are missing, being evidently cut out, and only the top and bottom left. The section (Folding-Plate IV) expresses the foregoing views of the structure of the region. The wide-spreading New Harbour Beds are probably disposed in countless ruptured isoclines of small amplitude and low undulating pitch, for the lavas and jaspers are repeated all across, as if the general effect were approximately horizontal. The low pitch is due to the eastward waxing of the Bodfardden thrust-plane. The combined effect is to spread out the New Harbour Beds in both directions, thus accounting for their large area. But there may be deeper infolds at Penial and Llanddeusant, where tuff-like beds occur. Near Glan-alaw the strike swings round somewhat, and the contents of the Ordovician conglomerates indicate that the Tuffs and Gwna Beds come on below them in the Cors y Bol country.

The reversal of the direction of thrust and overfold is most remarkable, and there is no sign whatever that the region is riding upon any single great thrust above the isoclines of Holy Isle. None can be seen in the section on the estuary of the Alaw, and the evidence of that section and of those at Llanfair-yn-neubwll (Figs. 71—76) points clearly to the change of overdrive being effected by means of a zone of innumerable minor thrusts.

The Northern Inliers.

The Garn and Fydlyn Inliers afford important evidence as to the succession in the Complex ; the Gader Inlier, the finest section in the Gneisses. They raise problems as to dynamics that are not easy of solution, for the southerly dip so persistent in the Western Region disappears, and is replaced once more by northerly foliation-dips and south-ward thrusts and isoclines. As there is clear evidence at Fydlyn (pp. 214, 289) that the succession is inverted, as the evidence on the Garn points to the same conclusion, and as that in the other inliers is in harmony therewith so far as it goes, they are all supposed to be still on the inverted Nappe of Holyhead, the major secondary isoclines, however, being here of great amplitude.

At the *Garn Inlier* (Folding-Plate IX), New Harbour Beds of the Soldier's Point Group (in the condition of green-mica-schist) are succeeded by comparatively thin Church Bay Tuffs, and those by Gwna mélange, metamorphism waning rapidly in that direction. The New Harbour Beds are isoclinally folded with a southward impulse.

At the *Fydlyn Inlier* (Folding-Plates X, XIII), the stratigraphically lowest and tectonically highest member is the Fydlyn felsitic suite, succeeded by Gwna mélange with quartzite, limestone, spilite, and diabases, and those by Church Bay Tuffs. Anamorphism is low, but not at a minimum. The Gwna Beds are seen (pp. 176, 289) to rise from below the Fydlyn rocks on an isoclinal anticline, so the succession is undoubtedly inverted. The inlier is nearly split by two ruptured Ordovician infolds, but their thrusts and slips appear to nearly neutralise one another, thus introducing less confusion than might have been feared. Ignoring that, its ancient isoclinal structure consists of a pair of synclines, each taking in the Fydlyn Beds. The southern one is compound, with rolls that bring up the Gwna Beds, and the northern one is complicated by the Hwch lower thrust-plane, which drives its northern limb (p. 291) right across its core and on to its southern limb. Between the two major synclines is an anticline bringing up the Church Bay Tuffs.

Over the Ordovician shale that bounds the Fydlyn Inlier on the north, the Gader Gneisses (Folding-Plates X, XIII) are driven on the Post-Ordovician Hwch thrust-plane. If the Mona succession be inverted, with the Gneisses uppermost and riding on the Gwna Beds on an ancient folded thrust (pp. 216, 221) then the Gader Gneiss, now the denuded core of a thrust Ordovician anticline, must have been the core of a secondary isoclinal Mona syncline. That syncline was probably not the same as the one which we see at Porth-yr-hwch in the Fydlyn Inlier, but one from further north, for there is reason to suspect (Chapter XIV) that the Hwch thrust-plane has considerable horizontal displacement and has carried this gneiss for some distance to the south. A small fragment of Gwna mélange is brought up against the gneiss on the coast, but the Fydlyn Group is cut out.

The *Corwas Inlier* is composed of New Harbour Beds of Soldier's Point type, which pitch towards a thrust that parts them from a tract of Gwna Beds. But the vicinity of the thrust is obscure, and the Church Bay Tuffs may be but partly cut out, and the thrust of no great magnitude. Metamorphism falls off eastward.

No more than suggestions can at present be offered in explanation of the structural contrasts between the Western Region and the three north-western inliers. Yet the contrast is not as violent and immediate as it seems at first sight. For the inliers are all riding upon Post-Ordovician thrust-planes, and have been brought much nearer (how much nearer is unknown) both to the Western Region and to one another than they were at the time when their structures were being produced. They have also been carried upwards. The Garn Inlier has been brought upward upon the Garn fault and both upward and southward upon the Garn thrust-plane (Chapter XIV). The tendency of the structures of the Western Region would be to ride somewhat upwards in a northerly direction, and it is probable, therefore, that the contrasts are those of differing tectonic horizons, now brought close together and to the same level. The isoclines of the Garn may be a survival of the old isoclines of Holy Isle, below or between planes of the secondary foliation of the Western Region. More than this it is not yet possible to indicate.

The Northern Region.

The succession is unusually complete in this region, the Coeden, Amlwch, Skerries, and Gwna Beds all outcropping, as well as the Gneisses, and there are a number of small intrusions of the serpentine-suite. The South Stack Series, New Harbour, and Skerries Groups are all represented by northern facies that are unknown elsewhere, and the same is the case, though but locally, with the Gwna Beds. The Coeden beds appear only on the southern margin. The Amlwch Beds occupy some two-thirds of the region, and their bedded jaspers, jaspery phyllites and spilitic lavas are finely developed, especially about Amlwch. There, also, their alternating type is most pronounced, but westward and south-westward rather less so, the lavas and jaspers at the same time dwindling somewhat. A number of large phyllitic tracts, most of them in Bodelwyn beds, have been delimited on the one-inch map, though not given a separate colour. The Skerries Group is represented only by the Grits proper along the central band, in which are The Skerries themselves (where the conglomerates are found), the West Mouse, and the long tract ranging from Llanrhwydrys to Llanfechell. In the Trwyn Bychan tract, between Hell's Mouth and Bull Bay, the Skerries Grits are seen to lie between the Amlwch Beds and the Church Bay Tuffs, which are finely developed along the northern coast. The Gwna Series is complete, alternating beds (now mostly mélange and green-schist), quartzite, limestone, graphitic phyllite, spilitic lavas, and jaspers being all present. The quartzite, limestone, and black beds are at a maximum, the lavas rather feebly developed: while in parts of Gynfor (as the district on either side of Llanlleiana may be called) vulcanism is at a minimum, the lavas being very thin and local, the alternating beds grey and free from pyroclastic matter, a condition unknown elsewhere in the group.

There is progressive anamorphism from the Gwna to the Coeden Beds, and, in a less degree, from north to south upon corresponding horizons; the Gynfor Gwnas (which have undergone great mechanical destruction but only a minimum of reconstruction) being in Van Hise's 'Zone of fracture,' the rest of the region in various depths of his 'Zone of flowage.'

The whole region (Folding-Plate V) is riding, at a generally low angle, upon the Post-Ordovician Carmel Head thrust-plane, by which (Chapter XVIII) it has been brought a long distance from the north. Its own structure is persistently isoclinal with, also, a steady south-ward overdrive, but these folds are far older (see p. 244 and Chapter XVIII) than the Post-Ordovician movements, by which they are broken, and belong to the ancient movements of the Mona Complex. The pitch is low and variable, sometimes east, sometimes west, while in the middle there may be none at all. The major isoclines are on a great scale, so that the form of most of them is not directly visible. Reasons have, however, been assigned (see p. 177) for supposing the succession to be inverted, the Coeden beds being tectonically lowest, the Gwna Beds and Gneisses tectonically highest, and for considering the whole region to be upon the Nappe of Holyhead.

The Llanfairynghornwy Belt.—This will be a convenient name for the marginal belt that can be traced from Carmel Head to Llanfflewyn, emerging from beneath the rest of the region. Lowest of the tectonic horizons of this belt is the wedge of Amlwch Beds that (Folding-Plate XIII) at Carmel Head itself, rides upon the Carmel Head thrust-plane, at which its ancient minor isoclinal folds are cut and shattered. This wedge is quickly cut out by another thrust (that may be either of Pre-Cambrian or Palæozoic date) which, from the name given on the ·0004 and six-inch maps to the next cove, may be called the Porth-y-wig or 'Wig' thrust-plane. It must be at a lower angle than the axis of the major isocline, and must be powerful, as it eliminates the whole of the Skerries Group, but its course land-wards is cut short in only 100 yards by the Carmel Head thrust-plane, on to which it laps, as if it were of older date. The Gwna Beds brought forward by it then come on to the Carmel Head thrust-plane, upon which they ride all the way to Llanfflewyn. They are of interest because of their spilitic lavas, which are the best development, in that group, in the Northern Region.

Involved with these Gwna Beds, the junctions all being evident ruptures (thus cutting out the Fydlyn Group), are the four strips of the Mynachdy Gneiss. Now, if the succession be inverted, the Gneisses must be uppermost, and the relations must be those of an ancient folded thrust-plane (Fig. 94), broken in its turn both by the

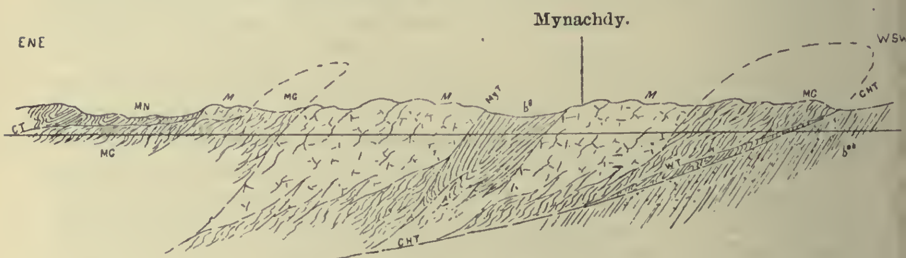


FIG. 94.—SECTION AT MYNACHDY.

Scale: Nine inches = one mile.

MN = Amlwch Beds. MG = Gwna Beds. *M* = Gneiss.
beb = Lower Ordovician Beds. bg = Glenkiln Beds.
CT = Caerau Thrust-plane. MyT = Mynachdy Thrust-plane.
WT = Wig Thrust-plane. CHT = Carmel Head Thrust-plane.

later mylonising movements of the Complex, and by those which have let in the wedge of Glenkiln shales and (see Chapters XIV, XVIII) torn their base to pieces. So the Mynachdy Gneiss is, as might have been expected, hardly more than a shattered and decayed wreck of a once crystalline formation.

The sinuous line along which these Gwna rocks and Gneisses are succeeded by the Amlwch Beds (once more cutting out the Skerries Group) is the upper boundary of the Llanfairynghornwy Belt, and must be the outcrop of another powerful thrust, which may be called the Caerau Thrust-plane. This fails to reach the coast, being there cut out by the Post-Ordovician Mynachdy thrust-plane, but its sole is laid bare at Llanfflewyn, where it is almost horizontal. There is reason to think that it is an ancient rupture of the Mona Complex, for the old thermal alteration at Caerau, which (see pp. 108—9, 320) belongs to an interval in the production of the Complex, does not seem to be cut up by it, but to obscure the outcrop of the thrust. As we approach the lake, a wedge of Church Bay Tuff is admitted below it, but, beyond the Geirian fault, it laps on to the Carmel Head thrust-plane, and the remarkable dynamic effects produced between the two great thrusts where close together are described in Chapter XVIII. The Caerau thrust-plane has not been traced beyond Gwaen-ydog.

The Llanfairynghornwy Belt is thus to be regarded as a long *lambeau*, nearly horizontal, that is caught between the Carmel Head and Caerau thrust-planes. Its thickness at Mynachdy marsh is not likely to exceed 500 or 600 feet. Its internal structures are at higher angles than its bounding planes, and are to be regarded as the remains of a deep isoclinal infold of the major series, which has been truncated both upwards and downwards. The Gwna Beds and Church Bay Tuffs of Llyn Llygeirian (Folding-Plate V) must be part of the northern limb of this infold, while the Mynachdy Gneiss is in its core, which was therefore multiple. The Amlwch Beds of Carmel Head doubtless rose upon its southern limb, but that limb has been cut through by the Wig thrust-plane, driving forward the Gwna Beds and leaving a subordinate *lambeau* below them that can only be some 50 feet in thickness. The Wig and Caerau thrust-planes (if of the Complex) belong to the major secondary structures, but the ancient folded thrust-plane of Mynachdy to the primary recumbent structures.

The Major Folds and Thrusts in the Main Body of the Region.—The Coeden beds now appear from below the Amlwch Beds in the curve of the thrusts ; and, riding first upon the one and then upon the other, take their place for some five miles as the tectonic base of the main body of the Northern Region. They are powerfully folded, the folds having a larger sweep than is usual in the thinner-bedded Amlwch Series. The isoclines are very steep, with even a few symmetrical folds (Fig. 132) ; revealing thus an approach to dynamic equilibrium, from which a steep cleavage-foliation might have been expected, but there is only a strain-slip (Fig. 70) in some thin lepidoblastic beds. The pitch is low and undulating, and is westerly at the west and easterly at the east end, indicating a rise from below the Amlwch Beds on a large major anticline.

Between them and the Skerries Grits of Bwlch there can hardly be room for the whole Amlwch Series, the spilites and jaspers, moreover, being almost absent. Their local development may have been poor, but there is reason (p. 316) to suspect thrusting west of Bwlch, and there are probably undetected thrusts in the Amlwch Beds themselves, cutting out most of the Lynas beds.

That the major isoclines of the region must be of great original amplitude (though now cut off at no great depth by the Carmel Head thrust-plane) has already been remarked. That which here takes in the Skerries Grits is boat-shaped (pp. 177, 317). Possibly, therefore, the West Mouse and The Skerries lie in another infold that is nearly but not quite on the strike of it. But neither of these infolds is deep enough to take in the Church Bay Tuffs. The infold of Llanrhwydrys is overthrust from the north-east (p. 317), and the thrust-plane must be at a low angle. But its age is unknown, it may be an ancient one, possibly even folded and cut by later ones, and must be supposed to pass into the Amlwch Beds in the obscure ground east of Llanfechell.

The broad tract of Amlwch Beds that follows must be anticlinal, probably bringing up the Bodelwyn phyllites from Tre-gele to Rhydgroes, but with innumerable corrugations. To the east of Amlwch are some of the most beautiful isoclinal folds in Anglesey (Figs. 49, 52), but towards Cemlyn folding is largely replaced by thrusting that is almost parallel to the bedding and that is ' healed up ' by crystalline foliation.

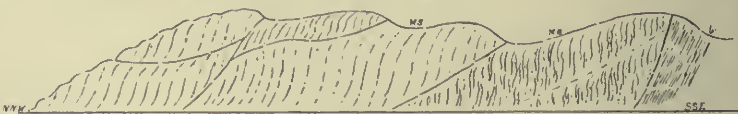


FIG. 95.—THE THRUST-PLANES AT TRWYN BYCHAN.
Sketched from a boat.
Cliffs about 100 feet in height.
MS = Church Bay Tuffs. MG = Gwna Mélange. b = Nemagraptus Shales.

The Trwyn Bychan tract is to be regarded as a second infold of the Skerries Group, deep enough to take in the Church Bay Tuffs and even the Gwna Beds ; and is compound, seeing that it takes the latter in on three distinct ranges of nips. This statement is, however, an extreme simplification, for in the Trwyn Bychan syncline almost every fold must be ripped out by thrusting. The high-dipping foliation of the Tuffs themselves is thrown into sigmoidal curves by innumerable ancient thrust-planes of the Complex, four of which are large. The greatest of them, which is horizontal at one place, and is cut by steeper ones, may be called the Trwyn Bychan thrust-plane (Fig. 95 and pp. 185, 314). The Tuffs are then driven on to the Gwna Beds by the Trwyn Bychan lower thrust-plane (*loc. cit.*), and it is evident, from the different beds that come against the junctions, that nearly all the nips are thrust. Further complications are introduced by the presence of Ordovician infolds, themselves torn out by the Porth Pridd and other thrust-planes. From Porth Wnol to Cemaes Bay the Skerries Group is once more cut out by a thrust (Fig. 96) which

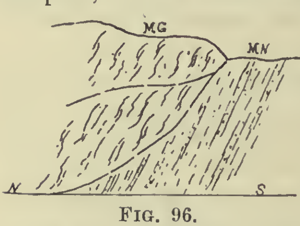


FIG. 96.
THE WYLFA THRUST-PLANE,
Porth Wnol.
Cliff about 80 feet in height.
MG = Gwna Mélange.
MN = Amlwch Beds.

may be called the Wylfa thrust-plane, shattered Gwna Beds of a deep infold being driven, at a lower angle than the dip, on to the Amlwch Beds. But on both sides of the Hell's Mouth fault the structures are extremely difficult to interpret with consistency, owing to the anomalous behaviour of that fracture. It is a downthrow to the north-west, for on that side it introduces nips of Ordovician rocks a mile further to the south-west than they are found on the other side. Producing several feet of breccia (p. 311) it cannot but be powerful. Yet it scarcely seems to displace the Ordovician base-line at Hell's Mouth. That may be partly explained by the nearly vertical Ordovician dip at that place. But neither does it appear to displace the Wylfa thrust-plane at Nenadd, and it is possible that the Gwna nip east of the fault, which must lie in a deep ruptured infold (possibly thrust southward as well) may not be resting on that same plane. The sudden thickening of the quartzite on Dinas Cynfor suggests that it is doubling over, possibly on a fold above the Nappe of Holyhead, brought down by the Hell's Mouth fault, which may be Pre- as well as Post-Ordovician, recurrent movement accounting for the great width of breccia. That a higher fold is coming on to the north is confirmed by finding that on the Middle Mouse the Skerries Beds underlie the Amlwch Beds. Whether this be the beginning of the Bodorgan Recumbent Fold, or some subsidiary one, is not known. It is known, however, that the Gwna quartzite, in spite of the Pre-Ordovician shattering of the group, was (Chapter XIV) locally horizontal in Ordovician times, though its horizontality was probably of the nature indicated in Fig. 97. It is now repeatedly

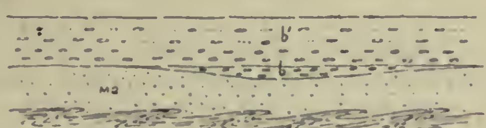


FIG. 97.—DIAGRAM OF SUPPOSED ORIGINAL RELATIONS OF THE GLENKILN CONGLOMERATES TO THE MONA COMPLEX IN THE GYNFOR DISTRICT.

b′ = Pale conglomerate.
b = Purple conglomerate.
MQ = Gwna Quartzite.

broken, and at high angles, or even vertical. To restore, in such case, ancient planes of movement whose original angle is unknown to us, is a problem that seems insoluble at present. But it is clear that the anomalies of the Hell's Mouth fault are the net result of the superimposition of Post-Ordovician thrusting and faulting upon the inversions, foldings, and thrustings of the ancient Complex.

THE MIDDLE REGION.

The members present are the Gneisses, the Coedana granite with its hornfels (which appears to be largely an altered condition of the Church Bay Tuffs), the Penmynydd Zone with Gwna sediments, the Gwna Beds in very full development and including both the north-western sedimentary and the eastern volcanic facies (pp. 155, 179), and the Tyfry Beds.

The Gneisses, of all types, are finely developed, and it is evident from the map that not only the small inliers among the Ordovician rocks but the large Nebo Inlier are continuous with the Middle Region tract itself, and that a great crescent of gneiss (indicated by the broken lines in Fig. 101) extends all through the middle of the Island from the Tywyn Trewan to the north-east coast. Xenoliths of crystalline hornfels are numerous within the Coedana granite, which is partly fringed on both sides by the crypto-crystalline type. Passing to the Penmynydd Zone ; a persistent fine and flaggy belt adjoins the hornfels, then flaggy and flaky flaser belts alternate. The hornblende-schists are small and thin, and glaucophane has not been found. The triple Gwna Group of quartz-schist, limestone, and graphitic-schist appears in small outcrops all across and along the Zone, as well as in its inliers to the east, and is of purely western facies. There is decisive evidence (see p. 385) that the Zone develops at different stratigraphical horizons. A considerable tract of it is hidden by the Ordovician of Llangwyllog. The Gwna rocks proper (as distinct from those in the Penmynydd Zone) consist first of typical Gwna Green-schist, in which lie the great Engan spilites, now completely converted into chlorite-epidote-actinolite-schists with their jaspers deformed and bleached (pp. 77, 88). East of them is a prodigious mass of autoclastic mélange with vertical divisional planes, in which are numerous nips of quartzite, all very slightly reconstructed, and also the Llanddwyn spilites of Ceinwen, which are not much deformed. They are associated with large ashy rose-limestones, whereas the Engan spilites are almost free from limestone. The Engan and Llanddwyn spilites, therefore, cannot be the same, but must be on different horizons ; and as the Llanddwyn lavas are surmounted by the Tyfry Beds, they must be the later of the two great flows. The large epidiorites of Bodorgan may (see pp. 109, 321, 348) be of approximately the same age as the dolerites of the Northern Region. The Tyfry Beds occur in the Ceinwen country and as a series of strips along the eastern margin of the Region, where they pass into the Gwna mélange. The great outcrops of quartzite in the extreme north-east at Mynydd Bodafon are an important circumstance in the stratigraphy.

Now, ignoring the Penmynydd metamorphism, and considering original material only, it is evident that the western Gwna facies, with its clean grey limestones, carbonaceous shales, and thin or no lavas, is well-developed in the western part of this region ; that the eastern Gwna facies, with its great spilites, ashy rose-limestones, and complete absence of the carbonaceous shales, is fully developed in the eastern parts ; and that the two facies come close together. Further : if the Church Bay Tuffs be represented in the hornfels, then both the western and eastern (Tyfry) facies of the Skerries Group are also present.

The region differs from all the others in the comparative rarity of rapid visible folding; instead of which we find persistent high or even vertical foliation-dips, with remarkably steady north-easterly strike (especially in the Gwna mélange). Along the eastern margin both deformation and metamorphism are comparatively low or moderate. Thence there is a generally progressive metamorphism westwards, but with sudden rises in and west of Gwna Vale.

The Major Folds and Thrusts to the West of Gwna Vale.—Structurally, the region is the most complex in the Island, and is extremely perplexing, more than one hypothesis being possible, while difficulties attend all that have been, so far, devised, most of which arise from the relations of the Penmynydd Zone. What follows (Folding-Plate VI) must therefore be understood, hardly as a theory, but rather as a suggestion in aid of a structural theory of the region.

The western part, it will be recalled, is considered to lie upon the great inverted Nappe of Holyhead, the Nappe of Bodorgan appearing in the eastern parts. There is independent evidence that the succession in the western part really is inverted, for the passage-beds from the Gwna sediments to the Church Bay Tuffs (see p. 64) undoubtedly pass under the Bodafon quartzite (pp. 160, 336) showing that the Gwna Group is resting there upon the Skerries Group. Towards an interpretation of the major secondary folds, one fact stands out as of prime importance, and that is the existence of a great compound anticline at Mynydd Bodafon. Its nature is shown in Figs. 154—8, and detailed evidence for it is given on pp. 336—40. It pitches to the north-east.

Now, if the succession be inverted, the Gneisses must be uppermost, and this view finds confirmation in their position to the west of the axial line of the Bodafon anticline, where a complementary syncline might be expected. They may be supposed to lie in a vast crescent-like depression, which may be called the Caradog syncline, some three miles wide, that sweeps past the shores of Cors y Bol to the Nebo Inlier. It has already (pp. 168, 184) been suggested that, as the rocks originally adjacent to them are missing, they must be lying on an ancient rupture, most of whose outcrop has been flooded by the Coedana granite, for that intrusion, it will be recalled (p. 167) is evidently later than the primary recumbent folding. The ancient primary rupture thus postulated may be alluded to as the Gwyndy Thrust-plane. The Gwyndy thrust-plane must be folded by the major secondary flexures, and sink down deeply into the Caradog infold. The Bodafon Moor Flags (see p. 336) that rise on the Bodafon anticline, must be some of the upper Gwna Beds. They are converted into hornfels near the (destroyed) cromlech, and the long zone of hornfels to their south-west, referred on petrological grounds to the Church Bay Tuffs, might be expected to rise from below them on the pitch. The Coedana granite points directly to the core of the anticline, under which it seems to sink, as its hornfels-effects diminish to the north-east, beyond its outcrop. It would therefore appear to be a great sill, rising into or on the anticline. If so, another great syncline should be expected along its south-east flank, and as the foliation- and bedding-dips there are either steeply to the south-east or vertical, the granite may be supposed to plunge down almost vertically. Now it is here that we find the Penmynydd Zone of metamorphism. That it should appear on this tectonic horizon is perplexing, but reasons have been given on p. 200 for supposing that there has been a transfer from the zone of fracture to the zone of flowage, explicable by the roll-over of a still higher *nappe de récouvrement*, making the Penmynydd alteration possible (see also footnote, p. 227). We have seen that alteration to be later than the intrusion of the granite. We know, too, that the impulse here was from the south-east. If we suppose rocks lying in or let down into a profound synclinal depression with nearly vertical axis, whose further side was a wall of granite cased in hornfels and backed by a deep syncline of gneiss; if we suppose them still granite-heated (thus facilitating chemical re-adjustments), and, in that condition, driven against the unyielding north-western wall, then the Penmynydd metamorphism becomes intelligible. Much of them, further, we know to be highly alkaline (pp. 112, 122—7), and probably rhyolitic dust, a material that would lend itself to re-crystallisation.

The zone, of course, is not an horizon. Yet stratigraphy is traceable within it. We have seen reason to suspect that the Church Bay Tuffs, inverted, plunge down into this infold, which may be called the Bodwrog syncline. We know that Gwna quartz-schist, graphitic-schist, and limestone are repeated many times both across and along it. The dominant material of the surface is more than suspected to represent the Fydlyn rhyolitic group. If, then, the great infold be compound, filled in the main by the Fydlyn Beds with Gwna sediments appearing here and there on the crests of subsidiary anticlines, the stratigraphy can be made, so far, consistent. There can be but little pitch, for the limestones are found far inland to the north-east. Connected with that, probably, is the fact that the Bodafon quartzite fails to run along the western margin of the Gwna rocks of the Penmynydd Zone, as it should do if plunging unbrokenly down into the syncline. It must be cut out by a north-westward thrust, raising the rocks of that infold and thus abolishing their pitch.

Major Folds and Thrusts of the Nappe of Bodorgan.—On their further side is a long tract of Gwna Green-schist, with many trains of lenticular tracts of Penmynydd schist. On the theory just propounded, it is unlikely that these are merely "capricious" local alterations, they are more likely to be the upper parts of the Penmynydd Zone brought up, a view confirmed by the singular fact that they are often more strongly folded than the principal tract of the zone. Almost at the same time the great Engan spilite-schist appears, and with remarkable suddenness. For the basic rocks of the Penmynydd Zone are thin hornblende-schists and amphibolites probably all intrusive, and if any spilites at all are associated with the local Gwna sediments of the zone (which is doubtful) they must be quite thin, just as they are in Gynfor, whereas the Engan spilite is the greatest of all the lavas of the Island. Yet its first infolds occur on the same strike as, and its main body only five-eighths of a mile from the western Gwna facies, from which circumstance the change of tectonic horizon from the Nappe of Holyhead to the Nappe of Bodorgan (ushered in really by the Bodorgan thrust-plane) is inferred to come on somewhat below its base. The Bodorgan thrust-plane is regarded as folded, and as rising again on the major secondary anticlines which, about Plâs-bach, Bodwrdin, and elsewhere, bring up inliers of Penmynydd mica-schist in which are nips of Western-Gwna limestone with graphitic films. Only 160 yards beyond one of these inliers the Llanddwyn spilites of the Ceinwen infold come on, quite unreconstructed and in great part even undeformed, with ashy rose-limestones, and followed by the Tyfry Beds. So the western and eastern facies of the Gwna Group, each in full development, lie close together, and are interfolded with each other on the major secondary flexures.

It has not been considered wise to lay down the Bodorgan thrust-plane on the maps (though this has been done, approximately, on the small chart of Fig. 100 and on the Folding-Plate section), but it cannot be far from the margins of the Penmynydd Zone tracts, rolling over and over, possibly also cut by vertical secondary slides along the strike. The plane itself is doubtless now masked by crystallisation, so as to appear on its outcrop merely as one among countless foliation-planes in a zone of anamorphism. As it passes eastwards, it eliminates one by one the lower members of the Nappe of Bodorgan; first the Gneisses, and then the Fydlyn Beds, having been cut out by the time it has descended to the present level of erosion. Still rising to higher and higher horizons, it thins the Gwna Beds, and by the time we reach the Plâs-bach anticline, it has risen almost to the base of the Engan spilites. Passing still further east, the Engan spilites themselves fail to reappear. They are not repeated by the Plâs-bach anticline, on whose south-eastern limb, instead of them, appear the Llanddwyn spilites. The Gwna Green-schist on the two limbs must therefore be on two different horizons, that on the west being below the Engan, that on the east below the Llanddwyn spilites. The effects of the secondary anticline are thus quite abnormal, which is accounted for by supposing that the Bodorgan thrust-plane, where it rolls over, is in the act of cutting out the Engan and lower beds. But at this place, the great thrust seems to have attained its highest position. For, as the western Gwna facies never reappears, the Bodorgan thrust-plane cannot emerge on the further side of the Ceinwen infold, and is therefore supposed, after having risen almost up to the Llanddwyn spilites, to be returning to lower horizons, allowing the beds between the Llanddwyn and Engan spilites to appear upon an anticline.

The tract thence to the Carboniferous is regarded as a compound anticline of mélange, called the Hermon anticline, though it is somewhat difficult to realise that any major folding at all can be hidden within this eleven-mile tract in which hardly anything is to be seen but lenticular masses all standing vertically. There is a Tyfry nip at Cefn-cwmmwd, and finally the Tyfry Beds come in along the margin of the Complex, tucked in under the great fold. They graduate into the Gwna Beds, and yet the Llanddwyn spilites and limestones are but feebly represented, and in many places absent, being doubtless cut out along some of the countless planes of rupture.

The section (Folding-Plate VI), which must be understood as a suggestion merely, may serve to render the hypothesis here set forth intelligible. The positions regarded as probable for the Gwyndy and Bodorgan thrust-planes (omitted on the maps) are indicated. But the section has been simplified exceedingly, only the larger folds being shown. It will be seen that the arrangement of the major secondary folds, and of the resulting foliation-dips, is fan-like. It cannot be called synclinal, for the deepest infold of all is at the south-eastern margin where the large tract of Tyfry Beds is taken in; so that the general inclination of the region is at a considerable angle to the south-east.

The Gneissic Inliers.

The Nebo Inlier, as well as the small ones about Llanerchymedd and Bryngwran, are undoubtedly in continuity with the Gneiss of the Middle Region, and thus on the inverted Nappe of Holyhead, cut by the Gwyndy thrust-plane, itself infolded into the Caradog major syncline.

The Deri Inlier.

The rocks are evidently those of Mynydd Bodafon, but more foliated, and must be on the south limb of another anticline, whose core is invaded by the granite and whose north limb is concealed below the Ordovician.

The Pentraeth Inliers.

These, caught between and broken by the Berw faults, are closely related to each other. They consist almost entirely of Gwna Beds, with one small inlier of the Penmynydd Zone, a number of large infolds of the Tyfry Beds, and one small serpentine. The Gwna Beds are wholly of the eastern facies, being Green-schist and mélange, with a great development of the spilitic lavas, and especially the limestones, as well as jaspers, jaspery phyllites, and albite-diabases, the latter on a greater scale than usual. But the Engan spilites and the quartzite appear to be absent. Some of the most perfect examples of the variolitic structure, both glassy and felspathic, have been found in these inliers. Several of the rose-limestones are very ashy. The Tyfry Beds are typical, with much purplish phyllite as well as ashy grit, and their bedding is in unusual preservation. In both inliers, however, the rocks have been excessively torn up, and the spilites, though so beautifully preserved in certain cores, are for the most part sheared into dull green and purple schists, and their junctions with the albite-diabases obliterated. Except in the little inlier of the Penmynydd Zone, the metamorphism is of a low order, but somewhat higher in the Western than in the Eastern inlier. Folding is rarely seen, dips at moderate angles are but few, and the dominant structure is a vertical schistosity.

Both inliers are supposed to lie, like the eastern Middle Region, on the Nappe of Bodorgan; the sequence being normal, with the Tyfry Beds uppermost.[1] But the major secondary folds are probably ripped out in every case. Their positions may be roughly indicated, thus :—

The Western Inlier must be crossed obliquely by an anticlinal axis near the Smithy, up into the core of which the Penmynydd rocks are driven between a pair of slides ; and by a broad compound syncline with slight northerly pitch about Tan-y-graig, taking in the Tyfry Beds. The Eastern Inlier must be synclinal south-west of Pentraeth, the principal tract of Tyfry Beds lying in a symmetrical infold that is probably both deep and steep-sided. East of it, near Tyfry, three smaller synclinal nips occur. There must be a slight south-westerly pitch from the sea-ward end as far as Tyfry. The inliers are complicated by superimposition of powerful faulting, not only Post-Ordovician but Post-Carboniferous, upon the already excessive secondary ruptures of the Nappe of Bodorgan, and the direction of the throw of faults has been reversed in later times (Chapter XXVII). But the lines of the old Mona movements can be distinguished. They strike more northerly, meeting the Berw faults at angles of as much as 20°, thus carrying the bands obliquely across the inliers.

The Aethwy Region.

The members present are the Penmynydd schists, the Gwna Group, and the Tyfry Beds. Some basic gneisses which occur among the Penmynydd rocks near the western margin are correlated with the Gneisses of the other regions. The Penmynydd Zone is chiefly mica-schist, with large masses of hornblende- and glaucophane-schist, no quartzite, limestone, or graphitic schist being known within it here. The Gwna rocks of Aethwy proper are chiefly green-schist and mélange, with large masses of basic schist, jaspers, limestones, and quartzites (the last being rare). The basic schists are known to be in great part reconstructed spilitic lava, but may be partly after albite-diabase. In what may be called the Llanddona Highlands, little nips of them are extremely numerous. Ashy rose-limestones are associated with the lavas, and so the only Gwna facies present is the eastern one.

[1] It is possible, however, that they may be on the tectonic horizon of the Llanddwyn Wedge (p. 228).

In a narrow tract on the north-western margin, between the Aethwy Region proper and the Berw fault, which may be called the Llanddwyn Wedge (see the chart, Fig. 100), Gwna rocks reappear, now accompanied by Tyfry Beds. This wedge is distinct from the rest of the region, and may be on a higher tectonic horizon. It is the type-district of the eastern volcanic facies of the Gwna Beds. Mélange and green-schist are subordinate, while the ellipsoidal spilites are developed on a great scale, often, too, in perfect preservation (even retaining their augite), with their inter-ellipsoidal jaspers. Spilitic tuffs, albite-diabases, and ashy rose-limestones accompany them. They are the type-spilites of the Island. Though the Llanddwyn wedge is cut by lines of powerful shearing, and the spilites locally converted into dull spilite-schist, anamorphism is not found on Llanddwyn or in the dunes of Newborough, but only in the narrow north-eastern part, and even there is of a low order.

In the Aethwy Region proper, the Gwna Beds have undergone more metamorphism than anywhere else in the Island (outside the Penmynydd Zone). Original spilitic structure survives at a few places only, the lavas being almost everywhere converted into chlorite-epidote-schists with a good deal of actinolite and with ternary albite. Not only the Green-schist, but even the matrix of the Autoclastic Mélange, has been considerably reconstructed, with tolerably well-developed mica, and the stages reached along the Menai Strait are as high as any. Quartz has segregated on an enormous scale. Bedding has disappeared, and nemablastic texture is intense. In fact, all the higher characters of the Green-schist, described on pp. 67—9, are in reality the characters of this region. Connected with this is the rapid folding, not only of green-schist but even of mélange, which presents a strong contrast to the persistent high dips of the mélange in the Middle Region. The polyclinal type is developed on a great scale, and is peculiarly characteristic of these rocks. The existence of cross-folding, which produces a continual unsteady wavering of strike, presents a similar contrast. Two tracts of specially gritty mélange run, from Pen-y-parc to the Bulkeley Memorial, and from Cadnant to Llansadwrn; and so, as tracts of highly siliceous nemablastic schist (at the Suspension Bridge and at Llanddona) are found at each end of the larger of these tracts, it is evident that they are an altered condition of these gritty beds.

In the Penmynydd Zone, the flaser type is dominant. The survivals of original material, and the passages from the Gwna Beds, have been described (pp. 122—5). The rocks are perhaps more highly crystalline than in the Middle Region. But the differences from that region are chiefly (as in the Gwna Beds) that there has been a much greater segregation of quartz; and that instead of a persistent high dip with subordinate visible small symmetrical folds, rapid folding, chiefly isoclinal but often polyclinal, is conspicuous, and is the rule everywhere, both in acid and in basic schists. Basic rocks are present on a vastly greater scale, and glaucophane-schist is abundant. With regard to the horizons present in the zone, the acid mica-schists have been (pp. 122—6, 162) correlated with the Fydlyn Group, which must be very thick; and it is possible that the glaucophane-schist may represent the great Engan spilites.

Pitch being to the north-east, the Fydlyn must pass under the Gwna Beds, and the succession must be uninverted. Reasons have been given (p. 180) for supposing the whole region except the Llanddwyn wedge to lie upon the Nappe of Bodorgan.

It is disconcerting, undoubtedly, to find that the high Penmynydd grade of metamorphism has mounted from the Nappe of Holyhead to that of Bodorgan.[1] Yet the ascent is less real than apparent, for the anamorphism in question does not, after all, reach the base of the Llanddwyn spilites, though it seems to involve the Engan spilites, thus mounting somewhat, though not greatly, higher than in the Middle Region. The Bodorgan thrust-plane, we may recall, was, when last seen, passing to lower horizons; and here the vast mass of the Fydlyn Group has been admitted above it; the base of the nappe having thus descended rather than the metamorphism having ascended. Concordantly with this we may note that the general inclination of the Middle Region is at a considerable angle to the south-east; and that the Aethwy Region has undoubtedly been raised on the Berw fault from a depth of at least 2,300 feet (Chapter XXVII) while its more crystalline parts had already been raised an unknown distance on the Newborough slide (see below). It has, moreover, been shown (pp. 198—200) that the Aethwy rocks have been transferred from the zone of fracture to that of flowage, and that this is explicable by the rolling over them of another large *nappe de récouvrement*. A difficulty remains, however, in that there is no sign of the Coedana granite, whose influence has been appealed to in partial explanation of the Penmynydd metamorphism in the Middle Region (p. 222). Yet we may reflect that, but for the denudation of the core of the Bodafon anticline, the existence of the Coedana granite would have remained unknown. That there are plutonic intrusions in the Aethwy Region is certain, for, whatever be the relations of the basic gneisses (p. 231), diorites are exposed in Llangaffo cutting.

[1] Disconcerting, because these highly altered Penmynydd rocks have thus to be placed on a higher tectonic horizon than that of the Church Bay Tuffs and Gwna Beds of the Nappe of Holyhead, which are but slightly altered (see notes on pp. 200, 240). It is natural to suppose that, both in the Middle and Aethwy Regions, the Penmynydd anamorphism must be upon a tectonic horizon lower than that of the Nappe of Holyhead. Yet, if we attempt to place them upon the lower limb of the Holyhead Recumbent Fold, or upon either limb of the Rhoscolyn Fold, we find that the same difficulty reappears in a new form, and that we have placed slightly altered rocks under highly altered rocks. For we have then placed the slightly altered Gwna and Tyfry Beds of the Middle and Aethwy Regions under the Green-mica-schists of the Nappe of Holyhead. Stratigraphical difficulties as to inversion also emerge. Most serious of all, it will be found that the facies of the Skerries and Gwna Groups do not then develop in the right directions. Thus, we have to encounter difficulties of some kind whichever arrangement we adopt, and the one adopted as a working hypothesis appears to be, on the whole, that which presents the least embarrassments.

The whole question is more difficult, for the foliation-planes have been folded, and their original position, with the original direction of impulse, is unknown.

The Major Folds and Thrusts.—Let us now consider the nature of the major secondary folds and ruptures (Folding-Plates VII, VIII). The Llanddwyn wedge comes in quite suddenly, and must be brought against the Penmynydd Zone by a powerful rupture, which may be called the Newborough slide, evidently now at a high angle, but probably folded. Now as the rocks of the wedge contain much less altered cores than any known parts of the Nappe of Bodorgan, far less altered than the other Aethwy Gwnas, it is probable that they belong to the upper limb of the Bodorgan Fold, in which case they would be the highest tectonic horizon of the Complex known in the Island, and would be inverted. Little can be made out of their own major folds, which being in the zone of fracture, are evidently all ruptured along powerful shear-lines, and the dips at high angles. There seem to be two parallel anticlines, with Tyfry Beds in the core of each, one running east of Bryn Llwyd, the other through Llanddwyn Island, the great ellipsoidal spilite being taken in on a syncline between them. Their axes must be approximately vertical, and their strike is obliquely across the wedge, more northerly than that of the Berw fault, but approximately parallel to the Newborough slide. As these unaltered rocks are at the south-west end, the pitch is presumably in that direction, but there is a reversal near Cerig Mawr. The Newborough slide is cut off by the Berw fault at a point west of Llangaffo Church.

Turning to the Aethwy Region proper, it is evident from the map that the major secondary folds must be on a great scale, and a generally anticlinal structure is at once suggested, with the western limb truncated by the Newborough slide and the Berw fault. As soon, however, as the structures are examined, a number of anomalies appear. They will best be grasped by means of the following summary, aided by the simplifications of the map given in Fig. 98.

1. The anticline that is obvious from the dips is really a foliation-anticline.
2. Coincident with it, however, is an anticline of the axes of minor opposing isoclines.
3. Yet the disposition of the glaucophane-schists about the margins of the Penmynydd Zone tract indicates a true stratigraphic anticline.
4. To some extent at any rate, especially along Mynydd Llwydiarth, foliation-dip certainly coincides with mass- or true-dip.
5. The axes of the stratigraphic and foliation anticlines do not coincide—are indeed a considerable distance apart even where nearest.
6. Nor are they parallel. That of the stratigraphic anticline strikes north-east—south-west, that of the other north—south, a divergence to the south of some 45°, so that at Llandysilio and Newborough they are eight miles apart.

7. The axis of the stratigraphic anticline must begin on the western side of Mynydd Llwydiarth (about a mile within the Penmynydd Zone tract), running thence by Penmynydd Church, Gaerwen, and Llangaffo to Newborough, where it is cut off by the Newborough slide.
8. The axis of the foliation-anticline keeps close to the eastern margin of the Penmynydd Zone, but is usually about three-eighths of a mile within the Gwna tract.
9. At the axis of the stratigraphic anticline folial dips are often confused, but where distinct are north-westerly.
10. At the axis of the foliation anticline folial dips, instead of being horizontal, are vertical.
11. Yet their verticality is usually not a true plane verticality, but is thrown into a series of a-clinal corrugations.
12. In the same axial tract there may be no dip at all, but polyclinal folding, or mere bundles of nemablastic siliceous pencils.

FIG. 98.—STRIKE, DIP, OVERFOLDING, AND PITCH IN THE AETHWY REGION.

Scale: Six miles = one inch.

Broken line — Junction of Penmynydd Schist and Gwna Green-schist.
Long-tailed arrows — Pitch.

13. About a quarter of a mile west of the same axis there is in places violent horizontal contortion about vertical axes (Fig. 61), so that severe torsion must have taken place.
14. Folding transverse to the dominant strike is common all over the Gwna tract, and for some distance into the Penmynydd tract. It is usually a horizontal wrench, but sometimes isoclinal with a northward overdrive.
15. Near the axis of the great foliation-anticline, the nemablastic lineation crosses the crests of small anticlines obliquely, another evidence of torsion.
16. The pitch is on the whole north-easterly in the main Penmynydd area, northerly in the Gwna area ; and is high on the western margin.

17. The strike of the Gwna Beds curves round in a crescent concave to the west. Their prevalent dip is to the right when walking northward on that crescent.
18. The Penmynydd Zone rises at several places within the Gwna tract, but, apparently, at different stratigraphical horizons.
19. There are subsidiary rolls both of pitch and foliation-isoclination dip.

It is evident that in Aethwy there must be excessive complication in the secondary and minor folding, unusual even for the Mona Complex.

The existence of a great foliation-anticline that is a-symmetrical stratigraphically, recalls the great foliation-anticline of Cowal in the Scottish Highlands, described by Mr. Clough in the Geological Survey Memoir on that region.[1] But that of Aethwy differs from that of Cowal in the vertical dips at its axis, in the opposition of the facing isoclines, and in the development of a great real anticline to the west of the foliation-anticline. Now a general stratigraphic syncline, with a foliation-anticline, opposition of isoclines, and vertical dips at the axis, are essentially the features of a synclinorium ; and there can be no doubt that the Aethwy foliation-anticline is, in a way, synclinorial, for the Penmynydd Zone rises on both sides of it (see item 17 of summary above). But in a true synclinorium folial symmetry should coincide with stratigraphical ; whereas in Aethwy, the vertical dips are some way to one side of the only possible synclinal axis, in addition to which the Aethwy verticality is not plane but is a-clinally contorted. And powerful horizontal torsion has also taken place along the Aethwy axis, in which it resembles the axes of later movement in the Lewisian Gneiss of Scotland. The nemablastic pencilling at the axis appears to be a special character.

On the whole, the Aethwy Region appears to be somewhat as in the horizontal sections (Folding-Plates VII, VIII), which are of course greatly simplified. The pitch is away from the observer. On the left, the upper inverted limb of the Bodorgan Recumbent Fold appears on the (folded) Newborough slide ; the rest of the section being on the lower limb (the Nappe of Bodorgan). The leading features are, from west to east ; the main Aethwy (real) anticline, all in Penmynydd rocks ; then what may be called the Llanddona syncline (in which, on the map, appear the numerous nips of basic schist) ; then subsidiary rises of the Penmynydd Zone (though on higher horizons eastward) ; then the Llaniestyn syncline (apparent on the maps, but not reached in the sections), taking in the highest lavas with limestone. The main Aethwy anticline is isoclinal, and has been driven eastwards over the Llanddona syncline, which is also isoclinal but in an opposite direction. Between these opposing overdrives the Llanddona

[1] "Geology of Cowal" (Fig. 47, pp. 84-87).

syncline has become synclinorial, but the axis of the foliation-anticline became established in it a-symmetrically. Its vertical dips may once have been plane, but are now a-clinally contorted, probably from oscillations during the conflict between the major opposing isoclines, under a permanent load from above. Rotation, under the same influences, probably produced the nemablastic pencilling. But the pencils are not merely rotated, they are powerfully drawn-out, or they would not be nemablastic. This would be due to the torsion in the vertical dimension, of which independent evidence has been set forth above. The wrenching along east and west lines (with some amount of northward over-drive) is later, and is the last movement that was accompanied by crystalline anamorphism. The two diverging ruptures of Mynydd Llwydiarth (described on pp. 373—6), which look like thrusts on the limb that is common to the Llanddona synclinorium and the main Aethwy anticline, may really be connected with the torsion in the horizontal dimension.

The position of the basic gneisses is perplexing. They may be merely deep-seated cores of the intrusions from which came the sills that are now hornblende-schist, as the Llangaffo diorite seems to be. But it is curious that they should all appear along the western margin; that they should be banded, heterogeneous, with occasional north-westerly foliation-strike, full of coarse albite-pegmatites, and that a strip of coarse, acid albite-gneiss appears along the margin of one of them. One would hardly expect such characters in the mere cores of the basic intrusions. They are rather those of an ancient gneissic floor. In either case these rocks must, if on this uninverted limb, be rising from below. The contrast which they always present to the adjacent rocks shows that their boundaries are slides, one of which may be in part Post-Ordovician (Chapter XVII). But they are crushed and mylonised, and can hardly have come up from the lower parts of the Penmynydd anamorphic zone. It is more likely that they are shattered catamorphic nips like those of Mynachdy, brought in on infolds of the (primary) Newborough slide from the inverted upper limb of the Bodorgan Fold.

Considered as a whole, the Aethwy Region must be anticlinal. The western limb is brought in by the Newborough slides, and the rest has a gradual eastward inclination which must be bringing in the same horizons not far beyond the Menai Strait.

DEVELOPMENTS OVER THE ISLAND CONSIDERED AS A WHOLE.

Probable Thickness.

No reliable measurements have been obtained. But by combining several methods it is possible to arrive at a general idea of the thicknesses. One of these is by means of the pitch. Now, if the meaning of pitch be that corrugated instead of plane sheets rest on each other with an inclination in the direction of the greatest axes of the corrugations, it follows that the pitch-angle is also the true dip of the sheets as a whole. Errors may be introduced in several ways, most serious (though least likely) being a possibility that the minor isoclines on which the angle is measured may have been imposed on pre-existing major folds that had a different strike. They may arise from uncertainty as to the relation of foliation to bedding, from impersistence of the folds, from a spiral tendency, and other sources.

In Holy Isle and other districts, however, the pitch is remarkably steady; and as the results obtained from it show no serious divergence from those obtained by other methods in a case where that is possible, it seems better to make some attempt at estimates of thickness than to leave the question wholly nebulous, as a first attempt may lead the way to more successful ones in future, provided the difficulty of the subject be fully realised.

If the section in Fig. 91 be correct, then the thickness of the Holyhead Quartzite must be about 700 feet. Some 400 feet of the Stack Moor beds are seen in the cliff opposite the South Stack, and with a pitch of 15°, 800 feet more must come in between the cliff-top and the Quartzite outlier, making a total of 1,200 feet. The group measured by dip across the valley on the south side of the mountain is 1,100 feet, which agrees well with the result obtained from pitch. From Penrhynmawr to the North Stack fault the same pitch gives 1,500 feet of Llwyn beds, but as neither base nor top is visible, they are unlikely to be less than 2,000 feet. The top of the Celyn beds appears at Holyhead, but they widen at Trefignath, giving 1,800 feet on an average pitch of 14°, and as the base is not reached they are probably 2,000 feet. The Soldier's Point beds, from the Namarch fault to Salt Island, with an average pitch of 14°, measure 1,250 feet, but the top never appears, so this must be an under-estimate. Assuming the same pitch to continue, 1,750 feet more would come in by the time we reach Penial, but it is very doubtful whether the Penial rock be the Church Bay Tuff, and higher beds probably occur in the wide Llanddeusant country, so 3,000 feet is probably less than the total of the group. The Church Bay Tuffs at Clegyr-mawr are dipping at 30°, and such dips as can be seen to the north are higher. If, however, we assume only 30°, we obtain 2,000 feet as far as Yr-ogo-goch, where there are indications of the New Harbour Beds. The Skerries Grits may be as much as 800 feet in Bull Bay, and can hardly exceed 700 feet in the large infold. No estimates have been made of the Coeden or Amlwch Beds. The beds at Fydlyn cliff are dipping at 40°, so the Gwna Beds between the Fydlyn and the Hwch do not seem to exceed 350 feet, but they widen eastward where the sills appear, and may reach there 970 feet. At Llanfaethlu they are certainly pitching eastward (though greatly broken) off the Church Bay Tuff, and if we assume a pitch of 10°, 1,500 feet would have come on by the time the Ordovician base is reached. But the northern Gwna facies is likely, by its nature, to be attenuated in comparison with the south-eastern. Accordingly, if the section in Folding Plate VI represents something like the truth, the mélange between the Malldraeth and the Llanddwyn spilites at Ceinwen, doubled vertically on itself, must include some 4,500 feet of beds. The Ceinwen spilites would be, from the same section, about 375 feet (and they must be thicker at Llanddwyn). In the same way the Engan spilites and their underlying sediments would be about 1,200 feet. The Gwna quartzite in Gynfor cannot be less than 180 feet thick, as it and the Ordovician rocks are locally conformable, and the purple conglomerate fills old hollows in it to that depth (Chapter XIV). The thickness of the quartzite at Bodafon (Figs. 156—8) is 300 to 400 feet. The Fydlyn Group must approach 200 feet, the base, however, being nowhere seen. But the rocks of the Penmynydd Zone of metamorphism, correlated for the most part (pp. 127, 162) with the Fydlyn Group, must be vastly thicker, especially in the Aethwy Region. In that region (pp. 228—30) there is reason to believe the major secondary folds to be of great amplitude, in which case the group could not occupy the space it does unless it were some 4,000 feet in thickness. The total thickness of the Mona succession, exclusive of the Gneisses, appears therefore to be about 20,000 feet. But it must be understood that these estimates are put forward with the greatest reservation, and largely to serve as a starting-point for further research.

Facies and Physiography.

The changes of facies already alluded to afford a certain amount of evidence as to the physiography of the period, immeasurably remote though that is. But the present positions of the several facies are by no means to be taken as their positions at the time of deposition. The operation of the recumbent folding of the Complex, upon which is superimposed that of the Carmel Head thrust-plane, has brought about extraordinary changes of position, and even reversals of direction, and must be allowed for in every case. Figs. 35 and 100 should be consulted, and combined with a working-model of the folding. The view of the tectonics advocated in Chapter VII is of necessity assumed here. But as the physiographical results of the assumption are self-consistent, and much more probable, as such, than might have been hoped for under such circumstances, they afford some degree of confirmation to the tectonic views assumed.

Nothing can be made out concerning any principle governing the distribution of the types of gneiss. At present, there is an increase of basic gneiss in a southerly direction, but when we consider the tectonic succession, the original distribution appears merely sporadic.

What remains of the Fydlyn Group at the Fydlyn Inlier is so limited both horizontally and vertically that we have but scanty data for a study of the facies. Yet the great development of acid mica-schist in the Penmynydd Zone, especially in Aethwy, points to a thickness of acid volcanic rocks that seems incredible at Fydlyn. If the tectonic horizons be correctly determined, this thickening would have been to the north, and we may therefore look in that direction for the focus of the felsitic eruptions.

The facies of the Gwna Beds that are at present western and eastern evidently represent, respectively, attenuated thalassic and thickening hypo-littoral sedimentation. The spilitic eruptions thicken with the sediments, so that the volcanic centres appear to have been, as is so often the case, distributed along the margins of the land. When the tectonic horizons are allowed for, it would seem as if that land, with its volcanic fringe, is to be looked for somewhere to the north-west.

The Church Bay Tuffs are thickest about Llanrhyddlad, indicating proximity of the volcanic centres of those eruptions, which, therefore, allowing for the tectonics, appear to have been somewhere to the north-west as before. In the Northern Region, their upper parts are replaced by the Skerries Grits, which, though largely volcanic (see p. 59), have undergone some degree of water-sorting. In this case, we have better evidence than usual of the direction and even the position of the land, for the great igneous boulders of The Skerries cannot be far from their source. The land, then, must still have lain somewhere to the north-west, though not in the present position of The Skerries, for we must remember that (besides the recumbent folding of the Complex) the Northern Region is riding on the Carmel Head thrust-plane, and is *sans racine*. The Tyfry Beds, regarded as equivalents of the Church Bay Tuffs, must, according to the tectonic scheme adopted, have been deposited far to the north of where we (save possibly on the Middle Mouse) now see them. They contain fragments derived from an old land, and confirm the conclusion, therefore, that, throughout the period represented by the Skerries Group, it lay somewhere to the north or north-west.

In the New Harbour Group, the Lynas beds contain both more and thicker grits than do the Soldier's Point beds, and there are a few (see pp. 51, 303, 304) land-derived fragments of some size. The Amlwch facies was undoubtedly deposited far to the north of the New Harbour facies, and the land, therefore, must once more be looked for in a northerly direction. The spilitic lavas (like those of the Gwna Beds) thicken in the same direction. The Bodelwyn beds, however, are of much the same texture as the Celyn beds.

Both divisions of the South Stack Series thin from the South Stack to Rhoscolyn, but they seem to thicken again on the lower limb of the Holyhead Fold, thinning again at the Breakwater tract, and at the same time losing their coarser grits, while the Coeden beds are decidedly thinner-bedded and finer than the Llwyn beds of any part of Holy Isle. Perhaps we are, in this case, on the successive tectonic horizons, crossing, not following, the direction of the land. The close resemblance between the Bodelwyn and the Celyn beds may foreshadow this change in physiography.

The Holyhead Quartzite seems to change in the same directions as the South Stack Series, but the evidence is very scanty.

Thus, throughout the period represented by the Bedded Succession of the Mona Complex, as far up as the middle of the New Harbour Group, the direction of the land, and also of the foci of volcanic activity, seems to have been somewhere towards the north-west. Then come signs of change, suggesting that, for the rest of the period, it is to be looked for rather to the south-west or the north-east. This change, it is most interesting to note, was accompanied by extinction of the long-continued vulcanicity of the period.

Geographical Distribution of the Stratigraphical and Tectonic Members of the Complex.

The Bedded Succession occupies by far the greater part of the exposed area, the Gneisses occupying only about one-eighteenth, though if their probable extension on the Sub-Ordovician floor (indicated by the broken lines in the chart, Fig. 101) be taken into consideration, they may occupy as much as one-sixth of the Island. With regard to the distribution of the several members, it is to be noted that the Holyhead Quartzite is the most, the Gwna Beds (which besides their visible outcrop must occupy much of the Sub-Ordovician floor in the Cors y Bol country) the least restricted both as to extent of outcrop and of distribution; that, in fact, there is a tendency to increase of extension as we descend in the chronological succession. The Gneisses, in spite of their moderate outcrop, are distributed all over the Island, from the north-eastern coast to the Tywyn Trewan and from the Carmel Head Gader to the Aethwy Region. The Penmynydd Zone appears only in the Middle and Aethwy Regions.

The distribution of the tectonic (see chart, Fig. 100, p. 238) is the reverse of that of the stratigraphical horizons, for the lower occupy vastly less space than do the higher ones. There is a notable leap in matter of extent from the lower to the upper limb of the Holyhead Recumbent Fold, the latter (called the Nappe of Holyhead) being the most extensive of all the tectonic horizons. This contrast between the distribution of the stratigraphical and of the tectonic horizons, taken in connexion with the north-easterly pitch, points of itself to the existence of widespread inversion and of powerful primary thrust-planes. From the same chart (combined with Fig. 35) it will be seen that the succession must be inverted over

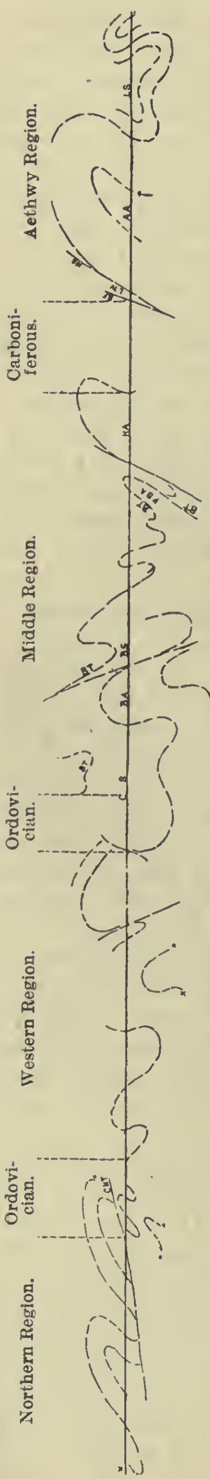


Fig. 99.—The Major Secondary Folds on the Main Island.

XX = Top of New Harbour Beds.
CHT = Carmel Head Thrust-plane.
CS = Caradog Syncline.
BA = Bodafon Anticline.
BS = Bodwrog Syncline.
BT = Bodorgan Thrust-plane.
PBA = Plâs-bach Anticline.
HA = Hermon Anticline.
BF = Berw Fault.
LW = Llanddwyn Wedge.
NS = Newborough Slide.
AA = Aethwy Anticline.
LS = Llanddona Synclinorium.

some two-thirds of the extent of the outcrops in the Island. The Post-Ordovician Carmel Head thrust-plane has also exerted most important influence upon the distribution of the horizons, whether stratigraphical or tectonic, and must never be forgotten in any study of the Complex.

Arrangement of the Post-Recumbent Foldings.

The major secondary folding is isoclinal in Holy Isle, in the Northern Inliers, and in the Northern Region, its impulse being southward. In the Western Region it is also isoclinal, though with a northward impulse. In the Middle Region it is fan-like or symmetrical. In the Aethwy Region it is again isoclinal, but with opposing impulses about a synclinorial axis. An abstract of the general arrangement of the major folds upon the Main Island is shown in Fig. 99, but it is to be remembered that the major folds of Holy Isle (Folding-Plate III) pitch under those displayed in that figure, and are not shown in it.

The minor folding is very strongly isoclinal, with a southward impulse, in Holy Isle and in the Northern Region. In the Western Region it is largely inconspicuous, a flaggy foliation-dip to south-east at moderate angles being very general. In the Middle Region it is still less conspicuous, vertical foliation-dips being dominant. In the Aethwy Region it is isoclinal to east and west, with opposing impulses, and is a-clinal and polyclinal about the synclinorial axis. Its impulses thus agree on the whole, though not strictly, with those of the major folding. In the Western Region, the Northern Inliers, the Northern Region, and the eastern Aethwy Region it slowly dies out as we pass to higher tectonic horizons, and gives place, first to thrusting, and finally to autoclastic mélange. The same change takes place as we cross the Middle Region from west to east and pass into the Pentraeth

Inliers, such minor folding as is visible dying out and being replaced by mélange, whose development attains a maximum in the eastern Middle Region. In eastern Aethwy it was re-imposed (see pp. 198—200) upon the lower parts of the Autoclastic Mélange which had once replaced it.

Pitch, Dip, and Strike throughout the Island.

The pitch, where visible, is usually to the north-east, save in the Northern and in the eastern Aethwy Regions, where it undulates. The pitch-angle is moderate except along the western Aethwy margin.

The foliation-dip is usually at moderate angles elsewhere than in the Middle Region, where it is vertical or nearly so. Its prevalent direction is northerly, save in the Western, and on the eastern margins of the Aethwy Region.

In considering the strikes, the Gneisses must be discounted, as they have (see p. 168) irregular strikes of their own, discordant from those of the adjacent rocks. The dominant strike of the foliation (as also of the bedding where that survives) in the Bedded Succession is north-easterly. To this (apart from a few merely local divergences) there are several exceptions of importance. In part of the Northern Region the strike is north-westerly ; on the eastern edge of the Western Region there is a bend round, as if to pitch under the concealed rocks of the sub-Ordovician floor ; and in the eastern part of the Aethwy Region it is northerly with a sweep round to north-north-west. But all these strikes may be seen at a glance in the chart (Fig. 101), which shows also the plunge of the isoclines, the dip, and the pitch. The discordances at the Carmel Head thrust-plane are clearly apparent on this chart.

Distribution of the Metamorphism.

The distribution of the metamorphism is at first sight so irregular as to seem actually capricious, high and low degrees of it being met with here and there all over the Island. Yet this apparent caprice is really due to the varying circumstances of the tectonics. The determining laws of the metamorphism are steadily the same, and can be made out in almost all the cases. First ; variable anamorphism is a feature of the Bedded Succession, not of the Gneisses. They are (as pointed out on p. 168) not merely far more coarsely and plutonically crystalline, but they are uniformly so. In whatever connexion they appear, they are, all over the Island, a thing *sui generis*, always in essentially the same crystalline condition. They can therefore be removed from the discussion, which is thereby greatly simplified.

Now the variations of crystalline anamorphism in the Bedded Succession are as follows. In Holy Isle it is at a maximum, and is approximately uniform throughout the Isle. In the Western Region it gradually wanes northward, until about Llanrhyddlad it has almost died away. It repeats the process, and rather more rapidly, in the Northern Inliers. In the Northern Region it begins once more at a high grade[1], and once more wanes northward in a most pronounced manner until in Gynfor it is at a minimum, and in some spots has died out altogether.

There seems at first sight to be an exception in the Llanfairynghornwy Belt (pp. 216—17), most of which is but slightly anamorphic. But this belt is caught between the Carmel Head and Caerau thrust-planes, and is to be regarded as really a tract of high tectonic horizon, over which the rest of the region has been driven.

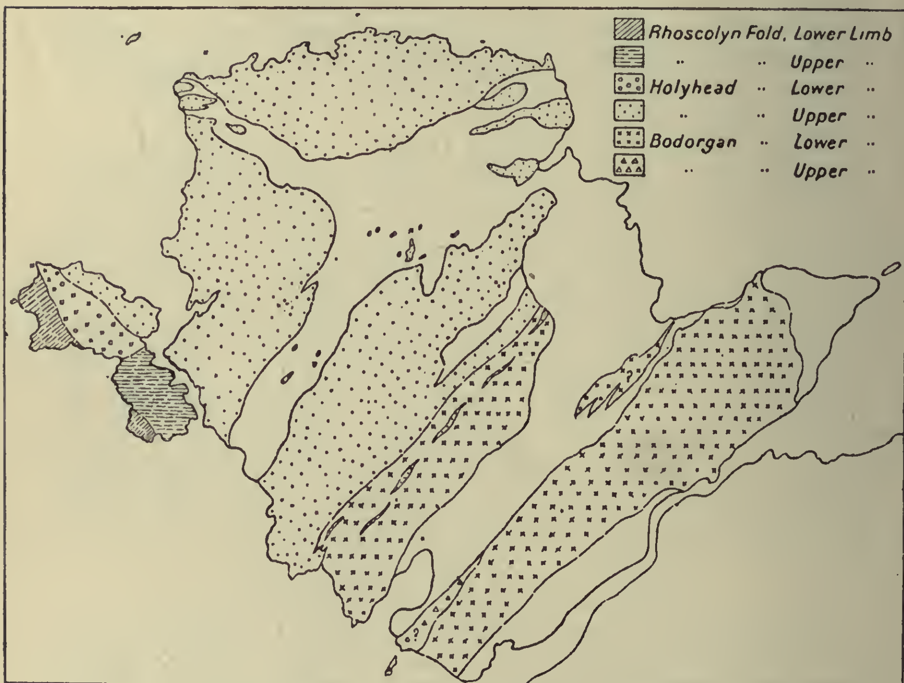


FIG. 100.—CHART SHOWING THE DISTRIBUTION OF THE TECTONIC HORIZONS OF THE MONA COMPLEX.

Scale: 1 inch = 6 miles.

Within itself, moreover, the belt repeats the same process, for anamorphism wanes northward in it from the Amlwch Beds of Carmel Head.

In the Middle Region we must exclude the hornfels, which is a local product of the Coedana granite. Anamorphism is resumed in the Penmynydd Zone at about the same grade as in Holy Isle. It then wanes eastward (interrupted only at the Plâs-bach and other inliers), until along the base of the Carboniferous rocks it is once

[1] Though this maximum has been brought far nearer to that of Holy Isle than it once was, by the Carmel Head thrust-plane.

more at a minimum and has nearly died away. At the Pentraeth Inliers it resumes a high grade for a few yards near Bryn-gwallen, but wanes at once rapidly to north-east and east.

In the Penmynydd Zone of the Aethwy Region crystalline anamorphism is once more at a maximum, being perhaps more intense than even in Holy Isle, and for a third time wanes eastward, never, however, sinking to quite so low an ebb as in the Middle Region or at Pentraeth. The Llanddwyn wedge is quite distinct, and differs from all the other tracts. Where it

FIG. 101.—CHART SHOWING THE GENERAL DIRECTIONS OF STRIKE AND OTHER STRUCTURES IN THE MONA COMPLEX.

Scale: 1 inch = 6 miles.

begins, at Llangaffo, the grade is that of Gwna Green-schist, but anamorphism wanes rapidly till in the Newborough Dunes and on Llanddwyn it reaches a minimum as low as at Gynfor, and has died out in places altogether. This is the only case where the waning is in a southerly or westerly direction, and goes to confirm the view that the Llanddwyn wedge is on a tectonic horizon of its own.

We have thus four maxima, Holy Isle, Llanfflewyn, and the Penmynydd Zones of the Middle and Aethwy Regions; and four minima, Llanrhyddlad, Gynfor, the Malldraeth slope, and Llanddwyn.

Throughout the north-western parts of the Island, anamorphism wanes northward; throughout the south-eastern parts it wanes eastward, save in the Llanddwyn wedge, where it wanes to the south-westward (Fig. 101B).

What, now, is the significance of these phenomena? In the first place, it is evident that anamorphism is completely independent both of stratigraphical horizon and of geographical direction. But it is equally evident that it is conditioned strictly by tectonic horizon. In every single case throughout the Island, it wanes as we ascend from

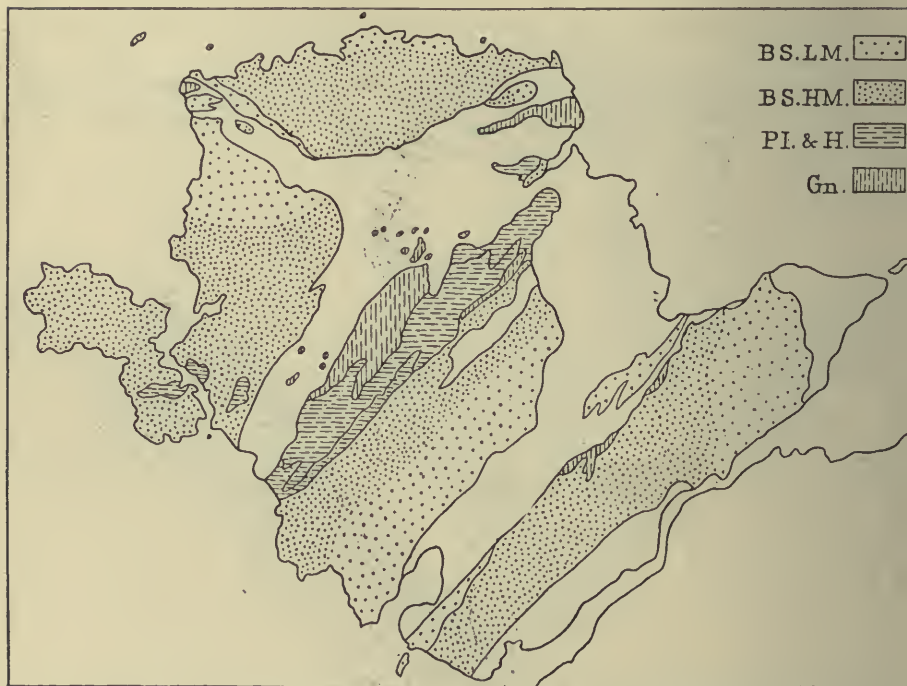


FIG. 101B.—CHART SHOWING THE DISTRIBUTION OF THE METAMORPHISM IN THE MONA COMPLEX.
Scale: 1 inch = 6 miles.
BS. LM. = Bedded Succession, Low Metamorphism.
BS. HM. = Bedded Succession, High Metamorphism.
PI. & H. = Plutonic Intrusions and Hornfels.
Gn. = Gneisses.
NOTE.—To bring out the waxings and wanings, delicate gradations of stipple would be required that could not be applied to a small-scale chart. The chart here given ignores all gradations and minor complications, but shows at a glance the general distribution of the metamorphism.

lower to higher tectonic horizons.[1] Its approximate uniformity in Holy Isle shows, however, that when a certain depth is reached, it

[1] In Chapter VII, pp. 176—80, waning anamorphism was occasionally appealed to in confirmation of the views there advocated; so that, to that extent, this argument is open to the charge of being a circular one. But the appeal was in confirmation only. The real evidence on which the tectonic succession is based is, throughout, stratigraphical, and is quite independent of metamorphic states. So strictly stratigraphical, indeed, that in two cases (those of the horizons on which the Penmynydd anamorphism is placed) it is relied upon in spite of actually waxing anamorphism.

begins to wax more slowly. Further; concurrently with the waning of crystallisation, folding is replaced by rupture, minor folding in particular giving place to autoclastic mélange. Connected with this is the somewhat singular circumstance that the best preservation of original bedding is on the lowest tectonic horizons that are laid bare.[1] The law thus emerges[2] that, given equal dynamical conditions, anamorphism is a function of depth. Dynamical conditions did not, however, continue to be equal throughout the processes to which we owe the Mona Complex; and to their inequality is due the apparently formidable exception to the above generalisation that the Penmynydd anamorphism appears on higher tectonic horizons than the two older maxima of Holy Isle and Llanfflewyn. The exception is but apparent. Reasons have been given (see pp. 198—200) for believing that we are dealing with the recurrence of similar dynamical conditions, inducing similar effects, upon what was once a zone of steadily upward-waning metamorphism, leaving the lower and older ones rigid and unaffected. And in the Penmynydd Zone itself, both in the Middle and Aethwy Regions, anamorphism wanes as we ascend in tectonic horizon, thus fulfilling the law of depth, and leaving the generalisation unimpaired.

There may thus be said to be three different successions in the Mona Complex, a stratigraphic, a tectonic, and a metamorphic succession.

Stratigraphic Succession.	Tectonic Succession.	Metamorphic Succession.
Holyhead Quartzite ...	... ...	Minima of the East.
South Stack Series ...	Bodorgan Fold ...	Zone of Upward Waning.
New Harbour Group ...	... ...	Penmynydd Maxima.
Skerries Group	Holyhead Fold ...	Minima of the North.
Gwna Group	... ...	Zone of Upward Waning.
Fydlyn Group	Rhoscolyn Fold ...	Maxima of Holy Isle and Llanfflewyn.
Gneisses	... ...	The Gneissic Metamorphism.

The first column is entirely independent of the other two; indeed, from the combined accidents of inversion, thrusting, and erosion, such coincidence as it has with them tends to be in inverse order. Between the second and third columns there is coincidence as far up as the base of the Penmynydd maxima (which appears high up in the Holyhead Fold); then there is a breach, after which there is another coincidence to the tops of both columns.

[1] On lower ones still, nevertheless, we may expect obliteration of the bedding from general plasticity, and flowage under stress. Incidentally, this confirms the view that the crystallisation of the Gneisses is their own. For they appear in all cases on tectonic horizons far higher than those of Holy Isle.

[2] Long ago expressed, I believe, by Dr. Teall.

Recapitulation.

The Mona Complex, as presented to us to-day, is therefore to be pictured, not as a stratigraphic but as a tectonic succession; and the dispositions that appear upon a one-inch map as resulting from the action of the major folding upon such a succession; most of the dispositions that are perceptible in the field being effects of the minor upon the major folding; while the crystalline condition in which we find its rocks is referable to their position in the metamorphic succession that is indicated in the third column. By combining these ideas a view can be reached that seems for the present satisfactory, unless it be in the high position that has had to be assigned to the Penmynydd anamorphic maximum, above tectonic horizons that contain rocks that are but slightly altered.[1]

It is hoped that the foregoing attempt at interpretation may serve at any rate as a clue to the labyrinth. But much work will have to be done (very likely with the aid of methods that are as yet undevised) before an adequate, or even a correct mental picture is gained of this wonderful Complex, as is doubtless also the case with others that resemble it.

[1] See, however, footnote on p. 227.

NOTE.—There is some evidence as to the respective parts that were played by the recumbent and the post-recumbent movements in the production of the dynamic metamorphism. Pertaining to the Chronology of the Foliation, it ought to have been given on page 205. Its omission escaped notice until too late for insertion in that chapter, and it has therefore been placed in Appendix IX.

CHAPTER IX.

THE AGE OF THE MONA COMPLEX.

The evidence that is now available upon this important question falls under two heads: first, the relations of the Complex to rocks of Ordovician age; and second, its relations to rocks of Cambrian age. On the second question, the evidence from Anglesey itself is indirect, and direct evidence has to be sought on the mainland of Wales.

Relations of the Complex to Ordovician Rocks.

It will be shown in Chapters XIII, XIV that the zone of *Didymograptus extensus* is clearly developed in those parts of the Island that lie to the south of the Carmel Head thrust-plane. Along the Menai Strait and thence to Llanddona the base of that zone rests upon highly schistose Gwna Beds, with their spilitic lavas, jaspers, limestones and quartzites, as well as on the Penmynydd Zone. In Central Anglesey the same zone rests in turn upon the Gneisses, the Coedana granite with its hornfels, and the New Harbour Schists with their spilites and bedded jaspers. It crosses the Bodfardden thrust-plane, there in the act of cutting out the Church Bay Tuffs, and laps on to the Gwna Beds. Where the Extensus zone has not been actually proved at the junction, it has been proved so near that the base of the Arenig Beds must be taken to be at the same horizon. About Holland Arms that base rests upon the Gneisses and upon the Penmynydd Zone, about Llangwyllog again on the Penmynydd Zone. At the Garn Inlier it passes, in the course of half a mile, across the edges of three members of the Complex, the Gwna Beds, the Church Bay Tuffs, and the New Harbour Schists. Ten sections lay bare the base of the Extensus zone, resting on six different divisions of the Complex. The stratigraphical evidence of unconformity is complete.

Along the northern coast, the Ordovician base is at a much higher zone, that of *Nemagraptus gracilis*, and it rests only on the Gwna Beds, but on different members of that group at different places; and at Ogo Gynfor cliff (see Chapter XIV, Figs, 220, 221, and Plate XXIX) a perfect unconformable junction is exposed.

The great conglomerates at the base of the Extensus zone in Central Anglesey are entirely composed of the materials of the

Complex, and the same is the case at the Garn and other inliers. The pebbles include gneiss, granite (Plate XXVII), hornfels, mica-schist, Church Bay Tuff (often schistose) with its wriggling delessite veinlets ; the mica-schist, bedded jasper and spilite of the New Harbour Beds ; and (even when the beds do not rest upon the Gwna Group) Gwna quartzite, limestone, jasper, spilite, black quartzite, and Gwna Green-schist. On the northern coast the Glenkiln conglomerates are full of boulders of the quartzites and schistose grits of the local Gwna type, and contain also many of scarlet Gwna jasper. The Holyhead Quartzite and the South Stack rocks have not been found, but the drift of the material was (Chapter XIII) towards Holyhead, so that they could not be expected.

All the members of the Complex represented in these pebbles are in the condition in which they exist *in situ*, with their metamorphic structures and foliation fully developed. On the northern coast some of the pebbles of schistose quartzite and phyllite lie with their foliation along the bedding, not along the cleavage, of the conglomerates. Not only so, but in the conglomerates of the Extensus zone many pebbles have been found, especially of the New Harbour Schists and their fine bedded jaspers, with the rapid folding of the Mona Complex easily visible within the limits of the pebble (Fig. 102, *a*, *b*, *c*, from the Tywyn Trewan, *d*, from Llyn Maelog).[1] The cross-corrugation has also been found. The folding of the Mona Complex is therefore Pre-Ordovician, and was completed long before the Ordovician rocks were in their turn folded. Other pebbles (Fig. 102, *e*, of gneiss with granite, from the Tywyn Trewan) contain the late planes of catamorphic shearing, running through the body of a pebble but not out into the enclosing gritty matrix, and sometimes, where a conglomerate is cleaved, truncated sharply (see p. 201) by that cleavage.

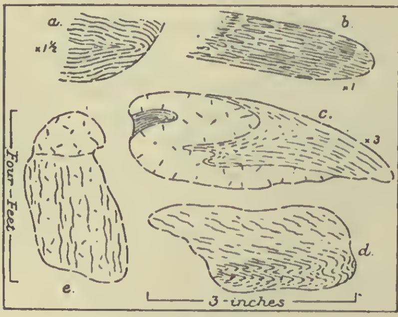


Fig. 102.

Pebbles from the basal Arenig Conglomerates

Containing old folds and thrusts of the Mona Complex.

It is therefore abundantly clear that the Ordovician rocks in Anglesey rest upon those of the Mona Complex with an unconformity of the first magnitude, that the folding and anamorphism of the Complex were complete, as we see them to-day, long before Ordovician times, and that erosion had cut deeply into even the most crystalline of its known members before the basal conglomerates of the zone of *Didymograptus extensus* began to be laid down upon it.

[1] Some of these pebbles are preserved in the Museum of the Geological Survey.

Relations of the Complex to Cambrian Rocks.

Such being its relations to the Ordovician, the burden of proof resting upon anyone who would assign to the Mona Complex a Cambrian age becomes (unless definitely Cambrian fossils are ever found within it[1]) a heavy one. For though unconformities exist in Wales both within and immediately above the Cambrian system, they are on a scale quite inadequate to represent intervals of time sufficient for the stupendous folding and regional metamorphism of the Mona Complex. Apart from such considerations as this, however, there is now no lack of evidence, direct as well as indirect.

The Indirect Evidence.

No rocks of demonstrably Cambrian age have been found in Anglesey. But in north-west Carnarvonshire, that system faces the Aethwy Region of the Complex across an interval of less than three miles. It is 5,000 feet in thickness, and is abundantly exposed on the rugged foothills, in the slate-quarries, and on the escarpments of the mountain-land, rising to a height of some 3,000 feet. Yet the composition of the two systems is quite different. The Cambrian rocks are, with the possible exception of some pyroclastic deposits near their base, composed entirely of mechanical sediment and are comparatively uniform: the Complex presents remarkable variety. Nowhere in the latter is anything whatever corresponding to the great mass of purple slate, some 900 feet in thickness; for the purple phyllites of the Gwna Group are thin, quite different in character, and associated with spilitic lavas. Nor has any trace been found in the whole Cambrian sequence of the rapidly changing varieties of the sequence in the Complex, particularly of the conspicuous Gwna Group with its thick limestones and white quartzites, scarlet jaspers and spilitic lavas, which is persistent over the whole of Anglesey from Carmel Head to Garth Ferry, without any sign of thinning out in the direction of the mainland. The lavas and jaspers, indeed, are markedly thickening in that direction. In short, without great changes of facies in the course of three miles, of which there is no sign whatever,[2] it is impossible that the Mona Complex should represent the Cambrian system of Carnarvonshire.

Noteworthy also is the fact that metamorphism in the Complex does not increase as we recede from the Cambrian frontage. Progressive anamorphism, along the Strait-side (see the one-inch map and Chapter X), is in a direction almost at right angles to that, being west-south-west-wards. Further, as a consequence of this, the

[1] The fossils (of Upper Cambrian aspect) obtained along the southern margin of the Scottish Highlands in association with jaspers and spilitic lavas have not been found in Anglesey, though Llanddwyn and other localities that offer hope of organisms have been searched.

[2] There may be some northward Post-Cambrian thrusting, but the relations of the members of the Cambrian system, and the verticality of the cleavage, indicate that it cannot be on the gigantic scale that is needed to bring differing facies together.

highly crystalline Penmynydd Zone, with its great glaucophane-schists, runs up as near to the Cambrian front as does any member of the Complex, and strikes almost directly at it. The disposition of the metamorphic structures is therefore quite independent of the position of the Cambrian frontage and of the strike of the Post-Cambrian cleavage.[1]

In Chapter XII some small outliers are described which rest upon the Mona Complex. Strong reasons are given for regarding them as Pre-Ordovician, in which case they must be either Cambrian or somewhat older. The Bangor volcanic rocks at Baron Hill are riding on a thrust-plane ; but, though locally sheared, they are certainly quite unaffected by the powerful deformation and considerable anamorphism which have affected the underlying Gwna schists. The Careg-onen Beds, however, lie upon their natural base, and their unconformable relations to the Complex are unquestionable ; so that if they be Pre-Ordovician then the Complex is Pre-Cambrian.

Pebbles in Conglomerates.

Direct evidence, however, has now been obtained. After the whole of Anglesey had been surveyed in detail and the various types of rock which enter into the Mona Complex had consequently become familiar to the present writer, a search was made for fragments of that Complex in the coarser deposits that occur low down in the Cambrian series of the mainland. The conglomerates and pebbly grits of Carnarvonshire were first examined, and then those that occur among the Harlech Grits in the great Harlech anticline. Also, before the latter was visited, Mr. T. C. Nicholas kindly lent for examination some pebbles found by him in the Upper Harlech Grits of the St. Tudwal's peninsula. Professor Lapworth and Dr. Stacey Wilson, and also Mr. Griffith J. Williams gave much valued aid by information as to localities among the Harlech mountains, where conglomerates were known by them to occur among the grits.

The results are decisive. Twenty-two different members of the Mona Complex, belonging to five of its principal horizons, have been found as pebbles in the Cambrian conglomerates. Of the twenty-two types, twelve are foliated rocks.

They are :

PENMYNYDD ZONE.	Quartz or quartzite-schist. Quartz-mica-schist. Mica-schist. Hornblende-schist.
HORNFELS (?)	
GRANITE OF COEDANA TYPE.	

[1] Since the present Chapter was written there has appeared the paper by Mr. Nicholas (*Quart. Journ. Geol. Soc.*, LXXI., p. 138) in which he remarks that 'the discovery of a great series of completely different and quite unaltered Cambrian beds in the St. Tudwal's peninsula, less than seven miles to the east [of the schistose rocks of the Lleyn,] seems to offer practically conclusive evidence that this metamorphism took place in Pre-Cambrian times' ; which, he adds, goes to confirm the view that the Mona Complex of Anglesey is of the same age.

SOUTH STACK SERIES.	Green crystalline grit, white-crusted.
NEW HARBOUR BEDS.	Fine green flaggy schist.
GWNA GROUP.	Quartzite. Black quartzite. Spilitic lava. Keratophyre. Scarlet jasper. Jasper partly bleached. Schistose quartzite. Schistose grit. Nemablastic quartz } Gwna Green-schist. Grey siliceous schist } Fine sericitic schist } Chloritic " " }
GNEISSES.	Gneiss. Albite-granite.

Most of the conglomerates have suffered from cleavage, so that some care has been needed to distinguish the effects of this from the original foliation of some of the less crystalline pebbles. In some cases pebbles lie with their major axes, and their contained foliation, parallel to the bedding and transverse to the cleavage of the conglomerate. But even where it is otherwise, it can often be shown that their foliation is their own, by one or other of the following considerations. Pebbles of the same rock, some schistose, some not so, can be found side by side. Pebbles of hard rocks, like vein quartz and quartzite, stand with their major axes along the cleavage without the least distortion of their smooth oval erosion outline, or the least internal shearing. When their foliation is nearly parallel to the cleavage, that of different pebbles may be in slightly different directions. The schistosity of the pebble is often far greater than that of the enclosing gritty matrix, even in such rocks as hard quartz-schist. In some of the siliceous chloritic schists, their thin quartz seams are strongly nemablastic.

Pebbles with Folded Foliation.—In two of the pebbles of fine siliceous Gwna Green-schist, small sharp folds of the foliation, cut by little quartz-veins that are confined to the pebbles, can be seen under the hand-lens (Fig. 102 B). A thin quartz-vein in another one is faulted in the middle of the pebble.

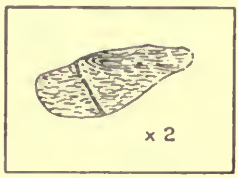


FIG. 102 B.
PEBBLE FROM LOWER CAMBRIAN GRITS
Containing an old fold and vein of the Mona Complex.

Horizons and Localities of the Conglomerates.

The following table shows the horizons of the conglomerates from which they were obtained.

The position of the Bangor conglomerate is still matter of discussion. That on the south-west side of Llyn Padarn was considered by Blake to lie unconformably above the Purple Slates, but as he correlated it with the Bronllwyd Grit which undoubtedly

Bangor Conglomerate. Gored-y-Gith.	Bronllwyd Grit. Bethesda.	St. Ann's Grit. Bethesda.	Llanberis Conglomerate. W. side of Llyn Padarn.	Llanberis Conglomerate. Dinas-Mawr.	Cilan Grits of Lleyn. (Nicholas Collection).	Harlech Grits of Harlech Anticline. Upper Beds.	Harlech Grits of Harlech Anticline. Lower Beds.
—	—	—	—	—	Quartz-schist	Quartz-schist	Quartz-schist
—	—	—	—	—	Quartz-mica-schist	Quartz-mica-schist	—
—	—	—	—	—	Mica-schist	Mica-schist	—
—	—	—	—	—	Hornblende-schist	—	—
—	—	—	—	—	—	Quartz of augen	Quartz of augen
—	—	Hornfels (?)	—	—	—	—	Hornfels (?)
—	—	—	—	—	Granite of Coedana type	—	—
—	—	—	—	—	—	—	South Stack type
—	—	—	—	—	—	New Harbour Schist	—
Quartzite	Quartzite	Quartzite	Quartzite	Quartzite	Quartzite	Quartzite	Quartzite
—	—	—	—	—	—	—	Black Quartzite
—	Schistose Quartzite	Schistose Quartzite	—	—	—	Schistose Quartzite	Schistose Quartzite
—	—	—	—	—	—	—	Keratophyre
—	—	—	—	—	—	—	Spilite
—	—	Jasper	Jasper	Jasper	—	—	Jasper
—	—	—	—	—	—	—	Bleached Jasper
Schistose Grit	—	—	—	—	—	—	—
Nemablastic Gwna Quartz	—	Nemablastic Gwna Quartz	—	—	—	—	Nemablastic Gwna Quartz
Gwna Green-schist	—	Gwna Green-schist	—	—	—	—	—
—	—	Fine Sericitic Schist	—	—	—	—	—
—	—	—	Grey Phyllite	Grey Phyllite	—	—	—
—	—	Fragmental Albite	—	—	—	—	Fragmental Albite
—	—	Albite-Granite	—	—	—	Granite	Albite-Granite
—	—	—	—	—	Gneiss	—	Gneiss

underlies the Lingula Flags, he still placed it in the Cambrian system. The other Carnarvonshire beds here quoted are admitted on all hands to lie beneath the Purple Slates of the great quarries. And the position of the Harlech Grits needs no discussion here. The pebbles from their upper beds (Barmouth Grits of Lapworth and Wilson) were obtained along the ridges from Barmouth to the crags that overlook Llyn Irddyn. Those from their lower beds (Rhinog Grits of L. and W.) from Trawsfynydd, from the eastern limb of the anticline near Y-gelli-goch, and from the escarpments and summits of the Rhinog line of mountains, on Llethr, Rhinog-fawr, at the summit of 'The Roman Steps' (Bwlch-tyddiad), at places to the north-east of Llyn-y-morwynion, on Graig-wion, and on Y-graig-ddrwg. The place-names are taken from the one-inch maps of the Geological Survey.

Pebbles from Llanberis and Bethesda.

The conglomerates of north-western Carnarvonshire are, as is well known, composed almost entirely of débris of a quartz-felsite of that district. Pebbles from the Mona Complex are, with one exception, both rare and small, and can seldom be found until after long search among the great crowd of felsite pebbles. The exception is quartzite, which is quite abundant in some of the beds, especially at Dinas-mawr. It is of thorough Gwna type, and in the state of moderate alteration that prevails on that horizon over so much of Anglesey. A few fragments are coarse enough to be from the Holyhead Quartzite, but they have not the foliation of the only known exposures of that rock, without which it cannot safely be identified. It must be remembered that the only known outcrops of the Holyhead Quartzite and of the South Stack Series are twenty miles from Llanberis, and forty from the Harlech anticline. Also that they emerge from *beneath* the rest of the Complex, and were probably covered in Cambrian times. They may, however, have emerged again in the Merionethshire country.

The jaspers are absolutely typical, and cannot be mistaken. They are bright scarlet, and have all the structures of the Gwna jaspers. A pebble an inch and a quarter in length, from Dinas-mawr, has the characteristic little spherulites often seen in those from the spilitic lavas. A beautiful little pebble, a quarter of an inch across, in the St. Ann's Grit, stands out in striking contrast to the blue matrix of that rock, and has the same characters. One from Llyn Padarn is purplish in parts, like some of those from the Gwna limestones.

In the coarser parts of the St. Ann's Grit, which lies below the Purple Slates, there are small oval pebbles of siliceous Gwna Green-schist. They are finely foliated. It is in one of these (Fig. 102 B), (from the slate-quarry railway, at '400,' half a mile west-north-west of Bethesda Station) about half an inch long, which lies quite across the cleavage, that a sharp fold is visible ; and in another is the thin quartz-vein that is faulted in the middle of the pebble (see p. 247). The metamorphism and all the structures of these pebbles are easily seen to have been completed before the deposition of the St. Ann's Grit.

The grey schists or gritty phyllites resemble some parts of the Gwna Beds that are free from chloritic matter, but in Anglesey such rocks (see pp. 65, 304) are rare, though they are found at the river's mouth at Carnarvon (see p. 382). Some parts of the St. Ann's Grit contain many fragments of an albite-granite that is indistinguishable from the dominant type in the Gneisses of the Complex, and granitoid pebbles are recorded by Prof. Bonney (in co-operation with Dr. Hicks and Miss Raisin) (*Quart. Journ. Geol. Soc.* 1884, pp. 187, 203; 1894, pp. 596, 600) from near Llanberis. The fragmental felspar is also albite.

Pebbles from the Harlech Anticline.

The above-mentioned pebbles are sufficient to decide the question. But the scantiness of the material induced the present writer to search the Harlech Grits in the Harlech anticline. For, although the base of the Cambrian system is not reached in that area, there seemed a hope of escaping, some twenty miles from Llanberis, the flood of felsite pebbles that crowd the conglomerates of the north. This proved to be the case. The conglomerates of the Harlech Grits, not being basal conglomerates, are not coarse, their pebbles rarely exceeding an inch in length, but they contain a much greater variety of material. It is unlikely that these pebbles were derived from the Anglesey portion of the Complex. The materials of the Harlech Grits are considered by Lapworth, Wilson and Nicholas to have come from regions to the east of the Harlech anticline.

Quartzite, again usually of Gwna type with a few fragments of a black quartzite like that of Gynfor, is found throughout the series. But the Holyhead Quartzite may be present, for in the Rhinog grits are fragments of a crystalline grit, white on the outside but bluish-green internally, of the type so common in the lower part of the South Stack Series. A deformed quartzite is also frequent.

But perhaps the most abundant pebble is a foliated quartz-schist, composed of granoblastic quartz, with well-formed flakes of secondary white mica (Plate XXI, Fig. 5). The reconstruction is (except that in one pebble two crystals of tourmaline were found) precisely like that which is general in the Penmynydd Zone of metamorphism, affecting in that zone both the partially incorporated secondary quartz of segregation and the Gwna quartzites where they are involved in the metamorphic zone. Many of the fragments of venous quartz have the streaky character of the augen in the same zone of alteration. These rocks are found throughout, from the highest Barmouth to the lowest Rhinog grits. Mr. Nicholas records hornblende-schist from the Cilan grits, but the pebbles are not in his collection. There can be little doubt that they are derived from the hornblende-schists of the Penmynydd Zone. The glaucophane-schist has not yet been found, nor has fragmental glaucophane been observed.[1] In the Barmouth grits at Llyn Irddyn was found a pebble an inch and a half in length, of pale green schist such as is frequent in the New Harbour Beds close to the passage into them of the Church Bay Tuffs. Most striking of all the metamorphic pebbles, however, is a highly crystalline mica-schist with siliceous bands, not uncommon in the Barmouth grits, and obtained also by Mr. Nicholas in his Cilan grits. The quartz of the siliceous bands is in the same condition as that of the quartz-schists described above, but the foliated seams are a mica-schist indistinguishable from that of the Penmynydd Zone. The most beautiful pebble yet obtained is one of this type, two inches in length, that was found on the summit of Craig Abermaw, Barmouth. It is partly of quartz, with a folium of white mica, the flakes of which are about half a millimetre in length.

Low down in the Rhinog grits there is a green conglomerate which was found by the writer on the lower escarpments of Llethr and Rhinog-fawr, and thence as far as about half-a-mile to the north of Bwlch-tyddiad. It is well seen in the latter pass, just at the summit of the 'Roman Steps.' Most of the pebbles that weather out are of the quartz-mica-schists already noticed, but on breaking the rock it is found to be crowded with green volcanic fragments. These are the spilitic lavas, with keratophyres and albite-trachytes of closely allied types. The detached fragmental felspars are also albite. The pyroxenes of the lavas have been chloritised, and the matrix is also full of chlorite. Indeed, the green material which, finely comminuted and now partially recrystallised,[2] has coloured the matrix of the Harlech Grits throughout, could easily have been derived from erosion of the Mona Complex.

There are also fragments of the scarlet jaspers. One of these, a third of an inch across, from the 'Roman Steps,' contains the minute spherulitic structures. Fragments of this type have the full jasper-scarlet and characteristic texture, and are unmistakable. But, along with them are others that are not so red, and through such, a gradation can be traced into siliceous pebbles that are but faintly tinged. It will be recalled (see p. 88) that, in the Middle Region, the jaspers of the Engan spilites are found to gradually lose their colour. These paler pebbles resemble the jaspers of a zone of bleaching. And it is possible that the grains of rose-quartz that are a feature both of the Harlech Grits and the St. Ann's Grit of Bethesda may be of the same nature. The beautiful blue opalescent quartz, however, which is also a feature of both grits, cannot be satisfactorily traced. Similar quartz occurs in the South Stack Series and the Gwna Beds, but not commonly; so the Cambrian blue quartz must be derived from some horizon that is not exposed in Anglesey.[3] For fragments of unknown rocks are also found.

[1] Confined, in Anglesey, to the Aethwy Region, it may not have been among the sources of the Harlech Grits of Merioneth. It may yet be found in slides of Cambrian grits from Moel Tryfan or St. Tudwal's.

[2] See *Trans. Edin. Geol. Soc.*, 1897, 'Incipient Metamorphism in the Harlech Grits,' by Edward Greenly.

[3] Quartz of this kind is a feature of some of the rocks of the Scottish Highlands. See 'Geology of the North-West Highlands,' p. 134, &c., and 'Geology of Cowal,' p. 15, &c

Granites of Mona types are found throughout the grits in moderate quantity. Some of the fragments found by Mr. Nicholas contain orthoclase, and are therefore probably from the Coedana suite of intrusions. A few fragments resemble the crypto-crystalline hornfels. On the ridge of Y-graig-ddrwg are pebbles that exceed an inch in length, of a coarse albite-granite poor in mica, like the granitoid component of the Gneiss (Plate XXI, Fig. 4) traversed sometimes by a deformation that is older than the cleavage of the grits. Most of the detached albites, moreover, are stout crystals that must have been derived from these granites, and the detached quartz is largely of plutonic type. Finally, along with these granitic pebbles are a few of a true gneiss, very felspathic and with white mica, closely resembling that of the Middle Region of Anglesey. One is a biotite-gneiss, and its biotite is crowded with needles crossing at angles of 60°, precisely like those of the sillimanite-gneisses of the Nebo Inlier.[1]

Review of the Evidence.

Such is the evidence of the Cambrian conglomerates. Before a final consideration of it, let us review the arguments on either side.

In favour of assigning to the Complex, or to any part of it, a Cambrian age, is the fact that the genera to which the fossils of the South Stack Series (see p. 150) have been referred, are well known in Cambrian deposits. All of them, however, are lowly forms, and when we consider the great range of certain genera, such as some of the brachiopoda ; it will be seen that the presence of such forms, unsupported either by definite zonal genera (not to speak of zonal species) or by the stratigraphy, is quite insufficient for purposes of correlation. Of those from the South Stack Series, moreover, even the generic names must be regarded as provisional. In such a case, the palæontology is of less weight than the stratigraphy. To attempt to elevate it into zonal evidence may blind our eyes to the discovery of a Pre-Cambrian fauna. In that connexion, too, a recent publication by Dr. Walcott may be of significance. He has described[2] certain fossils under the name of *Atikokamia*, a new genus which he regards as having affinities at once to the Porifera and to the Archaeocyathinae, its mode of growth being essentially that of the latter. They are from the Steeprock Series of the Lower Huronian of Canada. That fossils such as those of the South Stack Series should range downwards from the Cambrian system is, indeed, only what might be expected.

In favour of regarding the Complex as Pre-Cambrian are the following considerations. It and the Cambrian are quite different ; one is lithologically homogeneous, the other heterogeneous, even where only three miles apart. One is never more than slightly, the

[1] These Cambrian pebbles are preserved in the Museum of the Geological Survey, with slides E. 9737—9746 cut from them. Mr. Nicholas has also kindly presented his Cambrian pebbles to the Museum.

[2] 'Notes on Fossils from Limestone of Steeprock Lake, Ontario.' Appendix to Memoir No. 28, *Geol. Surv., Canada*, 1912.

other often very highly anamorphic. Along the Menai Strait the metamorphic zones of the Complex and its foliation strike directly at the Cambrian. Small Pre-Ordovician outliers rest unconformably upon the Complex. Twenty-two different members of the Complex, twelve of them being foliated rocks, are found as pebbles in Cambrian deposits. Some of the foliated pebbles contain Pre-Cambrian folding, veining, and faulting.

If, therefore, the South Stack Series is to be assigned to the Olenellus zone, very cogent evidence must be required for such a thesis. For in such case an unconformity, and one of the first magnitude, must be inserted either between the zone of Paradoxides and that of Olenellus, or somewhere between the South Stack Series and the Gwna Beds. The only break, however, of which any sign has been detected, that at the base of the Skerries Group, is but slight and local, and, moreover, an accompaniment of strong volcanic action. The evidence of the pebbles in the Skerries Grits indicates (p. 166) that, at the time when those grits began to be laid down, the Gwna rocks had not been affected by any regional metamorphism. Everywhere else the Skerries and Gwna Groups are closely knit together (pp. 63-4, 159-61), drawing their materials from the same source (p. 65), while the fragments of old schists which the Skerries Group contains have been found also in the Gwna Beds, which beds themselves have yielded pebbles to the Cambrian. The stratigraphical difficulties are enormous. Zones of passage exist between all the clastic members of the Complex, and it has been found impossible to separate the Holyhead Group from the rest of the succession. That group, moreover, has been subjected to the whole of the stupendous folding of the Complex, and to the highest grade of metamorphism (that of the Gneisses only excepted) which it has undergone.[1] Further, the metamorphism of the South Stack Series is the first of the three that affect the Bedded Succession, whereas many of the metamorphic pebbles of the Cambrian are from Penmynydd and Gwna rocks reconstituted during the third episode of metamorphism, by which time the South Stack Series had not merely been deposited, but long since metamorphosed.

Conditions of the Cambrian Erosion.

Most of the volcanic fragments of the Rhinog grits are quite undeformed, whereas in Anglesey to-day the tracts of spilitic lava that are free from deformation are comparatively small. It would appear, therefore, that the pebbles were derived in great measure from zones of the earth crust not so low down as the zone of flowage. Such would be found on the tectonic horizons that must once have overlain the Bodorgan Fold. They would be exposed to the denuding forces much sooner, and for much longer, than the schistose rocks upon the lower folds, which would, however, begin to be exposed

[1] There is yet another stratigraphical consideration. But as it is connected with the nature of the Sub-Ordovician floor, it will be well to postpone it to Chapter XIII, which see.

along with them as soon as the major secondary anticlines had been cut into. These upper folds are not found in Anglesey. They had, indeed, been swept away before even Ordovician denudation had begun, for nearly all the pebbles in the Arenig conglomerates are schistose (Chapter XIII). In early Cambrian time they still formed a large part of the ancient surface. But in the course of the great Cambrian erosion they were totally destroyed, and the deposits of that system are their sole surviving monument.

A series of geological accidents has combined in a curious way to conceal the true relations of the Mona Complex to the Cambrian. First: Arenig denudation seems to have removed such Cambrian deposits as once existed upon the tracts of the Complex that are now exposed to view.[1] Next: The Cambrian material came chiefly from folds higher than the Bodorgan Fold, upon which the rocks were undeformed; and at the same time those folds were totally destroyed by the Cambrian denudation. Thirdly: About Llanberis, at the close of Pre-Cambrian time, an acid lava was poured out upon the slopes of the old land, covering it with a shield upon which the forces of Cambrian erosion were obliged, locally, to spend themselves.[2] It would seem, however, that on those old slopes there were hills of quartzite, round about which the lava flowed without burying their tops, from which the conglomerates were thus able to obtain their quartzite pebbles. Further away to the south-east, wide tracts of the Complex were quite bare, the waste of which furnished the vast deposits of the Harlech Grits. Unfortunately, in those districts the Cambrian base is not exposed, so that evidence has had to be sought from beds that are hundreds, and some of them even thousands of feet up in the series. That conglomerates of such a composition could be formed at all on such horizons indicates that below the base of the Harlech Grits there must lie a coarse conglomerate like that of the Arenig Beds of Anglesey, resting upon the surface of the Mona Complex, and composed of a great variety both of undeformed and of metamorphic rocks.

Conclusion.

However this may be, it is now abundantly evident that the Complex is Pre-Cambrian. And that it is Pre-Cambrian as a Complex, not its material only, but its regional metamorphism being of that date. For the pebbles include, as well as rocks that are but slightly altered, such as Gwna spilite, quartzite and jasper, the Penmynydd mica-schists and even the Gneisses, the most highly crystalline of all its members. The same rock is found among the pebbles in more than one stage of alteration. The Gwna cherts, for example, were first jasperised, and then dejasperised (see pp. 88, 166) by dynamic metamorphism, the quartz sands quartzitised and then deformed, in Pre-Cambrian times. Foliation, often

[1] See the paper by Mr. Nicholas, already cited; also Chapter XII of this work.

[2] This may account for the failure to find glaucophane in any of the Cambrian sediments.

accompanied by a high grade of crystallisation, was induced, and the rocks became crystalline schists. The foliation was very sharply folded, then it was fissured and cut by veins of quartz, and these again cut by later faults ; all before the lowest beds of the Cambrian system were deposited. No subsequent alterations have produced any perceptible effects. In the Ordovician conglomerates we find the rocks of the Mona Complex in the condition in which they are to-day. In the Cambrian conglomerates we find them just as they are in the Ordovician conglomerates.

CHAPTER X.

THE DETAIL OF THE MONA COMPLEX.

This will be dealt with region by region, district by district. And, as the detail here given is intended for the most part as a local guide to those who will carry on research in future, matter of a theoretical nature will be avoided as much as possible, or confined at any rate to that which can be inferred with confidence. In other words, in references to tectonics, the major secondary and lesser structures only will be discussed. The views of the present writer as to the primary recumbent structures will be excluded; except in one or two places (the Breakwater tract at Holyhead, for example), where discussion of them in Chapter VIII would have encumbered that chapter with too much local detail.

At the close of Chapter VI (p. 169) the reader was referred to this chapter for the detailed evidence as to the sequence of the minor sub-divisions of the Complex. A summary of this, with page-references, is therefore given on pp. 383—5.

HOLY ISLE.

This will be described in the following order:—

1. Tracts west of the North Stack fault, from north-west to south-east.
2. Country between the two main faults, from Rhoscolyn to Holyhead Mountain.
3. Tract east of the Namarch fault from Tre-gof to the Breakwater coast.

Tracts West of the North Stack Fault.

The North Stack is composed of true white quartzite, but good even bedding, dipping southward, can be seen from the sea on the north face, so that it is taken to be the very base of the Quartzite, immediately above the South Stack Series, the fault passing between it and the land (see p. 207). The fissure of the great fault, on the mountain-side above Gigorth Bay (Plate XVI), can be got at from above, but fallen blocks roof it, making a sort of cave at the head of the chasm. Through chinks in this roof one can look down and see the breccia, but by going round outside the blocks at the very edge of the cliff (seeing to it carefully not to trust to crumbling foothold) a much better view can be obtained. From the same view-point some ten or more parallel faults can be seen in the great quartzite cliffs, all hading to the north-east, and producing an overhang at the cliff's foot. The south walls of Gigorth Bay are determined by the vertical foliation, and are only strike-sections, but the chasms into which they bend show something of the structures.

The Stack Moor.—The surface of the Stack Moor is composed of the massive beds, which at the rugged western end [E. 6076] are very well exposed. At the cliff's foot, north-west of the tarn, where a buttress runs out, thinner beds appear, showing that the Llwyn beds are beginning to rise. The highest members, brought in by the pitch towards the eastern end [E. 10658] are felspathic, decomposing readily. The two little outliers of the Quartzite are taken in on sharp infolds. The western, a double one, forms a conspicuous craggy knob, which rises to the 500-foot contour, and its relations are tolerably well exposed (Fig. 28). The eastern one forms only a gentle dome, but immediately to the south of it dips of 60°—90° are seen in the narrow quarry 50 feet below, so its infold must be quite as deep and sharp. They are parted by a fault with a downthrow to the east, along whose course are the aforesaid quarry, and a savage narrow gully that runs down to the sea, revealing several folds upon its walls. *Scolithus* may be seen in abundance [Af. 3681—4] on the crags between the tarn, Goferydd, and the coastguard flagstaff. The burrow-castings have been deformed, and have also been driven somewhat out of their original position (Fig. 103) of verticality to the bedding, thus affording a measure of the deformation of the rock.

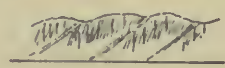


FIG. 103.
DEFLECTION OF SCOLITHUS PIPES.

The South Stack.—Rugged as is the summit of the Moor, it gives no hint of the amazing revelation of structures that awaits the geologist who descends to the South Stack. The folding-phenomena (Frontispiece and Folding Plate I) have already been studied on p. 183, and need not be re-described here. The folding can be seen in its full grandeur only from a boat (and seldom can a boat be brought round through the tide-race to the foot of these wild cliffs—see p. 183). The northern folds, however, are seen finely from the Stack, the approach to which is by a flight of steps, carried zig-zag down the cliff, at whose foot is a suspension bridge. Permission to cross to the islet can be obtained only from the Honourable Corporation of the Trinity House. Geologists wishing to study the folding should therefore apply to the Secretary, Trinity House, Tower Hill, London, E.C., for a permit, enclosing a note of introduction from an officer of H.M. Geological Survey, or from a member of the Council of the Geological Society of London.

The finest view of the major folding to be had from the Stack is that from the foot of its southern crags. The relations of minor to major folding (Fig. 38) can be seen (especially with the aid of a small glass) from the western end of the bridge. The relations of folding to foliation, and also the secondary thrusting with folding of the foliation (Fig. 88) are admirably shown (Plate XXIV) at the outer end of the islet, outside the walls, both north and south of the lighthouse. The Stack is carved out of two large anticlines, visible together only from the sea. It will be seen that the thin Llwyn beds rise on the pitch. In them, low down on the southern escarpments of the Stack, were obtained [Af. 3670—80] the finest specimens of *Planolites* and the forms referred to *Archaeocyathus* or *Archaeoscyphia.* Some of the grits [E. 10130] contain a good deal of tourmaline ; and there is a coarse one [E. 10570] full of blue opalescent quartz, and with fragments of old grits (one containing tourmaline), granites, granoblastic rocks, and mica-schist.

But even without crossing to the islet, fine parts of the great section can be seen from the steps. The southern of the two Stack anticlines is disclosed in a chasm that cuts into the south side of the islet, with the incessant ripple of the minor folding running round it. At the last zig-zag above the door, there is a fissure in a crag, through which, as through a window, one of the major synclines, with a vertical amplitude of 330 feet, can be seen sweeping up the cliff. A still better view of the same syncline, with part of an adjacent anticline, can be obtained by getting over the wall and creeping (with careful regard to foothold) along the top of a buttress that looks into the chasm. Curious details of the nature of the bedding (Fig. 104) may also be seen in some of the massive grits. The remainder of the great section, from the South Stack to Henborth (except for a glimpse at Pen Lâs Rock) is visible only from the sea.

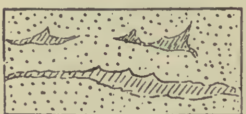


FIG. 104.
NIPPED 'GALLS' IN THE GRITS
On the Steps above the South Stack.

The Stack Moor Syncline.—Beyond the monument called on the six-inch maps 'Ellen's Tower,' the base of the Stack Moor beds rises once more, and runs inland, by the Cyttiau, to the fault. Referring again to Folding-Plate I (where they are easily distinguished from the thin and flaggy Llwyn beds) we shall see that these beds are sinking into a broad and deep syncline, of which even the tremendous visible folds are but the crumplings. Remembering, further, that their base rises just along the surface of the South Stack, it becomes evident that the whole of these beds of the Stack Moor are taken in on a vast crumpled infold, some 600 feet deep at the coast, which, deepening inland on the pitch, just admits of the survival of the two little infolded outliers of the Quartzite on the crest of the moor, and is then cut off against the North Stack fault at the crags below the summit of Holyhead Mountain. Where it is thus cut off, the Stack Moor syncline must have a depth of 1,200 feet.

By combining together Folding-Plate I, Fig. 28, and the one-inch map, the succession, given in the table on p. 164—

Holyhead Quartzite,
Stack Moor Beds,
Llwyn Beds,

becomes perfectly evident.

Henborth and the Llwyn-y-berth Promontory.—Returning to the coast, the folding has now become completely isoclinal, and another fine glimpse of it is to be had in the chasm of the great dyke (Fig. 36). On the Henborth cliffs, where a group of thrusts appears, the amplitudes are still very great, but the major folds are not yet (save details such as Fig. 105) well seen from the land, though some of the southern isoclines can be made out from the side of the long promontory. Nevertheless, with these great folds are found the smallest yet detected in the Complex (Plate XXI, Fig. 3). *Planolites* [Af. 3694—98] was obtained in moderate preservation at Henborth beach, but fine specimens, almost as good as those of the South Stack, are tolerably plentiful [Af. 792, 3685—93] on the cliffs west-north-west of Gors-goch.

FIG. 105.
NORTH CLIFF OF HENBORTH.

The coast of the Llwyn-y-berth promontory, from Henborth to Porth Dafarch, affords a series of sections, three miles in length and 70 to 100 feet in height, that are unsurpassed in the Mona Complex, and can seldom be surpassed in Great Britain, for the study of isoclinal folding and its relation to foliation. The principles of this have been set forth on pp. 185—9, 201—3, so little detail need be added here save an indication of the most instructive sections. In the south cove of Henborth are fine examples [E. 10158] of the extreme encarsioblastism that gives rise to prismatic fracture (p. 44), and at the creek west of Gors-goch are excellent encarsioblasts that appear as green spots of biotite [E. 10139], (Plate II, Fig. 1). This cliff is a steep foliation-dip-slope, but, at the headland, pitching isoclines and foliation with changing angle are well seen all together (Figs. 48, 106). Fine sections continue to Penrhyn-mawr, where, looking back north-eastward, the relations of minor to major isoclines, and of the former to vertical bedding-dip, are displayed (Fig. 107) in a cliff some 70 feet in height. From Penrhyn-mawr to the next headland is a good deal of the softer greener type [E. 10133, 10141—2], the only material in the series that may contain volcanic dust, and the pitch is well displayed in the long chasm at that headland. A little before the small dyke is reached are good structural sections (Fig. 108), strain-slip and minimum corrugation being finely seen [E. 10143] in lepidoblastic partings; and on the western side of Porth Ruffydd a thrusting along the foliation produces incipient lenticular isolation of the grits, the same structure as that of the Autoclastic Mélange developed on a regional scale in the Gwna Beds. But the structures for the most part preserve the bedding well, with sharp isoclinal folding in the lepidoblastic partings. At the cove, however, the foliation

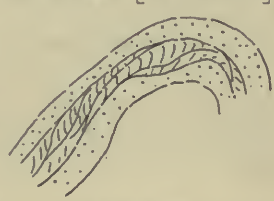


FIG. 106.
THIN SILICEOUS SEAMS AND FISSILE SEAMS.
Specimen from near Gors-goch.

of the grits, usually rectilinear, is folded sharply (Fig. 85), and the soft beds thrust between the foliation-laminæ. The folds are then longer limbed and smoother for some way, but on the headland between Clybyddiad and Porth Rhwydan sharp minor isoclines again set in. The structures are splendidly displayed (Plate XVIII and Fig. 89), and being easy of access, this is perhaps the best locality for a study in detail both of rock-types [E. 10134, 10142], folding, and foliation. From Porth Rhwydan to Porth Dafarch a series of beautiful cliff-sections about 80 feet in height (Fig. 37), show strong flaggy grits with lepidoblastic seams, dipping almost vertically, but corrugated by rapid minor isoclines with moderate inclination, and traversed by foliation generally parallel to the isoclinal axes. Beyond Porth Dafarch a larger fold appears. The North Stack fault emerges in a chasm on the side of Porth y Post. Its fissure is concealed by fallen blocks, but the chasm-wall hades north-east at about 15°. Similar structures are seen on the shallower sections inland, which are good on the slopes of Penrhos Feilw [E. 6071—4]. The thin coarse grits may be found a little to the west of Porth y Post, on a steep escarpment some 600 yards south-west of Plâs Meilw [E. 10135] (where they contain a fragment of coarse muscovite-biotite-gneiss), at spots 30 to 100 yards to the south-east, on the cliff-top west of Gorsgoch, and at other places.

FIG. 107.
MAJOR AND MINOR ISOCLINES IN LLWYN BEDS.
Cliff looking north from Penrhyn-mawr.

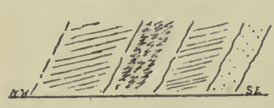


FIG. 108.
MINIMUM FOLDS ON LIMB OF MINOR FOLD.
About one-eighth of a mile south-west of Porth Ruffydd.

Rhoscolyn.

Passing to Rhoscolyn: The fault at Bwa-du (which is evidently the North Stack fault) passes into a little chasm. Débris hides its breccia, but the north-easterly hade is clear on both sides. In Borth Wen it runs out upon a shallow beach. There are several slight changes of facies at Rhoscolyn. The Quartzite is not quite as hard and siliceous as on Holyhead Mountain, being [E. 10159] more like that of analysis No. III, on p. 41. It is also rich in zircon and other heavy minerals. Bedding is more often perceptible in it, besides which there is a strong bed of lepidoblastic mica-schist. The South Stack Series is thinner, hardly exceeding 1,600 feet. The flaggy Llwyn portion [E. 10160] is unchanged; but the Stack Moor part is represented only by the massive beds near the Quartzite, and is greatly reduced. At Borth Saint it is bright red and brown, but this is only staining (for which no cause can be assigned at present), as the colour changes rapidly along the same horizon. A coarse grit [E. 10161] is seen at the 'b' of 'Lifeboat,' in which are fragments of quartzite of Gwna type.

The section given in Folding-Plate II, and quoted on p. 156, in evidence of the succession, was drawn from a boat (which is necessary in order to grasp its true proportions), but the details (from which minor thrusts and faults are omitted) were filled in from the cliffs, which, except under the rugged Rhoscolyn Hill, are accessible most of the way along. From the 'White Arch,' south of Bwa-du, called Bwa-gwyn on the six-inch map, to Borth Saint, are excellent sections in the Quartzite, showing the corrugated seam of mica-schist very clearly. On the north cliffs of Borth Saint the Quartzite is faulted against the reddened South Stack Series; and where the steep track descends to the beach the core of the large Borth Saint anticline can be seen. Rhoscolyn Head is a fine section through a major isocline of quartzite, with its thin mica-schist. On the cliffs opposite Maen y Fran, the characters of the South Stack Series are admirably seen. The minor isoclining is most beautiful, and the folding of the vertical foliation of the thick beds (Fig. 86) close to the corrugated fissile partings can be better studied here than at any other place. At the two great fault-chasms the minor isoclines can be seen to maintain their direction in spite of the southerly dip as the beds pass below the quartzite. Where the rugged, mountainous hill descends to the sea, the corrugated seam of mica-schist within the Quartzite (Fig. 39, *c*) is revealed in a wild gully; but the great doubling back of the Quartzite is perceptible only from a boat. Bedding can be made out on the summit of the hill. Where the South Stack Series comes on again there is a small crush, but it leaves the junction intact in part of the cliff. The beds are here dipping at nearly 90° S.E., yet the minor isoclining of the lepidoblastic seams (Fig. 39, *a*, *b*) is unaffected, and retains its persistent inclination and direction. Massive bedding as of the Stack Moor beds prevails next the Quartzite, but the flaggy Llwyn type develops rapidly as we pass to the south-east.

Just before we reach the cove that runs out south-westward from the Lifeboat Station there is a chasm, and on its north-west cliff the passage from the New Harbour Beds to the South Stack Series is laid bare, with the little spilitic tuff-schist just within the New Harbour Beds. It is not so green as usual, the ferro-magnesian matter being densely studded with the granoblastic felspar, which is albite-oligoclase. The band is repeated by the minor isoclines (Fig. 31). The islets at Rhoscolyn Beacon are typical New Harbour Beds, thinly foliated and evidently the Celyn portion, folded on beautiful minor isoclines.

The Country between the two Main Faults.

The Rhoscolyn Anticline.

The coast from Borth Wen to the entrance of the Strait of Holy Isle is a very fine strike section of New Harbour Beds with beautiful pitching minor isoclines, often overdriven at very low angles or even horizontal. Similar sections abound in the rugged country about Pentre-gwyddel and on the moor that rises between the Strait and Bodior dyke. On a boss 150 yards south-east of Bryn-y-bar one of the quartz-knots with albite contains well-foliated chlorite [E. 10164]. In the Rhoscolyn anticline (which is bisected by the North Stack fault) Llwyn beds of the South Stack Series are well exposed north and east of the alluvium and around the eastern margin. Where the basic band so often alluded to (pp. 157, 264—7, 270, &c.) appears on the beach of Borth Wen, it is much thicker than usual, and closely resembles, moreover, the spilites of the New Harbour Beds in the Llanfwrog and Amlwch districts, retaining even traces of ellipsoidal structure, and [E. 10165] is highly epidotic, with ternary albite. Everywhere else in Holy Isle the band is to be regarded as a thin spilitic tuff, but here it is evident that a lava was poured out upon the same horizon. The junction (folded) with the green-mica-schist is exposed upon the upper side. Rapidly thinning, and resuming its usual characters, it is to be seen on the bosses between this and the dyke, just within the green-mica-schist, with which it is folded several times. Just to the south of the 'a' of 'Iago' a cottage (Ty-dudur of the six-inch map) stands on the edge of the South Stack Series; and 50 to 100 yards south-east of this cottage, those beds are seen within a yard of the green-mica-schists, pitching under them. True to its precise horizon, the basic tuff, here only a foot thick, appears just within the green-mica-schists. The junction of the groups is exposed 170 yards south-east of the cottage, at the foot of the escarpment, and the basic tuff, here six inches thick, lies in the green-mica-schist a yard from the junction.

New Harbour Beds, all, so far as is known, of Celyn type [E. 6081], are also very well seen about Cromlech farm, whence came the partly analysed specimen [E. 10162], and 350 yards to the south is an unusually coarse grit [E. 10163] in which composite fragments may be looked for, though only doubtful quartzites have been identified. Indeed, all about Rhoscolyn, clastic grains are more easily seen than in the corresponding beds at Holyhead.

Rhoscolyn to the Tre-Arddur Gap.

Details of the Serpentine-suite of intrusions will be found on pp. 274—7.

Strike and dip, isoclines and pitch, are normal almost as far as the epidosites that behave as a thermal halo to the serpentines, but a deflection begins to be perceptible along Cromlech alluvium and about Bodior, becoming marked in the Fadog promontory, where dips are vertical, as they are in the epidositic zone. Between Cae'r-sais and Four Mile Bridge the strike swings round to north-west. But it is interesting to note that between Cae'r-sais and Porth y Garan, on the north-western side of a curved line that very nearly coincides with the parish boundary (*i.e.* the dotted line), the normal structures are suddenly resumed, even where the green-mica-schist actually comes against the intrusions. There is no thermal alteration at that junction, and the line (all along which is a sharp escarpment) is undoubtedly a southward overthrust at a low angle, which we have called the Garan Thrust-plane (Folding-Plate III). The Gareg-lwyd fault which cuts off the intrusions towards the south-west runs up to meet the Garan thrust-plane at an angle of 45°. Thrust, fault, and intrusions leave between them a little triangle of ground, and in this, accordingly, we find the marginal vertical dips and disturbance. The fault seems at first sight to cut off the thrust opposite Porth y Garan, but the features indicate that, executing a turn, the thrust escapes, and runs alongside the fault, only about 25 yards from it, until they both pass out at the cove a quarter of a mile away, where there is a crush at the foot of the escarpment.

From the North Stack fault at Bwa-du to Tre-Arddur Bay the coast is a splendid series of sections in the Celyn part of the New Harbour Beds; and those on the rocky land that extends almost all across the Isle, are scarcely inferior. The Soldier's Point beds (which were not recognised as an horizon at the time this was surveyed) should be looked for by future investigators, flaggy beds having been noted about Castell, as well as in the disturbed ground about Four Mile Bridge and Fadog. To establish either their presence or their absence would throw great light on the nature of the major folding, and perhaps on the form of the intrusions.

About the Tre-Arddur Gap, the Soldier's Point beds (flaggy, and with definite thin grits) have been observed at the coves of Isallt, at Isallt-bach, and [E. 10282] along the road to Tre-gof, especially just where it leaves the alluvium. But they should be sought for also among the alluvium a little to the south. Near Towyn Lodge and Castell the minor isoclines are often quite recumbent. In the vicinity of the Tre-Arddur Gap there are innumerable planes of thrusting (Figs. 62, 63), which are at the same time true foliation-planes, and at the cove west-south-west of Isallt-bach are seen to be folded on the minor isoclines. (Fig. 109).

FIG. 109.
SECOND FOLIATION IN NEW HARBOUR BEDS. TRE-ARDDUR.

The Gap is undoubtedly a zone of thrusting, and in these planes we see some of the minor thrusts themselves. Albite is found in venous quartz [E. 10227] 117 yards south-east of Tre-Arddur garden, most of it untwinned; and south-east of Towyn Lodge, at the semi-ring of a pitch-arrow, similar albite has a nemablastic foliation [E. 10228].

The Country about Holyhead.

The coast from Tre-Arddur Bay to the North Stack fault at Porth y Post is another fine series of sections in the Celyn division[1] of the New Harbour Beds, which are almost as well exposed inland

[1] If the Soldier's Point beds appear at all, it would be on some of the larger anticlines, but only close to the North Stack fault.

on the wide tracts that extend, with but little interruption, all the way to Mynydd Celyn. A variety [E. 10152] poor in muscovite, and therefore unusually green from the green biotite on its foliation-planes, occurs north of the Cyttiau. A quartz-albite knot [E. 10147] with foliated chlorite was found 100 yards south-west of Mynydd Celyn farm. Thin hæmatite-mica-schists [E. 6078, 10148—9, 10557] that may be recrystallised jaspery phyllites occur in the Celyn beds north of the 're' of 'Dafarch,' at Mynydd Celyn farmyard, at the foot of the crag a quarter of a mile east (and south) of Tre-Wilmot, and at some other places. Lines have been drawn for the most definite of them. All the characters and structures of the Celyn beds, the foliation-types, the successive generations of segregated quartz with incorporation of the older ones (p. 48), and especially the minor pitching isoclines (Fig. 47) are splendidly displayed on the high rugged moor north-west of Mynydd Celyn.

The South Stack Series is represented only by the Llwyn beds as far as Capel Gorllas. They are well exposed at Kingsland on both sides of the road, thence to the great dyke, at and south-west of Stryd, and form a very rugged tract about Capel Gorllas [E. 10132], and are everywhere perfectly typical, the usual fine white-weathering thinnish grits with lepidoblastic partings. Encarsioblastic structure [E. 10083] is well developed at Kingsland. At Capel Gorllas, and thence to Tre-Wilmot the beds become very massive, and must be regarded as the passage to the Stack Moor Group. About 150 yards east of Tre-Wilmot is a thin coarse bed with quarter-inch pebbles of granite and Gwna quartzite, as well as plates of old gneiss-muscovite. Just east of the 'a' of 'Pont Hwfa,' close to a tall house with a tower, which is at the end of what is called Gors Avenue, is an interesting greywacke-like grit [E. 10131]. No slide is richer in felspars (chiefly albite) that show the old weathering decay with reconstituted margins (pp. 44, 145, and Fig. 27). A few of them contain small ancient fresh cores as well, though none so clearly as the one in E. 10151 (Fig. 27). It is also the slide containing an old mica-schist with a large porphyroblast of tourmaline, besides which there are fragments of homœoblastic albite-quartz-mica-schists, though none of these lie across the foliation of the grit.

The country south and west of the town of Holyhead is of great stratigraphical importance, because of its four miles of hardly broken junction between the Celyn part of the New Harbour Beds and the Llwyn division of the South Stack Series. With the unfailing little spilitic tuff-schist always about a yard within the New Harbour Beds (see p. 157), the junction is actually cut across at nine sections, and four more only fail to do so by an interval of three or four paces of covered ground. Probably the tuff might have been drawn almost continuously along the junction all the way from Tre-fignath to Tre-Wilmot, but as it may be cut out by thrusts here and there, it has been coloured only where actually seen. Perhaps the clearest sections are on some ridges half-a-mile west of Tre-fignath (in ground that is now part of the golf-links). Stronger white-crusted grits come on between the fissile beds, which become at the same time less green. The spilitic tuff, about a yard thick,[1] is just within the New Harbour Beds, and is repeated on 10 minor isoclines. It is [E. 10556] highly epidotic, with chlorite that seems to be after actinolite, and is rich in ternary albite. It appears again, twice, at Bodwradd, the junction of the groups being seen on the crag-face by the dyke-hollow, along which there is local disturbance of the pitch. The Green-mica-schists, with the basic band just within them, pass, folding, under the Llwyn beds. Jasper-like aggregates [E. 10157] occur in the basic band. Two small bosses in a hollow, 125 yards to the north, again show the basic band close to the junction; and so does another, 300 yards to the west of them. Then, on a high boss, overlooking a watercourse, about 160 yards from the road, the section shown in Fig. 30 can be made out. On its escarpments, the passage from green-mica-schist to basic schist is clear and unbroken, though rapid. Thin jasper-like seams [E. 10145] are present, but they are of doubtful nature, as they contain epidote and albite. About 50 yards further on is a lower boss on whose south-west end are two nips of good solid basic schist lying in thin-seamed mica-schist. Then the high boss next the road has two more basic nips on its southern escarpment. The base of the Llwyn beds keeps on zig-zagging across the strike a few yards to the north-east. The basic nips just described are all ranged along the north-eastern side of a deep hollow (into which the water-course has turned) which runs on south-eastward to join the strong dyke-feature, an arrangement clearly indicating a small cross-fault. Accordingly, we find alongside this feature a local disturbance of the otherwise persistent north-easterly pitch.

The junction is again cut through at the crag by the Porth Dafarch road, close to where that road crosses the great dyke. There is a perfectly conformable passage from group to group, seven yards north-east of the turning that leads to Kingsland Windmill; and in spite of a little vegetation, the base of the folded Llwyn beds, pitching off the New Harbour Beds, can be fixed to an inch, where the first hard grits begin. Below them come about a yard or so (when allowance has been made for thickening due to minute thrusting and corrugating) of soft green ashy-looking passage-beds, which are found all over this district. True to its horizon, the spilite-tuff, a foot or so in thickness and rich in granular albite, immediately underlies them. It is repeated by folding in the cliff, and at the top occurs again about four feet below the South Stack Series. The Celyn beds adjacent to it have a purplish tinge, from scales of hæmatite, and are very rich in granular albite [A.P. 289], a peculiar type that, round about Holyhead, heralds the appearance of the tuff, into which it rapidly graduates. The junction still zig-zags between the exposures, but

[1] This beautiful ridge of tuff, the finest in the Isle, has unfortunately been destroyed for the purpose of smoothing the Golf Links. The Committee, however, consented to retain two small exposures, one at each end of the ridge, by which its position can still be identified.

is not visible for some distance. Just before it is crossed by the Stryd road, however, is an isolated exposure of the basic tuff, immediately beyond which is a craglet of the South Stack Series, with room for four feet of beds between, showing that the tuff keeps to its horizon. A fault, with downthrow to north-east, now breaks the folded junction. On the downthrow side, 370 yards from the Stryd road, what seem the green passage-beds occur on the top of a boss (Fig. 110), thrust on to the South Stack Series,

FIG. 110.—OUTLIER FROM THRUST AT 'H' OF 'HOLY.'
Height: About 30 feet.

probably the core of a hidden anticline carried a little to the south-east.

A large anticline then rises and runs all the way to the Namarch fault. At its north-eastern end, the foot of a strong escarpment of grits just reveals the passage-beds rising on the crest of a minor anticline that fails to bring up the tuff (Fig. 111), but shows the junction clearly. South of this, in the middle of the major anticline, a subsidiary syncline is exposed north of the 'S' of 'Stryd,' on a low boss, but a wall running along it has been built just upon the junction. On the north-west side of the wall are the South Stack Series, on the south-east side appear a yard of the green passage-beds, and then, true to its horizon, the basic tuff itself, here a yard in thickness, with the purplish beds upon its other side. South of this, across the hollow, is a long wall, on the other side of which a footpath runs, and at the hither foot the junction of the groups is again seen (Fig. 112), a nipped outlier of the grits lying on the green passage-beds, here piled up by packing and foliation-thrusting. The section is a foliation-dip-slope, and the tuff is not seen, though there is room for it under some bushes towards the south-west end. Beyond the footpath, on a low boss, the same junction is once more exposed, but there is no room for the tuff on the exposure. At the western end of the major anticline, between the dyke and the fault, a steep escarpment, 50 feet in height, looks down upon a little farm (Caeallt-wen of the six-inch map). It is a complete section through the junction, the South Stack Series forming its brow and the Green-mica-schists its foot, with the passage-beds and the tuff

FIG. 111.
SOUTH STACK SERIES,
with anticline of passage beds. North-west of Stryd.

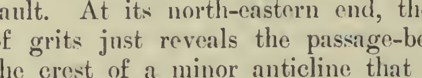


FIG. 112.
PASSAGE BEDS.
South-west of Millbank Gardens; north of 't' of 'Stryd.' With infolds of South Stack Series.

between; but is greatly complicated by folding, which is shown, considerably simplified, in Fig. 29. A purple phyllite [E. 10144] occurs in the zone of passage here. About 150 yards north-westward along the fault, a line of crags (at whose foot is a marshy tarn) evidently a strike-fault, is seen to be cut off by it; and between this fault and the South Stack Series, towards Tre-Wilmot, eight small infolded outliers of the spilitic tuff [E. 10146] have been mapped. The probable structure is shown in Fig. 113. The

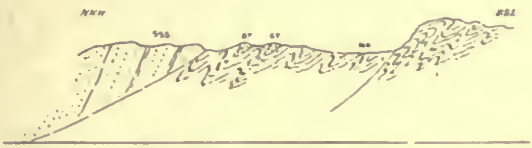


FIG. 113.—SECTION QUARTER-MILE SOUTH-WEST OF CAPEL GORLLAS.

Scale: 18 inches = one mile.

SSS = South Stack Series. ST = Spilitic Tuff.
MN = New Harbour Beds.

suite of sections at Holyhead and Rhoscolyn demonstrate the remarkable precision of the horizon indicated by this thin spilitic tuff-schist, which is comparable with that of a graptolitic zone.

Holyhead Mountain.

Beyond the grits of Capel Gorllas and Tre-Wilmot a valley, choked with boulder-clay, runs along the foot of Holyhead Mountain, and must be occupied by the outcrop of the Stack Moor beds. These are exposed alongside the road, north of the 'o' of 'Reservoirs' by a chapel, and (less clearly) at the foot of the green drive that goes up the hill near the 55° dip-arrow. They are felspathic, with lepidoblastic mica-seams, very massive, typical Stack Moor beds in fact, and (by the chapel) are seen to graduate up conformably into the base of the Quartzite.

No rock in Anglesey is laid bare in such a series of exposures as the Holyhead Quartzite. Its coast is uninterrupted rugged cliff, which under the Old Telegraph Station is 500 feet in height (Plate XVI), the greatest cliff in Anglesey; and where the North Stack fault crosses the mountain, the Quartzite looks down upon the South Stack Moors in a line of crag of nearly 200 feet in places, a feature that is conspicuous for many miles; besides which the great quarries from which the Breakwater was made have cut into it on a scale second only to that of nature; and the surface of the mountain, 720 feet in height, is nearly bare of cover. The whole is a solid mass of quartzite, interrupted only by a foot or so of white mica-schist (like the seam at Rhoscolyn) at the north end of the old quarry that is east of the large dyke, and by a crushed nip of similar schist in the quarry above Porth Namarch. The massive unfoliated type [E. 10127] (in which little scarlet grains are frequent) is well seen all along the southern crags above the road. The pebbly quartzite [E. 10128—9, comprising five slides] is found about 140 yards south-south-west of Twr, on the face of the spur just above the road, as well as about 50 yards to the north-west of this crag. It contains good fragments of scarlet Gwna jasper, with the characteristic hæmatite-mottling, (though no good ones were cut through in the slides), of micacised igneous rocks, old granoblastic rocks, and mica-schists with original foliation. The foliated, which is really the normal, quartzite [E. 6068—70, 10126, 10600] may be studied almost anywhere, but specimens are best obtained in the great quarries, where the internal whiteness is remarkable. Objects that may possibly be *Scolithus* occur on the 400-foot contour, 150 yards south-south-west of where the small dyke is cut through in the large quarry.

No bedding has been made out upon the surface of the mountain, or in the quarries (for some planes dipping at moderate angles in both directions there appear to be due to movement). Undoubted bedding, however, is visible over the vast caverns at the North Stack. Fig. 114 was drawn from the lifeboat, but the section can be seen by looking southwards from the Signal Station. In a favourable light, looking from near Plâs Nico, planes that seem to be bedding, dipping at various angles, may be made out on the great fault crags that cross the mountain. And if we stand on the north side of the moorland, somewhat east of the tarn, we shall have no doubt (especially if the light be good) of true bedding on the great cliffs (Plate XVI) between the North Stack and the old Telegraph Station. But the section (Fig. 91) is the result of several re-drawings in different lights, and its dotted line parts are conjectural. The foliation is vertical over most of the mountain, but a slight fan-like divergence can be made out. Sills of venous quartz often lie along it. There is a good deal of slight undulation horizontally, with many small cross-wrenches. If the section be correct, the base must be about to rise at the North Stack Signal Station, so that the bedding there seen is probably a herald of this.

FIG. 114.
BEDDING IN THE QUARTZITE AT THE NORTH STACK.
Height: about 100 feet.

DISTRICT NORTH-EAST OF THE NAMARCH FAULT.

Stanley Gate to Soldier's Point.

Except in the Breakwater tract, only Soldier's Point beds are known. From where the fault runs out south of Tre-gof to Gorsedd-y-Penrhyn the structures are not pronounced, and there is a local reversal of the pitch. But along the low cliffs north-east of Penrhos house is a curious exception to the general structural law—a local foliation-dip to south-east on unfolded parts, between which are minor isoclines that face in the usual direction (Fig. 115) and are thus in conflict with the dip. The normal relations are resumed on the Llanfawr coast.

Fine sections with isoclinal folding in flaggy beds are seen on the crags by the roadside below the Monument quite near the station. The banding is well marked : only a slight change of facies would give the Garn type, and a moderate one (especially if less foliated) the Amlwch type. There are a few thin white saccharoid quartz-schist seams. The sections on Salt Island are on its western side ; the beautiful structures already described (p. 192 and Plate XX) being seen about 100 yards north of the bridge that leads the road and railway to the mail-boat pier, on a stack of the foreshore that is isolated for a while at high water. From a few yards away only isoclinal folding catches the eye, but the peculiar strain-slip appears on approaching near, in fissile bands between horizontal hard ones, especially at the foot of the stack on its outer side, and perhaps even better at the summit. The rock is beautifully crystalline, and the lepidoblastic seams are encarsioblastic, with a great development of green biotite, and a good deal of apatite. The sharply curved quartz-seams appear to be later than the folding [E. 10154].

FIG. 115.
FOLDING AGAINST DIP AT PENRHOS.

Some of the grits are unusually coarse [E. 10155] and contain clastic microcline as well as albite. On the foreshore opposite the Coastguard Station ('C.G.S.') is a very fine display of isoclinal folding ; and, a few yards further, below the house called on the six-inch maps New Harbour View, are the coarsest grits known in the Green-mica-schists [E. 10156], with small rolled fragments of quartzite of Gwna type, and salmon-tinted felsitic-looking scraps like those common in the Skerries Grits, drawn out along the foliation. The Coastguard shore is the only place in these beds where planes that suggest a second foliation in hard beds have been seen, dipping at a lower angle than the dominant planes. Fine sections begin again at the Trinity Stores (the large building on the shore below Porth-y-felin), and isoclinal folding, sometimes with a strain-slip foliation in the lepidoblastic (not noted in the hard granoblastic) seams (Fig. 116), may be seen anywhere as far as Soldier's Point. The Soldier's Point beds are also finely seen in the roadway-cutting at Government House, where they are unusually massive. In the cutting on the upper road, just after it has been carried over the curved embankment, is perhaps the finest display of minor isoclines in the whole Complex, beautifully smooth, with amplitudes of about six to ten feet. A few of them are shown in Fig. 44. The thin seams of saccharoid quartz are well seen also. The rocky land between the town and the Breakwater railway shows the same beds very well, the type specimens that were analysed [E. 10151, cf. E. 10282] having come from a little north-west of the new church with the spire (called St. Seiriol's on the six-inch maps). It will be remembered that

FIG. 116.
SECOND FOLIATION SOLDIER'S POINT.
About one foot.

E. 10151 is the specimen containing piedmontite, which should therefore be further sought for in the lepidoblastic bands at this place. It also shows very well the ancient stages of decomposition in clastic albite with reconstituted margins, and one ancient undecayed core as well (Fig. 27) (Plate II, Fig. 2). The ground whence it came is now being formed into a public park for Holyhead, and the topography of the six-inch map will be altered. The most massive beds known in the Soldier's Point beds, a yard or more in thickness, are to be seen at and about Porth-y-felin Mill [E. 10150]. They contain small fragments of granite, and large twinned albites that show the cores of old sub-aerial decay and reconstituted margins very well. Two hundred yards north-north-east of the Mill the rock [E. 10153] has a bluish tint, but the source of this is not apparent in thin section. The folds near Porth-y-felin have long horizontal and short inclined limbs (Fig. 53), so that the strike often seems indefinite for some yards of outcrop.

The Breakwater Coast.

The Celyn beds [E. 6077], cut down to only about 70 feet, are seen with beautiful isoclinal folding (Plate XIX and Fig. 46) on the bosses that are partly built into the western face of the Breakwater, just outside the cove, and at the cove itself the little spilitic tuff appears in them, here only a few inches thick, and [E. 10555] rich in ternary albite. Beyond the Celyn beds thin-bedded greenish grits of South Stack (Llwyn) type, of which there is not room for more than about 80 feet, appear on the beach ; and, then, at the beach's end, are typical felspathic Stack Moor beds, which may reach 280 feet, and range westwards all the way to Porth Namarch. They are often blue-hearted, and close to the Namarch fault are a good deal reddened. The bedding is distinct, though sometimes massive, and there are some lepidoblastic seams. At Porth Namarch a rusty bed on the foreshore contains pebbles one-third of an inch across of a quartzite of Gwna type. At the Trinity Magazine, just beyond the second bridge over the railway, is a rude conglomerate, containing rolled fragments of Gwna quartzite, mica-schist, and paragonitised albite [E. 10137]. It is thoroughly schistose, with bedded partings of corrugated mica-schist, and belongs without doubt to the South Stack Series. *Scolithus* is abundant at the Breakwater cove, and on the coast 300 to 400 yards east of the Namarch fault [Af. 791, 3662—9]. The beds dip for the most part at moderate angles to the south-east, occasionally rolling over northward. Yet between the great dyke and the Namarch fault, and also just north of the Breakwater cove (Fig. 117), the fissile partings are vigorously folded in sharp isoclines with a strong southward impulse, close to which the foliation of the massive beds

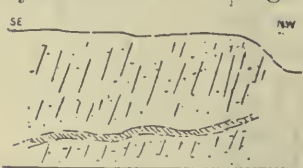


FIG. 117.

ISOCLINES IN FISSILE BED IN STACK MOOR BEDS.
Overfolding contrary to dip.

becomes likewise folded. The dynamics are therefore the same as those opposite the South Stack, and among the southerly dips at Rhoscolyn (pp. 186, 207). The Quartzite is neither quite as white internally, nor quite as massive as it is on the Mountain, or even at Rhoscolyn, so that there is a slight change of facies. Yet it is easily distinguishable from the Stack Moor beds, which are blue internally and well bedded, though the change from the one to the other comes on almost imperceptibly, especially where the vertical foliation masks the bedding of the passage rocks, as is well seen on the coast south of the 'e' of 'Wellt.'

The Quartzite rises at a nook beyond the Breakwater cove, and forms Ynys Wellt Point, where it is cut off by the Wellt fault. It rises again 250 yards to the west-south-west, and runs, underneath the conglomerate, as far as another fault. But the South Stack Series has, in the meantime, risen from below this quartzite along the cliff, so as to both underlie and overlie a cake of it (Fig. 93). A massive rock rises beyond the fault, and runs to the dyke, but

FIG. 118.—SECTION ALONG PORTH NAMARCH.
Height of Cliff: 50—60 feet.
HQ = Holyhead Quartzite. BC = Boulder-clay.
SSS = South Stack Series. BT = Breakwater Thrust-plane.
NF = Namarch Fault.

does not seem clean enough for the Quartzite. Beyond the dyke, however, quartzite appears once more, but is cut off by a small fault, so that it fails to run on to the Namarch fault. It rests upon the South Stack Series, and they appear also above it just before it is cut off (Figs. 118, 119). There is even a suspicion of it below them on the buttress against the Namarch fault, north of the beach (Plate XVII). The masses of quartzite along this coast vary a good deal in thickness, the one to the north of the 'Magazine' conglomerate being about 270 feet, that west of the dyke only some 30 feet, so that one at any rate of the junctions (apparently the lower one) must be ruptured. The rupture is laid bare in

FIG. 119.
PORTH NAMARCH.
Section at right angles to Fig. 118, at x.

FIG. 120.
DETAIL OF THE BREAKWATER THRUST-PLANE.
From Fig. 119.

the cliffs north of the western bridge, and also some 70 yards east of the Namarch fault, where it behaves as a southward overthrust (Fig. 120). This must be one of the primary thrust-planes ancillary to the Breakwater fold itself.[1] Those which cut out all but some 70 feet each of the Celyn and Llwyn beds are not exposed, but their displacement by the Wellt fault (which is a downthrow to the west) shows that they must have a southward inclination. This could not be the case with secondary thrusts cutting the whole Breakwater core and driving it up. They must therefore also be primary thrusts, dipping with the axis of the folded Breakwater core, which must be rising on the south limb of a secondary major anticline, whose northern limb has been destroyed by the sea.

THE SERPENTINE-SUITE ABOUT THE STRAIT OF HOLY ISLE.[2]

1. Mainland and Islets.

Four-Mile-Bridge to Cymyran.

In the large intrusion east of Four-Mile-Bridge the gabbro is well exposed in its high western boss [E. 10644], which has been quarried, and in many bosses throughout its area. It is not severely deformed save along certain lines, especially on the margin west of the dam, but contains compact seams that may be cataclastic. The serpentine is not well exposed, except on the islets at the south end, where it is schistose. North and south of the high gabbro boss it is spherulitic, but the northern exposure is now rather poor. Tremolite-schist occurs on the north shore of the large islet. The islet south of the channel is composed of green-mica-schist, ophicalcite, gabbro, and serpentine. Serpentine is driven on to mica-schist on the shore south of the high gabbro boss, and some crushed pyroxenite is seen close by.

The gabbro of the next large intrusion is well exposed west of the church, and is locally schistose. Where a tongue of it runs into a boss of serpentine by the east-and-west lane, highly crystalline tremolite-schist [E. 10319] is found at the junction. The ophicalcites (which are complex) and serpentines are but moderately exposed.

[1] References to the general theory of the Tectonics that was set forth on pp. 171—82 have been (see p. 256) excluded from the descriptions of the Detail. An exception to that rule has been admitted here, as it is almost impossible to discuss the sections along the Breakwater coast without it.

[2] In order to keep the descriptions of these rocks all together, those on the main Island will be given here as well as those on Holy Isle.

On the north edge of the Felin-wen intrusion is a little pyroxenite, and the serpentine is very schistose. On its south margin the New Harbour Beds are slightly hornfelsed. At the junction, and about 20 yards to the south, is a little tremolite-schist; and then follows a complicated zone of schistose gabbro, serpentine, epidotic schist, and ophicalcite, some 20 yards wide; beyond which thin bands of tremolitic and epidotic rocks appear in the New Harbour Beds, doubtless the recrystallised edges of sheared basic masses, and at the little headland is much epidote-hornfels [E. 10320]. Islets of gabbro lie off the shore.

The most southerly of the intrusions is the gabbro at Cymyran [E. 10321] largely converted into an epidote-amphibolite; but if a mass of gabbro-schist on the beach east of 'Bay' be *in situ* there are some still further south. The gabbro of Carnau contains, at the 's' of 'Reservoir,' the largest plates of diallage yet seen. Epidosite is found among the blown sand west of Harlech cottage.

The Lakes.

At the north end of Llyn Dinam the serpentine (which is schistose) is poorly, the gabbro well exposed. At the islet west of 'Llyn' it is massive, though schistose on the western side. A little reef by the alluvium between this and Dinam farm is composed of gabbro and fine, banded, epidote-hornfels [E. 10292], and the junction is well exposed, the gabbro behaving as a sill, slightly transgressing the banding of the hornfels. There is no chilled selvage, but the gabbro at the junction is a rather fine schist. Between the lakes, and on the island in Llyn Penrhyn, the gabbro, locally schistose, is finely exposed. The basic schist north of the stream that comes out of Llyn Dinam seems to be a deformed spilite. The serpentine associated with this gabbro is mainly schistose: chlorite-rock occurs close to it by Llyn Penrhyn, south of the stream; and a wedge of siliceous hornfels occurs in a nook between gabbro and serpentine by the lake-edge. The chief interest of the tract by the railway south of Treflesg, apart from a variegated ophicalcite, and a small chlorite-chromite-magnetite-rock north-west of the cottage on the promontory in the alluvium, is the schistosity of the gabbro. On the western side of the promontory, near the parish boundary, this attains a maximum, the gabbro being converted into a fissile epidotic pale-amphibole-schist [E. 10295] (Plate IX, Fig. 4) with minute corrugations.

Porth-delisc.

The exposures are all on the foreshore, and can be studied only at low water. At the north end, a sill of highly altered gabbro [E. 10486] lies between calcareous mica-schists. The pyroxene is represented by large plates of pale hornblende, the felspar by saussurite, needles of actinolite also streaming along the foliation. A similar gabbro is to be seen in the middle of the little bay, but more interesting here is a beautiful talcose calcite-marble [E. 10487] containing chromite. Another like it [E. 10488, 10501] at Cliperau is richer in talc, and the carbonate is either dolomite or magnesite.

The Strait Islets.

Three of the islets between the bridges are composed of gabbro, a little hornfels adjoining it on those near Tre-gof. On the islet north of the Cyttiau, some of the gabbro is a fissile schist. With these islets may be placed the peninsula west of Four-Mile-Bridge, on whose shore, by the 'B,' a bright green antigorite [E. 11388] may be seen, as if serpentine were near.

Holy Isle.

Many parts of the large intrusion are so complex that they can be shown only on the ·0004 ('25-inch') scale. Its boundary to the south-west is clearly a fault, called the Gareg-lwyd fault, the foliation of the New Harbour Group striking at that of the serpentine. Towards the north-west, where there is a strong escarpment for about half a mile, the New Harbour Beds are in their usual condition, and are undoubtedly driven over the intrusions on the Garan thrust-plane (pp. 208, 263). Along its other margins, especially to the north and south of Pwll-pillo, are hornfels and epidosite (in which are outlying strips of serpentine and gabbro), and it is clear that these are the original intrusive margins, cut out locally by ruptures.

Between the Strait and the Alluvium.

Where the basic rocks first appear on the shore of the channel south of Four-Mile-Bridge, there is evidently a thrust, for the adjacent schist is normal while the basic rocks are schistose, and so carded together that there is room for some thirteen bands of gabbro, serpentine, and calcareous chloritic-schist along the little creek. At its northern point, some spherulitic serpentine (with a diallagic variety) is to be seen on the beach. On the islet off the mouth of Rhyd-bont (large) creek is enstatite-pyroxenite, chiefly at the south end and on the western beach, apparently veining serpentine. On the shore opposite this islet, pyroxenes appear in the serpentine itself; and along the north shores of Rhyd-bont creek veins of both pyroxenites as well as websterite keep on appearing. South of Rhyd-bont the serpentine itself contains the great plates of diallage, enstatite, and bastite mentioned on p. 100, the coarsest rock known among these intrusions. Between Rhyd-bont and the creek the serpentine is well exposed, often with good massive cores. Some of the most richly spherulitic serpentine is found on the eastern side of the road, 170 yards south of the School [E. 6423][1] but only for a space of some 10 square yards. A complex ophicalcite with tremolite and chromite [E. 10215] occurs about 80 yards further south.

The tract beyond the creek (Fig. 121) is extremely complex, even the high gabbro boss [E. 10645—6] containing four tongues of serpentine, while 233 yards south-east of the dam a half-inch vein

[1] The best slides of the spherulitic serpentine, however, are those cut by Prof. Bonney and Miss Raisin, and figured in their paper.

of tremolite cuts a serpentine, the fibres being set across the vein. Many strips of modified New Harbour Beds occur also as inclusions. East of the dam, the shore for 150 yards consists largely of hornfels [E. 9759, 10222] with needles of actinolite: and there is a small

FIG. 121.—THE RHYD-BONT CREEK INTRUSIONS.
From the six-inch map.
Reduced from the ·0004 maps.
MN = New Harbour Beds. U = Serpentine. E = Gabbro.

chlorite-rock adjoining serpentine. Tremolite-schist occurs on the creek-ward face of the lofty boss, at a junction of serpentine with gabbro; and four other occurrences exist in the field south-east of that boss. Brucite (see p. 104) is found in a talcose rock on the islet north-east of the lofty boss [A.P. 281]. The enstatite-gabbro described occurs as a dyke in serpentine on the shore between the lofty boss and the little farm to the east of it. The remaining details of this tract, whose basic rocks are usually more or less deformed, could not be described without reference to the ·0004 maps.

The small outlying masses about Fadog are tolerably normal, and the serpentine 150 yards east of the farm is unusually massive. The islets in the creek are mostly serpentine. The chief subjects of interest here, however, are the metamorphic rocks. A fine white tremolite-schist occurs where Fadog lane comes down to the creek, at a junction of serpentine with gabbro, and tremolite-epidote-schist [E. 10294] on a reef 600 yards east of Fadog. The reefs on the south side of the inner reach of the creek are dark, platy actinolite-schist [E. 10218—20], probably at a junction of New Harbour Beds and serpentine; and 165 yards west-south-west of the house a similar schist with magnetite octahedra lies against a gabbro. In the last field of the promontory are little radial groups of actinolite.

West of the Alluvium.

Passing west of the alluvium spherulitic serpentine is recorded by Prof. Bonney and Miss Raisin a few yards east of Pwll-pillo. The long curving ophicalcite along the northern margin is not well exposed except at an escarpment 140 yards from the School, where a foliated white quartz-chlorite-marble dips under green-mica-schist. Between this and the road south of Cae'r Sais the New Harbour Beds are baked. West of this road the concentric disposition of the gabbros [E. 6424] is remarkable (Fig. 122), and they are unusually free from deformation, especially at the high boss by the lane (whence came the specimen analysed [E. 10213]), veins in which contain one-inch plates of diallage. The crescent of gabbro north-west of this ring has a nook on its outer side (north of the 'w' of 'Pwll'), and in this nook, serpentine being close by, an eight-foot wedge of tremolite-schist runs into the gabbro. This is the beautiful tremolite-schist that was analysed [E. 6425, 10226] (Plate IX, Fig. 5). About 130 yards to the west-south-west is an obscure actinolitic rock associated with an inclusion of New Harbour Beds of which it seems to be a thermal modification. About Cerig-moelion (six-inch map, the farm west of the 'P' of 'Pwll' on one-inch map) the serpentine [E. 6422, 9899] is well-preserved in places, with spherulites a few yards to the north and east-north-east, and diallage a little to the south.

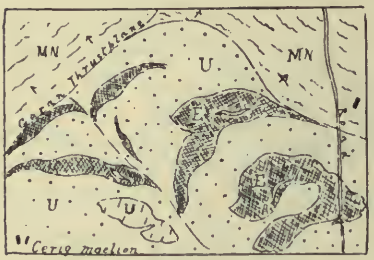


FIG. 122.

THE CERIG-MOELION INTRUSIONS AND THE GARAN THRUST-PLANE.

From the six-inch map.
Reduced from the ·0004 map.

MN = New Harbour Beds.
U = Serpentine and Ophicalcite.
E = Gabbro in ring dykes.

The beautiful calcium-ophicalcite east of Cerig-moelion analysed [E. 10214 and analysis] is a thick band about 110 yards in length, striking west-north-west to east-south-east, conformably to the local foliation of the serpentine, tongues of which run into it. On the south-west it passes into calcareous serpentine, but is sharply bounded on the north-east. It is exposed in three natural bosses, and there is a fine section at the old marble quarry in the middle one, where it has a massive slabby structure dipping steeply to the north-east. On the north-western boss [E. 10216] it is a white rock with crystals of what seem to be diopside. At the top of the quarry it is cut in all directions by innumerable veins of pale actinolite whose needles are set at right angles to the vein-face. As these veins are later than the carbonate (from which they have evidently subtracted the magnesium), it is clear (see p. 106) that the ophicalcites belong to the period of the Mona Complex.

The large limestone south of Cerig-moelion is the dark hard one that was analysed [E. 10217], south of which again is a reddish ophicalcite with magnetite, and on the boss east of this a foliated serpentine is folded. East of these limestones are extensive exposures of good serpentine. A few yards to the south-east of Gareg-lwyd house, in serpentine but close to a small gabbro, is the beautiful tremolite-rock [E. 11392], and the tremolite-marble [E. 10563] that was analysed. The exposure is inconspicuous.

The Southern Margin.

Along the southern margin of the great serpentine, from the Gareg-lwyd fault as far as Bodior woods, ranges the zone of epidosite described on pp. 108—9 [E. 9752—8, 9761, 9763—4, 10166—7, 10221] (Plate IX, Fig. 6). It is full of minor intrusions of serpentine (in the largest of which a foliated modification [E. 9762] is very sharply folded), gabbro, and chlorite-chromite-magnetite-rock ; and, as the epidosite itself varies rapidly, its details cannot well be described without the ·0004 and six-inch maps. It is best studied in the tract that is nearly enclosed by the large alluvia. The more normal epidosites are best seen on the high bosses east of the Rhoscolyn road ; and the actinolite-epidosites by the alluvium west of the 'D,' as well as on the crags just west of the great dyke nearly north of Cromlech farm. At the great bend of the alluvium, near the large 'D,' some epidotised massive rocks that retain traces of igneous texture occur in the zone [E. 9760]. Quartz occurs in them only as veinlets in the larger epidote aggregates, between which are wisps of a pale amphibole, and west of the serpentine they seem to pass marginally into sharply contorted seams of the same amphibole [E. 10221]. There is a suspicion that they were in some degree deformed before the epidotisation, and if so they must be older than the serpentines.

The typical talc-schist [E. 10168] and chlorite-chromite-magnetite-rock (both analysed) are exposed in a quarry facing south near the eight-foot level 250 yards north of Bronddel (near Plâs-coch of the six-inch maps), overlooking a little channel of alluvium. The chlorite-chromite-magnetite-rock appears to have ellipsoidal structure, but some broken ellipsoids show 'cores' of hard epidosite, and may possibly be the fronts of anticlinal folds. White tremolite-schist, in which are later needles of actinolite, occurs along with them. The quarry is on the outer margin of the epidosite zone, and the still clastic epidosites occur on the platform just above it.

A feature of all these intrusions is the way in which they have interfered with the dynamics of the district. Away from them, the overfolding-dip, strike, and pitch are wonderfully steady all over Holy Isle ; but, round about them, are quite irregular. The strike of the igneous masses themselves, and of their own planes of schistosity, partakes of the same irregularity, especially about the gabbro rings and crescents near Cerig-moelion.

WESTERN REGION.

The New Harbour Group.

The Sea-Board.

The coast of this district is low, and the section interrupted by superficial deposits in many places. From the Cymyran gabbro[1] to the Carnau water, where a branch of the Namarch fault probably runs in, the Green-mica-schist is tolerably normal both in character and structures. Opposite Ynys-lâs, and on the adjacent bosses, it is rough and quartzose, and contains many basic bands quite unlike the gabbros. They are albite-chlorite-epidote-schists [E. 10310] and probably belong to the spilitic suite. At the little headland north of Ynys-lâs one of them contains an inclusion of bedded jasper, so they may have been albite-diabases, a type not yet found undeformed in this series. A good many purple phyllites follow, but this reach is full of exceptional types due to the serpentines. From the creek to the dam the mica-schist is fairly normal, but with variable dip and pitch, as is usual near these intrusions. This is the case also about Four-Mile-Bridge and Valley, though the north-westerly dip is there still dominant. About the station and village thin hard grits are frequent, foreshadowing the Amlwch facies. The New Harbour Beds are, indeed, so far as is known, represented only by the Soldier's Point division throughout this region.

The important section along the foreshore from the Embankment to the Alaw's mouth has already been partly described in connexion with the change of structure (p. 196, Fig. 71). The nature of the rocks is also important. The green-mica-schist is in much the same condition as in Holy Isle, but purple seams appear in it in a few yards, increase and thicken, till, half a mile from the Embankment is the best section in jaspery phyllite of the region. Thin bands of hard pale jasper are also present, and a basic rock is visible at low water. On Traeth-y-gribin sand similar beds reappear, with a spilite at the north end of the reefs. A similar lava, with good surviving ellipsoids, is exposed at Bodlasan.

Rock is next seen at Penial, and is a fine mica-schist at the south end of the section under the drumlin. At the north end is a compact rock with wriggling veinlets [E. 10491] like the Church Bay Tuff. It contains clastic felspar and quartz, with small sheared lapilli, is full also of epidote, sometimes almost crypto-crystalline, but in general more reconstructed than the Tuffs of Church Bay. There is a clear passage from its schistose margin into the mica-schist.

[1] The serpentine-suite of intrusions has been described along with those of Holy Isle (pp. 272—4).

But whether this Penial tuff be a nip of the main Skerries Group, or a volcanic band in the New Harbour Group, is not yet known. Crystallisation then waxes, until, in the little cove beyond Porth Penrhyn-mawr, a pale rose-coloured schist, brilliant with white mica and hæmatite, is as highly reconstructed as anything at Holyhead. Just beyond this, at the south end of Porth-delisc, is a recrystallised coarse quartz-albite grit [E. 10495].

The basic bands in Porth-delisc ('the sea-weed cove') are evidently the sheared ends of the large ellipsoidal variolitic spilite which is well exposed about the farm west of Plâs-y-glyn. Probably the best section in the spilitic lavas of the region is in the mass north of Llanfwrog Church, a quarry just west of a roadside chapel, close to the ring of a glaciation-arrow [E. 10474, 10545—6]. All the characters of the New Harbour spilites can be studied here. At the north end of Porth-delisc there is a beautiful calc-mica- schist [E. 10494] after which tolerably normal types, with variable dips, and some bedded jasper, recur as far as the remarkable little complex of Cliperau. There is not space in this volume to describe the intricate and interesting details of this group. It may be summarised as a flow or flows of ellipsoidal spilite [E. 10478], beautifully variolitic in parts, resting on flaggy calcareous chloritic schists which graduate into the ordinary New Harbour Beds. These green schists [E. 10499—500] are full of albite and are evidently reconstructed spilitic tuffs. The spilitic lavas have been sheared and their internal textures destroyed even in the hard ellipsoids, while the dark inter-ellipsoidal skins have passed into fissile chloritic schists which have begun to fold. As well as the spilitic suite, there is a beautiful talc-marble (p. 105), so the peridotite-intrusions here must have been precisely on the horizon of the spilitic lavas.

At the north end of Porth-tywyn-mawr, and thence to Porth-y-defaid, are silvery albite-green-mica-schists with fissile partings like the Soldier's Point beds of Holyhead, and containing a little opalescent quartz. They are overfolded from north-north-west, but the longer limbs and strain-slips are at very low angles. Over-riding these are later thrusts at angles not quite so low, coming from the south-east (Fig. 123), which belong to the movements that soon

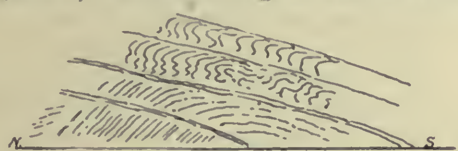


FIG. 123.—NORTHWARD THRUSTS,
PORTH-Y-DEFAID.
Height: about six feet.

dominate the Western Region. Close to the junction with the Church Bay Tuffs is an epidotised igneous rock [E. 1544]. It is distinct from the Palæozoic dyke; and probably belongs to the spilitic suite. The foreshore section is complicated both by thrusting and cross-faulting, which confuse much of the junction with the Tuffs.

The Interior.

The description of the interior will be best begun at Valley. From the alluvium to the Treflesg road there are fine exposures on the heights that overlook the railway from the east; and opposite the church are the remarkable structures described on pp. 197—8 (Figs. 72—75). The nature of the material is also of importance, for here in the Soldier's Point division of the New Harbour Beds appear the thin hard grits which become so marked a feature in the Amlwch facies.

About Caergeiliog Windmill is a considerable development of the bedded jaspers, with which are basic epidotic schists, evidently the spilitic lavas highly deformed. A similar group recurs at Llanfihangel-yn-nhowyn. Between Caergeiliog and Bodedern the lavas are less deformed, retaining traces of their ellipsoids. The large Palæozoic dykes contrast interestingly with them. About Llanynghenedl and Bodedern exposures are scanty, but enough to show that the same types continue. The spilite of Ty'n-llan, Llanllibio [E. 10476] is variolitic, with remains of ellipsoids, but highly amphibolised. About Llywenan the flaggy mica-schist [E. 10489], though fine, is well crystallised, sometimes with encarsioblastic seams; and an apparent falling off in crystallisation at Presaddfed is not really such. The folding in this district (Fig. 124) is usually on vertical axes, but good over-folding from the north, with lineation at right angles to the strike, which rolls over on the folds, is well seen on the little moor north of the Woollen Factory. At Penllyn, and still better on the high knobs three-eighths of a mile to the north-north-east, the same phenomenon as that by the railway is to be seen, the old folding surviving, cut by later strain-slip, this folded in its turn, sometimes isoclinally (Fig. 125). These planes are really the dominant foliation of the district, dipping for the most part south-east, the dip being, however, not plane but corrugated (Fig. 126), and the strike very variable all over the Llanfachraeth and Bodedern areas. The folding must therefore be regarded as a corrugated strain-slip. Thence to the Tomb of Bronwen the same types are scantily exposed, in positions that may be found by the drift-lines.

FIG. 124.
MINOR FOLDING, NORTH END LLYN LLYWENAN.

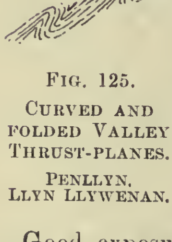


FIG. 125.
CURVED AND FOLDED VALLEY THRUST-PLANES.
PENLLYN. LLYN LLYWENAN.

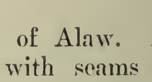


FIG. 126.
UNDULATING FOLIATION-DIP.

Good exposures are frequent all along the Vale of Alaw. At Mynydd-yr-eithin is an unusually massive grit, with seams of purple phyllite. The large spilite of Llanfigael [E. 10476] is best exposed east of the church, where it is very pale, and highly amphibolised. At its south-west end, in the curve of the alluvium by Erw-goch, it is schistose, and interdigitates with mica-schist.

In a smaller spilite [E. 10477] on the north bank of the river, west of the 'f' of 'Afon,' ellipsoids, with little white spherulites, are unusually well preserved, but even this one is amphibolised, though the felspar-brushes have survived as at Llanfwrog. Thence to Treffynnon, the mica-schist is well seen along the little rocky ravines. At a steep islet in alluvium north of the 'n' a thin quartz-seam which passes across the foliation at an angle of about 30°, and is nearly vertical, is (Fig. 127) cut and shifted by a series of little thrusts from the east-south-east. Yet these do not shatter the rock, which is 'healed up' along them, so they are movements of the Complex. On a southern slope 633 yards south-west of Llantrisant old church is a small epidote-actinolite-schist [E. 10490] with seams of clear granoblastic ternary albite, evidently a highly reconstructed spilitic lava. Along these reaches of the river are many bands of jaspery phyllite, which at the old mill east of the Smithy are lustrous haematite-mica-schists. Purplish mica-schist, folded as in Fig. 128, is well exposed also at Meiriogen, and along the south side of the boundary at Brwynog this alternates with what seems to be re-crystallised Church Bay Tuff, so that the zone of passage is evidently reached (pp. 159, 282, 286). East of Glan-alaw there is a bend in the strike, which brings the Mona Complex into pseudo-conformity with the Arenig conglomerate. Returning sea-wards, the massive pale epidosites east of Llanddeusant Church closely resemble the Church Bay Tuffs and are probably a nip of them. By the cross-roads at the south-west end of the village strain-slip can be seen, though less distinctly than at Penllyn and the railway. The large masses of spilite along the Llyn-on Water are best exposed north of Llyn-on Hall, at Bryn-palma, and at Pen-yr-argae. All are more or less schistose. Finally, it is noteworthy that the contents of the Arenig conglomerates of Bod-Deiniol show that a tract of much less altered Gwna Beds must come on to the east, under the great Ordovician syncline of Cors y Bol.

FIG. 127.
SMALL THRUSTS IN QUARTZ-VEIN. ALAW RAVINE.
Boss in alluvium east of Stryd-y-facsen.
Two-thirds natural size.

FIG. 128.
MINOR FOLDING. LOW TYPE. MEIRIOGEN.

The reef called Ynys Feirig contains many small nips of basic schist that probably belong to the spilitic suite. The outermost reefs at Rhosneigr consist of green and purple schists, rising from beneath the Arenig conglomerate. They also contain basic bands, and appear to belong to the New Harbour Group.

THE GWNA GROUP.

Every member of the Gwna Group is developed in the Western Region. It will be convenient to describe the Llanfaethlu country first, then Llanrhyddlad, then the high land about Foel.

Llanfaethlu to Brwynog.

All about Llanfaethlu the Gwna Green-schist and Mélange are exposed in many places. In Gareg-lwyd Park are fine sections in mélange, full of lenticles of grit, with a few knots of limestone. On the south side of the woods the matrix is epidositic, evidently in great part volcanic dust, of the same nature as the adjacent Church Bay Tuffs, but highly schistose. The rock should now be described as 'Gwna Green-schist' [E. 10498], and at Bryn-maethlu is almost as crystalline as in the eastern Aethwy Region, with much chlorite, mica being fairly developed, but many clastic grains surviving. Passing south-eastwards from Llanfaethlu, the main divisional planes grow more micaceous, but the mosaic between them does not become saccharoid as are the New Harbour Beds, and the structure is lenticular, not flaggy. There is an absence of sharp folding, the foliation having a tolerably steady dip at moderate angles, with continual small undulations, and 'hitches' at intervals.

The rocks are well exposed at Bod-wyn, in Gareg-lwyd Park, all over Llanfaethlu hill, between the Maen-hir and the southern boundary, around Clwch-dyrnog, and at Brwynog. The quartzites, well seen about the Smithy, differ from those of Gynfor only in that any little schistose films traversing them are here well coated with fine white mica. The leading feature of the Llanfaethlu rocks is the limestone, 16 outcrops being laid down upon the six-inch maps, besides which are many too small for that. There are fine sections in the old quarries at Bryn-maethlu. The rock [E. 10482] is massive, grey, fine, calcitic, and sometimes mottled, as in Gynfor, but is slightly saccharoid, and where schistose films traverse it, they are bright with mica, the Gwna Green-schist adjacent being also more crystalline than elsewhere. In the large quarry a massive bed is cut off at the top by a curving slide, above which the structure is more lenticular. Bedded limestone and graphitic phyllite [E. 10483] like that of Gynfor appear on the western wall of the quarry, and must have been better exposed in the lesser quarry, for a wall along a footpath near the 'a' of 'Llan' is built of them. The bodies that resemble foraminifera are just above the massive limestone, at the south end of the pool in the large quarry. The only basic rock of interest is a six-foot band of heavy chlorite-schist in the large quarry by the road, 360 yards west of Fadog-frech [E. 10480], which contains abundant undeformed cubes of pyrite that are often half an inch in diameter, enclosed in shells of fibrous calcite. No other such rock is known in Anglesey.

About Clwch-dyrnog, in spite of the survival of lenticular cores of grit, the green-schist is decidedly crystalline, the quartzites are granoblastic, and the limestone [E. 10484] shows a distinct access of anamorphism. It is full of seams of graphitic schist. The same rise in anamorphism continues to Brwynog, where nevertheless, clastic cores also survive. The passage to the Church Bay Tuffs (see p. 159) is discernible on the slopes towards the little river, but the Gwna Beds are undoubted, and are defined by quartzites.

These are too small to be shown upon the maps, but are of good Gwna type. Some of the dips about Brwynog House are to the north-west, others to the north-east, indicating (like those in the New Harbour Beds near Meiriogen) an anticline pitching to the north-east, which doubtless brings on higher tectonic horizons of the Complex in the Sub-Ordovician floor.

Llanrhyddlad.

The Gwna Green-schist becomes less crystalline as we pass north-west from Gareg-lwyd, here and there taking on some of the characters of the adjacent tuffs, a rock at Rhydwyn Windmill being a felspathic gritty tuff, not severely sheared. Thence along the little valley there are good exposures, and near the other windmill some lenticular jaspers (evidently stripped from a basic rock) appear in the Mélange. On the slopes below Llanrhyddlad Rectory are important exposures of sheared ellipsoidal spilite [E. 10429—30] with nests of jasper, now partly bleached and slightly schistose. Variolitic brushes of decomposed felspars are still to be seen in the spilite; which, however, is highly epidotised, and some needles of pale amphibole have developed. In Porth-swtan the Gwna Beds are extremely decomposed, even the quartzites decaying at every possible point, and what was the Green-schist being now [E. 11070] soft and bright straw-yellow. At the north end of the beach the rocks are again fresh, and for 200 yards along the foot of the high cliffs there is one of the best sections in the Island of Gwna Green-schist with large lenticular masses of quartzite and dolomite. The upper part of this cliff is obscure from decomposition, but seems to consist of Gwna mélange. The good Gwna section ends at a fault beyond which only a little mélange and green-schist is left, which passes by interdigitation into the Church Bay Tuffs of the great cliffs.

Foel High Land.

Foel hill itself, 450 feet in height, is composed of dull Gwna Green-schist [E. 11069], retaining near the summit a little of the original grey tint of the sediment, and sometimes the old bedding, but for the most part full of small hard phacoids, with some of quartzite a yard or so in length. On the south-west brows that overlook the cliffs just described, it becomes much more ashy-looking, and was at first regarded as Church Bay Tuff, but, on account of the presence of numerous lenticular quartzites, must be placed in the Gwna Group, though evidently a zone of passage. A long tongue of schistose tuff now runs inland, beyond which is again Gwna Green-schist, with five quartzites and three limestones large enough to be shown upon the six-inch maps. The largest limestone [E. 10377—80] has been quarried alongside the grassy road; it is grey, dolomitic, and massive, with compound oolitic grains. With it are excellent black phyllites, shaly-looking, with minute clastic quartz, and pyritous. The horizon is therefore undoubted. Near the sea these Gwna Beds are quite distinct from the Church Bay

Tuff of the high rocky tops of Clegyr-mawr, but as the line runs inland along the moorland by Orsedd-goch, it becomes, in spite of good exposures, extremely uncertain (see p. 159), gritty matter and flaser-structure appearing on the south-east and ashy matter on the north-west side. Doubtless it runs through a zone of alternation, complicated by broken folding and repetition, and still further obscured by the old silicification of the tuffs, which when sheared into augen simulates closely the Gwna mélange and even the Quartzite. A little to the west of the large limestone, among the little farmsteads, are three small nips [E. 10369] of crushed albite-granite. The largest and most north-easterly, which adjoins a building 25 yards from the road, is well exposed, and actually in visible foliated contact with Gwna Green-schist. The granite is coarse to the margin, the schist shows no sign of thermal alteration, and the junction is evidently a slide-plane. Being albite-rocks, there is little doubt that they really belong to the Gneisses, and are shattered nips like those of Mynachdy and Mynydd y Wylfa (pp. 296, 307).

The Church Bay Tuffs.

Except the rugged summits of Clegyr-mawr, 320 feet in height, there are no inland exposures of importance; but along the coast is a continuous section for a distance of three miles. The rock that rises on the steep slide of Yr-ogo-goch (Fig. 203) is a uniform dull-green porcellanous tuff, slightly schistose. About 100 yards to the south, where the cliff turns a little westward, is one of the best sections in bedded material known in the formation, thin green grits and evenly banded pale jaspers being interstratified for a short distance with the fine porcellanous tuff. After this, banding decreases; and 400 yards from Yr-ogo-goch, a massive green ashy grit of Skerries type appears [E. 9681, 10371] and runs out into a little headland. The section here is of the first importance, for it yields the pebbles of keratophyre, quartz-felsite, granite, quartzite, and scarlet jasper mentioned on pp. 57, 166, which are found on a greater scale in the Skerries Grits, and are therefore so valuable for correlation. Those of jasper are quite small, the others usually about half an inch, and occasionally two inches in diameter. Bedded jaspers [E. 10372] occur close by (with short thin bands of basic rock), and resting on the pebbly grit are bands of porcellanous epidosite which pass locally into groups of clots, a phenomenon seen here on a greater scale than at any other place. Uniform and massive green tuff extends to Porth-y-dwr, where there are some bedded pale jaspers, and a thin basic bed with a suspicion of ellipsoidal structure. Old silicification [E. 11341] torn out into augen is to be seen on the high moor above the cliffs. These hard augen contain also veinlets of secondary clear albite. The two little limestones are of the late metasomatic type (Chapter XIX). The massive tuff now shows no special feature as far as Ogo Lowry, but from the foot of the cliff north of the chasm signs of bedding can be seen. Beyond that the tuff is still very massive, but streaks (rather than beds) of coarser matter are appearing as we round the headland, and where the cliffs look southward there is a good deal of this [E. 10370], containing fragments of keratophyre and old mica-schist, and with short thin bands of a fine tuff in it, though the headland shows no bedding from a distance. Overlooking this headland are the high rugged summits of Clegyr-mawr, which [E. 9315, 10316] furnished the specimen analysed. Close at hand only a short thin banding can be seen, but from the coast in a good light the whole crag shows bedding, dipping at 20° to 30° as if to pass under the Gwna Beds. Incipient old silicification may be seen in places [E. 11342]. As there is no shearing this is the best locality for a study of the tuffs. At the south end of the great ivied sea-cliffs the tuffs are brought down by a fault, and the Gwna Beds occupy the cliff to the end of Porth Swtan, but the section is even here continuous, for the tuffs occupy the foreshore. The Swtan sections demonstrate (see p. 159) the stratigraphical passage from the here overlying Gwna Beds. At their south end there is another fault, and the tuffs once more form the cliffs.

In the cove south of the roadway and old brickworks [E. 10432] there is again good bedding in the tuffs, but never running more than a few yards, or imparting a bedded aspect to the cliff. One grit seems to cut down into bedded epidosite, suggesting that, locally, there is no inversion ; but the bedding, when examined, is so full of abnormalities, little faults, old brecciation that does not break the beds above and below, beds cutting across each other, and other such phenomena, that no reliable inference can be drawn. The conditions of deposit of this great pyroclastic accumulation are far from being fully understood. Local steam explosions, for example, such as those described by Anderson and Flett in St. Vincent[1] might erode and disturb the deposits, fine bedded dust then accumulating in the hollows, in which case the whole can after all be inverted (see below). It is quite likely that many of the small normal faults may be far older than the great earth movements—they may be due to settlement not long after the eruptions.

Cliff-sections in brown-weathering tuffs, massive and igneous-looking, follow as far as Crug-mor streamlet, after which is only a foreshore section to Porth Trwyn. In the first little cove beyond the sandy beach is the epidosite-clot bed described on p. 57 [E. 10433]. It lies between two zones of true fine-bedded rock, and cuts up into the overlying one, so that, here, the inference would be that there is inversion. A few yards to the south the cutting is once more downwards, from which it is evident that this cannot be relied on to prove the true order of succession. Beyond the natural arch is beautifully even bedding [E. 10431] cut by small step-faults (a specimen of which is preserved in the museum) at intervals of an eighth of an inch. There are also true mylonising crushes, and curious faulted folds as shown in Fig. 129.

[1] *Rep. Phil. Trans. Royal Soc.* 1903, p. 423, Plate 23, Fig. 1.

The Tuff is now becoming schistose, and, in the deep cove north of Careg-frân, there is a plane of movement above which it is for some yards hardly to be distinguished from the more ashy parts of the Gwna Green-schist. This degree of schistosity is not maintained, but the rock remains more or less deformed all the way to Trefadog. In other respects it is normal, and must have been quite massive and remarkably uniform.

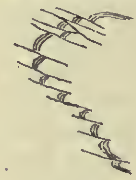


FIG. 129.
SMALL THRUSTS IN ONE-FOOT FOLD.
South-west of PORTH TRWYN.

On the foreshore below Castell drumlin, Trefadog, is the coarse tuff [E. 1543, 10497, 11078]. It is considerably deformed. Then follows the junction section quoted on page 157, on whose north side is the 50-foot band of green-mica-schist [E. 11189] into which the tuffs graduate.

In the foregoing description, spots where bedding is to be seen have been, of necessity, dwelt upon, giving, perhaps, the impression of a good deal of bedded tuff. In reality they are narrow zones, the great body of the tuff being quite unstratified.

At Brwynog the true porcellanous epidosite is undoubtedly present, but is not massive. On the north side of the boundary-hollow the tuff alternates with and graduates into siliceous Gwna sediment; on the south, it alternates with purple phyllite of the New Harbour (Soldier's Point) Beds, so that both zones of passage are unruptured. The Tuffs are thin, but this is almost certainly due to their central massive part being cut out by the Bodfardden thrust-plane.

BOUNDARIES.

The nature of the northern boundaries has just been described. At the south end of Llanfaethlu village, north-west of the "L.B.," schistose tuff is seen on a long low escarpment within a few yards of Gwna Green-schist, in the condition usual at the zone of passage. Except at this place, the western boundary of the Gwna tract is little better than conjectural from Crug-mor to Bodfardden, for it is almost entirely buried under great drumlins. There are, however, isolated exposures to guide it, and as it must in any case cross the foliation-strike it cannot fail to be serrated. The northern boundary of the New Harbour Beds, against which Gwna Beds are brought from Bodfardden to Brwynog alluvium, must be a rupture, and has been called the Bodfardden thrust-plane. For about a mile east of Bodfardden-ddu the line is taken along a strong feature, but near Gronant it is suddenly shifted southward, probably by a fault along the alluvium, and thence for some two miles is guided through rather obscure country by small outcrops of quartzite and limestone. At Brwynog (where there are good exposures) the line is taken along a hollow on whose southern side is a sudden rise of metamorphism. But metamorphism has already risen somewhat in the Church Bay Tuffs themselves on the north side of this line, decreasing where they graduate northwards into the Gwna Beds, and their material (much more crystalline) is recognisable among the New Harbour (Soldier's Point) Beds (see p. 158) on the south side of the hollow. As the thrust is still strong opposite Llanddeusant Windmill, the probable explanation is that at Brwynog it is cutting out all their central massive part, leaving both zones of passage intact. The thrust-plane is probably, like the Valley minor thrust-planes, a foliation-plane itself.

THE NORTHERN INLIERS.

The Garn Inlier.

The Garn Inlier, which rides upon the Garn thrust-plane (Folding-Plate IX), and is elsewhere bounded by the Garn fault and the Arenig conglomerate, is of great stratigraphical importance, for on its rugged, steep escarpments three members of the Complex, with good zones of passage, are admirably exposed. The Green-mica-schist of the southern belt is of Holyhead, not Amlwch, facies, for though grit-bands exist they are feebly developed, hardly more so than in the country to the east of Valley, but it is easily identified as the Soldier's Point group. Though less crystalline than at Holyhead [E. 9684, 11056] it is saccharoid, with fairly developed micas, resembling the condition prevalent about Llanddeusant. Clastic quartz is easily detected with the hand-lens. East of Bonw, just where a footpath crosses the Garn thrust-plane, jaspery phyllite and some bedded jasper may be seen ; and close to the northern margin of the belt, at the tail of a dip-arrow, is a 10-foot band of soft basic schist, resembling the deformed New Harbour spilites, adjacent to which are seams of pale bedded jasper, so that there is no doubt as to the horizon. In the southern part of the belt is a sharp isoclinal folding (though never so rapid as at Holyhead), the fold-axes dipping north at about 40° (with rather steep easterly pitch), but the angle increases to 70° on the higher escarpments, and along the northern margin of the belt folding dies out, giving place to a steeply-dipping platy foliation.

At the same time the metamorphism falls off, and about 170 yards east of the spilite is a band with the characters of the Church Bay Tuff. Then comes the zone of passage, which has already been described (p. 158). Along it is a narrow grassy platform, beyond which is platy crypto-crystalline sea-green rock with seams of fine mica-schist, and this type passes in a yard or two into typical Church Bay Tuff. For the tuffs of the inlier are typical, and not always even schistose. In places they are quite massive, and are the same dull green, unstratified material, full of wriggling delessite veinlets, as on the shores of Church Bay. Near their southern margin they show some bedding, with seams of pale jasper like that of the New Harbour Beds.

Towards the summit, thin courses of a fine siliceous grit appear in them; these then break up, and in a few yards the rock (see p. 159) becomes the Gwna mélange. In this are several phacoids of white quartzite, one of which, just below the cairn, is not less than nine feet long. The matrix of the mélange [E. 10356] retains an ashy aspect, and there is but little anamorphism, the micas of the foliation being very small.

The Mynachdy Inlier.

About half-a-mile west of Mynachdy a small strip of green Gwna mélange rises from beneath sheared Ordovician conglomerate (with which it is confusable near the junction), along the south side of the same slide as that which bounds the Gader gneiss at Porth Ogo'r-geifr (Folding-Plate XIII).

The Fydlyn Inlier.

The deeply indented coast of this inlier is almost continuous cliff, often 100 feet or more in height, and inland also the country is very bare and rocky, so that the inlier is very freely exposed. The whole of the north-western corner is extremely complicated (see Folding-Plate XIII, which includes the Fydlyn, Gader, and Mynachdy Inliers. The place-names used are taken from that map).

Trwyn-y-crewyn to Fydlyn Beach.

Along the southern margin, rising on the steep Crewyn thrust-plane, is a broad band of Gwna mélange, running westwards from Hendy to form the great rugged headland of Trewyn-y-crewyn. In this mélange [E. 10373] the hard gritty augen are very fine, weathering like porcellanite; and are often closely crowded, lapping on to one another, leaving thus but little room for the schistose matrix. A coarse felspathic grit near the Trewyn is regarded as a nip of the Ordovician base. Near it are one or two small basic schists. The northern margin of this tract, for about half a mile west of Hendy, is a good deal confused by late silicification.

On the western cliffs, 133 yards north of the Trewyn, is a chasm, in which (Folding-Plate X) a powerful-looking thrust is well exposed. It cuts out an unknown thickness of the Gwna mélange, for above it the green colour begins to fade in a yard or two, white seams of felsitic dust-schist appear, and in 16 yards there is a complete passage (see p. 161) into the Fydlyn rocks. Inland, the nature of the junction is not clear, it seems to zig-zag across the strike, and the thrust may be changing its horizon. Returning to the coast, a few thin grits remain in the Fydlyn Beds on the north side of the chasm, but they soon disappear, and for 180 yards the white felsitic schists [E. 9682—3] are finely exposed, this being the best section in the most purely igneous portion of the group. Shearing is powerful, but anamorphism feeble, and fissile matter winds about innumerable hard cores. Many of these are crowded with quite large phenocrysts of quartz, and here are the rounded cores that suggest original nodularity. Other hard cores are siliceous, and evidently due to ancient silicification at the close of the volcanic episode, long before the time of the great earth-movements. Except these knots, all the Fydlyn rocks are considerably decomposed. The impression left upon the mind is that of a series of several thin lavas, with intervening tuffs, all now sheared together. Both lavas and tuffs must be highly acid and wonderfully free from iron, for in spite of the decomposition the cliff is in many parts nearly as white as chalk. Further petrological study is much to be desired. Just north of the thrust, the cliff can be descended, and at low water a good view can be obtained from beneath, as a broad rocky shelf is laid bare. About 100 yards along, a rude isoclinal anticline of Gwna mélange rises (Folding-Plate X), but does not reach the cliff-brow. It is of structural importance, for it shows that the Gwna Beds really underlie the Fydlyn Group, and that the succession in the inlier is inverted. Viewing the cliff from Fydlyn outer island, this dark anticline can be made out, with indications of a syncline on its northern side. Then, at Fydlyn beach, Gwna mélange with a basic schist and a little jasper comes up and is thrust on to the Fydlyn rocks.

Fydlyn Beach to Porth-yr-hwch.

The beach and alluvium doubtless conceal a shattered anticline, followed by another infold. For at the Fydlyn island and cliff the felsitic rocks appear again, the junction probably being close to the island, for at the cliff's foot of the inner isle a little Gwna Green-schist is to be seen among the white rocks at low water. But on Fydlyn islands fine grit and even grey phyllite [E. 10353—4] (which have been searched for fossils) are present, and it is probable that most of the acid volcanic matter is pyroclastic here, but the bedding has been excessively broken up at the beach, though from a distance it seems tolerably regular on the outer isle. In a chasm at the seaward end some lumps that weather hollow have a very nodular aspect. Just where the inner isle faces the mainland, this thin bedding graduates once more into massive matter; and Fydlyn high cliff (pierced by the great caverns, Chapter XXXIV) is composed of a very massive white rock [E. 11333—6] like that of the southern cliffs. There is a vertical foliation, and some zones of silicification, but from the island there can be seen planes that appear to be bedding dipping at 40°, in which case the thickness of the mass must be about 130 feet. Massive though it is, the texture is far from homogeneous, for while some parts are little else than cryptocrystalline felsitic matter, now considerably sericitised, in others this matter functions merely as matrix to a crowd of sub-angular fragments, chiefly quartz, with a few sericitised felspars. The rock therefore appears to be a pure tuff, with showers of broken phenocrysts detached by explosion and embedded in felsitic dust. But the upper parts of the great bed need further investigation.

Inland, both tracts of these acid schists, though well exposed, are difficult to separate from the sheared felspathic Ordovician grits, and the lines drawn are but provisional. The deep hollow of Llyn-y-Fydlyn does not seem to be determined by any rupture of importance. It may be worth remarking that, the succession being inverted, infolds of the Gneisses might have been expected to occur as outliers ; and these should be sought for inland, as amid the general confusion due to the deformation of several acid felspathic rocks by earth-movements of at least two periods, they might easily escape notice.

Returning to the coast, the Fydlyn rocks are seen to graduate into the Gwna Beds, the latter passing quickly into mélange (Fig. 32), the sections being on the high brows just above the cliff edge. In spite of the general inversion, this graduation is upwards, the natural order being locally restored by the overdrive on the major secondary syncline. The Fydlyn rocks come to an end at a vertical zone of shearing that is exposed in an interesting chasm which can be reached either by getting down a spur of cliff, or by coming through the great Fydlyn caverns at dead low water.

The zone of shearing behaves as a fault, but produces autoclastic mélange in the Gwna Beds, which are driven up against the Fydlyn rocks. Planes parallel to what seems bedding cross the zone, but they are merely jointing. Then come several yards of an ellipsoidal spilite with some jasper. This lava [E. 11337], though its felspars are badly decomposed, retains in places the subradiate structure of the variolites. On it rests a massive grit that seems to fill cavities in its surface, and then follows a large phacoidal limestone, part of which remains as a natural arch that bridges the next chasm. North of this is a grand rugged sea-section in dull green Gwna mélange [E. 11074] with large lenticular quartzites and limestones, and at its north end are some more ellipsoidal spilites with jasper. Planes like bedding dipping north are perceptible, yet the large phacoidal masses are standing almost vertically. This is one of the finest Gwna sections in the Island. Eastward from the coast a rugged tract of mélange extends as far as the Carmel Head thrust-plane, where it is on the point of wedging out. The fissile matter is chlorite and sericite, and the anamorphism low, perhaps rather lower than at Bodorgan. The hard lumps, rather short and subangular, instead of good curving phacoids, are chiefly of a very fine siliceous grit [E. 10375] now largely crypto-crystalline, like those on Trewyn-y-crewyn. Besides a few quartzites there are some 23 nips of basic rock. Most of them are now chloritic schist, but about 266 yards east of Pant-yr-eglwys [E. 10381], although the pyroxene is chloritised and the felspar much crushed, they retain traces of ophitic structure, and are leucoxenic albite-diabases, evidently of the spilitic suite.

The passage (see p. 159) to the Church Bay Tuffs now comes on. At the cliff it is to be seen just on the north side of a chasm in which is a small shearing crush, but the boundary is unfaulted. Inland, the passage is perceptible all along the line, and the other good section across it is in the ravine west of Pant-yr-eglwys

[Face page 290.

The Hwch Lower Thrust-plane. Porth-yr-hwch.
Fydlyn Felsitic Tuff thrust over Gwna Green-schist.

alluvium, below the Fydlyn path, where a wall runs along the crag's brow. The Church Bay Tuffs are good and typical both on the coast and inland, in spite of shearing.

Porth-yr-hwch.

In Porth-yr-hwch (Plate XXV) they end at a plane that probably cuts them off rather steeply against a wedge of Gwna Green-schist with limestone, that forms part of the cliff wall at the back of the beach. At its north end this Gwna Green-schist graduates into a yard or two of rock with white seams, evidently the passage from the Fydlyn Beds.

But, before the passage is effected, comes a powerful thrust-plane, which may be called the Hwch Lower Thrust-plane (Fig. 130), very

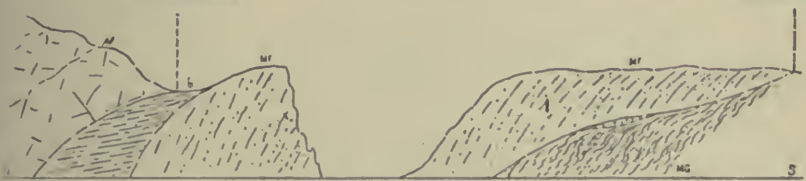


FIG. 130.—SECTION ACROSS THE TWO COVES AT PORTH-YR-HWCH.

M — Granitoid Gneiss. MF — Fydlyn Beds.
MG — Gwna Mélange, with limestone. b — Ordovician Shale.
Height at north end: about 200 feet.

clearly exposed and well seen in Plate XXV, which drives massive white Fydlyn rock, at a lower angle than the dip, completely over the Gwna rocks, and, apparently, on to the Church Bay Tuffs, so that this wedge of Gwna Green-schist only runs a few yards inland. This thrust is probably an ancient one of the Mona Complex, for some carding of the rocks into each other is superimposed upon it.

The Fydlyn rock now forms the remainder of the coast of the inlier, and runs out into a precipitous high spur between Porth-yr-hwch and Porth-yr-hwch-fach, on whose ridge it simulates the Ordovician grit, and has been searched for fossils. But there is no doubt of its identity, for on the seaward nose of the spur the white felsitic matter appears in abundance, and the old Mona shearing is very powerful. The simulation is due to late silicification (which may be the cause of the survival of the spur) such as has affected the Ordovician rocks a little to the east. Some green zones of Gwna type, with grit, also occur in association with it, completing the identification. The massive Fydlyn rock [E. 11338—40] of Porth-yr-hwch is largely felsitic matter, sericitised as usual, with broken phenocrysts of quartz, and may safely be taken to represent the thick felsitic tuff of Fydlyn cliff, though it is less crowded with phenocrysts.

At the back of the cove is a small Post-Ordovician cross-fault, beyond which rise rocky heights composed of a yellowish type of Gwna mélange with small quartzites, confused by silicification (which renders the lines to the east somewhat uncertain). Appearing from behind the Fydlyn rock, it is the most northerly member of the inlier; and, the succession being inverted, must be rising on the north limb of the major syncline that takes in the Fydlyn rock. But the southern limb is in great part abolished by the thrust (Folding Plate X), which, cutting the major infold at a lower angle than its axis, drives the Fydlyn rock of the core completely over the Gwna Beds of the southern limb; and then abolished altogether by a higher thrust inland, which drives the Gwna Beds of the northern limb right across the core and on to the Church Bay Tuffs of the southern limb. These two old thrust-planes are then truncated by the Post-Ordovician slide that lets in the wedge of shale, over which the Gneiss of the Gader Inlier is in its turn driven on the Post-Ordovician Hwch thrust-plane.

The Gader Inlier.

The lofty ground of Pen-bryn-yr-eglwys (Folding-Plate XIII) (always known locally as 'The Gader') is bare, and there is good exposure, especially on the southern escarpments; but the great feature of the inlier is the grand sea-section, which rises to a height of 200 feet. The whole is gneiss, except a narrow Gwna band along the sea cliff. All the types of gneiss are present, but the flaky 'C' type is dominant [E. 8448, 9672—80, 10363—5, 11001—3, 11054]. Eleven strips of hornblende-gneiss are known, but none exceed 100 yards in length.

Traversing the sea-section southwards, the first 170 yards from the north point consist chiefly of grey flaky gneiss with lenticular granite sills (Figs. 22, 23) and thin pegmatite seams and phacoids, while the smaller granites are full of films of gneiss (Fig. 26). The felspar of the gneiss is albite with some oligoclase, the biotite is largely bleached or else chloritised, and is often crowded with needles of rutile. Sillimanite is present, but is not abundant. It is interesting to note how the granite sills of the high land, thinning seawards, turn round so as to pass down the cliff along the foliation-dip (Fig. 131). Their felspars are albite and albite-oligoclase, with some oligoclase, which is abundant in parts of the large sill that runs up to the north edge near Porth y Dyfn. Granitic permeation is now setting in, and at Porth-ffau'r-llwynog ('the fox's den') by getting down a great oblique buttress or spur to the sea, the section shown in Plate XIV can be seen. There is hardly any dip or foliation as a whole, but the rock is a rude complex or 'plutonic breccia' of knots of albite-granite and dark gneiss, each included in each. The aspect strongly recalls the old parts of the Lewisian of Scotland, the dark knots here, however, not being amphibolite but fragments of the biotitic gneiss itself, which also runs in threads throughout the granite. Granitisation then wanes, and on the cliff to the south are excellent sections of flaky gneiss with lenticular interfelting of innumerable thin granitic seams. Although the foliation continually undulates, folding is rare, but here and there are micaceous partings that are sharply corrugated, in some of which are decomposing garnets as large as peas, and a few green crystals that may be idocrase. Permeation then again sets in, and waxes with such rapidity that all the four higher grades are to be seen in only about 40 yards. The great 'sill' that runs down the cliff overlooking Ogo'r Arian is really a locus of maximum granitisation, gneiss and granite being woven together within it by what may be called internal anastomosis. The felspar is albite-oligoclase.

The buttress between the two dark caverns at Ogo'r Arian (see p. 162) is composed of gritty Gwna mélange with trachytic fragments [E. 10368], very slightly altered, brought against the gneiss by an undulating fault. The band runs on southwards for another 110

FIG. 131.—NORTHERN PART OF THE GADER INLIER.
Scale = Two-thirds of ·0004 (1/2500) map.
Granite sills in Gneiss.

yards along the lower part of the crags of the great headland, the fault then bending as if to pass into the chasm between the land and the rocky islets. This fault is not quite simple, some inosculation taking place between the two rocks. It has a clear hade eastward, so that unless it be reversed (of which there is no sign, but rather the contrary) the Gneiss is brought down against the Gwna Beds, which is a confirmation of the view here taken that the succession is inverted.

The highest point of the sea-section, called Trwyn-cerig-yr-eryr ('Eagle's crag headland'), is crested at its conspicuous point by a complex granitoid gneiss. Among the flaky gneiss in which this lies is a good deal of the siliceous 'A' type. The great section is highly complex, and would well repay detailed petrological study.

High types of granitisation again set in, and along the southern sides of the great headland, cakes of the large granite of Pen-bryn-yr-eglwys adhere to the cliff, dipping at high angles. The white quartz rocks here are late silicifications (see Chapter XIX). The main sill is a good deal decomposed, but from a suite of specimens taken on the escarpments south of the summit of the hill, its felspars have been found to be albite and albite-oligoclase, with a very little oligoclase. It appears therefore that all the granites of this inlier are to be referred, not to the Coedana, but to the gneissic suite. The great granite is then driven southward upon the Hwch thrust-plane (Fig. 130 and Folding-plate X.)

The Corwas Inlier.

This inlier is bounded entirely by thrusts and slides. The western part is composed of platy green-mica-schist of New Harbour type with a few clastic grains. It is thin-seamed without any definite beds of grit, and is not of the Amlwch facies which lies close by across the Carmel Head thrust-plane, but of undoubted Holyhead (and Soldier's Point) type, a fact of great structural importance. In it lie some rather massive basic schists, largely composed of epidote with needles of a pale hornblende, which may represent the spilitic lavas of the group, for, though no unfoliated cores have been seen, thin seams of pale jasper are associated with them. The best exposures of both rocks are on the south side of the pool, and thence at intervals to Corwas. The eastern part is composed of Gwna Green-schist; so that the boundary must either be a back-slip or a thrust at a lower angle than the true dip, but it is not exposed, and in the obscure marshy hollow there is room for at any rate part of the Church Bay Tuffs. Dull tuff-like matter, like the Church Bay Tuffs, occurs among the Gwna Beds near the line, and if the Tuffs be locally thin, the thrust need not be of great magnitude. The Gwna type is pronounced, and were there any doubt of the horizon, it would be sufficiently indicated by the single quartzite, which has thorough Gwna characters. The rocks are abundantly exposed on the rugged flank of Mynydd Eilian, east of the Pengorphwysfa road. On the higher knobs of the eastern margin is a good deal of thin-seamed chloritic phyllite [E. 10441], but the prevalent rock is very siliceous, the harder bands weathering to a salmon-pink. Often these bands are very fine, and have a foliation that appears to have been 'sealed-up' by silicification and epidotisation at a late stage in the metamorphism. They are impersistent, but there is an absence of the usual phacoidal mélange, for the grits which give rise to such a mélange are absent. Indeed, even the coarser beds are quite fine, and lamination is general. The folding is a nearly a-clinal wrinkling on steeply dipping planes.

The basic sills at Pengorphwysfa are sheared, but have a chilled edge, and a tongue that seems to belong to them truncates the foliation of the schist, so that they are probably intrusions of a late stage in the Mona movements, as are those of Caerau (pp. 103, 320), which they resemble externally.

THE NORTHERN REGION.

The Llanfairynghornwy Belt.

The rock which rides immediately upon the Carmel Head thrust-plane at Carmel Head (Folding-Plates X, XIII) is a green-mica-schist with clastic grains [E. 9512], of New Harbour type, like that prevalent in the Lynas division of the Amlwch Beds, more crystalline than the group that lies behind it, and isoclinally folded at high angles from the north (Fig. 270)[1], the folding being older than the Carmel Head thrust-plane, by which it is cut. The Wig thrust-plane, which is not seen in section, may be of Pre-Cambrian age, and runs out in 100 yards upon the Carmel Head thrust-plane.

The rocks of Carmel Head itself, which ride first upon this and then upon the Carmel Head thrust-plane, are typical green Gwna mélange [E. 10374], in which is an extremely complicated zone full of great lenticles of quartzite and limestone, with seams of graphite-schist. On the low eastern cliffs, about 200 yards from the Point, are masses of spilitic lava with deformed ellipsoids [E. 10382] between which are nests of scarlet jasper. Variolitic felspar-brushes still survive in them. Thus, at this extreme point of Anglesey, the Gwna Group is curiously complete, and that in the space of only 200 yards. Reconstruction is very slight, and bedding survives at the Point, but south of that everything is torn to pieces, jaspers being ripped out of the spilitic lavas. Rocks of the same kind continue above the Carmel Head thrust-plane to Porth-yr-Ebol (as the cove a quarter of a mile south-east of Carmel Head is called on the ·0004 and six-inch maps), where the great thrust is shifted by a fault. Dull ashy material then appears in it, and confused types, greatly crushed [E. 10992], continue to the Porth Padrig slide, and in Porth Gron, the cove between Ebol and Padrig, is a massive grit, extremely decomposed. These rocks, west of Mynachdy, have such an ashy aspect (see p. 159) that they were at first assigned in part to the Church Bay Tuffs, but they contain lenticular grits and quartzites, and must be placed in the Gwna Beds. The line has therefore not been coloured, but is retained upon the one-inch map, as the sections are most perplexing.

Gwna Beds (very slightly anamorphic—see pp. 168, 238) re-appear beyond the Mynachdy Gneiss, and continue between the Carmel Head and Caerau thrust-planes to Llanfflewyn. On Mynachdy drive they contain a large quartzite, and much purple phyllite. This differs from the jaspery phyllites of the Amlwch Beds in being lumpy, lenticular, and associated with purple grit as it is in the Aethwy Region, and at the foot of the bold escarpment that looks down upon Mynachdy marsh is a thin strip of deformed spilite with nodular jasper. On the heights north of Caerau (see p. 159) matter of Church Bay type again appears, but the body of

[1] This folding is to be seen in an unpublished photograph (No. 1446).

the rock is Gwna Green-schist, with small quartzites. The eastern boundary is here obscured by the baking of the Amlwch Beds around the basic intrusions. Gwna Green-schist with large quartzites is well seen on the slopes of the Garn [E. 11064—8] about Hendre-fawr, and the old level driven close to the village was reported to Dr. Matley to have passed through a 12-yard limestone that has no outcrop.

Exposures are scanty for a mile, but Gwna Green-schist with small quartzites is again well exposed about the road-fork east of Bod-hedd and at the intakes of Llyn Llygeirian. On its northern margin it becomes (see p. 159) full of ashy matter, and typical Church Bay Tuff, a good deal sheared, is exposed by the outflow from the lake, so that the wedge is wide, and its outcrop must run as far west as the Maen-hir. The Caerau thrust-plane (see p. 217) is now thrown down by the Geirian fault, and, where it reappears, has almost overlapped on to the Carmel Head thrust-plane, which has also been thrown down. A platform only 50 yards wide, of Gwna Beds with a little limestone in them, winds round beneath the rugged escarpment of the Coeden beds for a quarter of a mile, and then the thrust-planes come together. Both must be at quite low angles. A thin plate of Gwna Beds reappears between them at Gwaen-ydog 'bay' (Chapter XVIII, Plate XXXII) and is completely shattered.

The Mynachdy Gneiss.

This is wedged into the Gwna Beds in four lenticular tracts (Fig. 94), the two larger being parted by the Ordovician tract, and the two smaller lying along the Caerau thrust-plane. The Gneiss differs in no way from that of other parts of Anglesey, save that sillimanite and garnet have not been seen, and is as coarsely crystalline as any. Many small granites have been picked out upon the maps, the gneissoid element is full of granitoid bands, and the granites are sometimes foliated. Both micas are present, much of the white mica being a bleached biotite. A granite [E. 10643] labelled by Blake 'Behind Mynachdy' contains orthoclase, but the felspar of six specimens of the granite and gneiss examined by the present writer is albite-oligoclase. Some of the rocks are highly quartzose and may have been silicified (see Chapter XIX). The section (see pp. 162, 168) where granitoid gneiss is seen within nine inches of scarcely altered Gwna Beds is below the drive, a quarter of a mile from Mynachdy. In the tract west of the Ordovician rocks are good sections with every grade from micaceous gneiss to granite in lenticles two or three feet thick in which are wisps of gneiss, and an obscure amphibolite appears in the farmyard. In the tract east of the Ordovician the best exposures are on the escarpments north-east of the garden, and on some ice-worn bosses just north-east of the wall on the top, granite is seen to graduate into gneiss. The mylonising crushes are probably later movements of the Complex, the rusty partings Post-Ordovician. The Mynachdy gneiss is unfortunately extremely decomposed, and it is difficult to obtain a specimen with a fresh fracture.

The Coeden Beds.

The outcrop of these beds is one of the most rugged tracts in Anglesey, so that good sections are innumerable; but as the rocks themselves do not present much variety, most of the local interest is in the structures. Coarser grits than usual, yet finer than many of the Mona grits, are to be seen in the valley due east of Tyddyn-y-pandy, 530 yards west of the Windmill; and on an escarpment 600 yards south of the 'c' of 'Mechell,' overlooking a cottage. The last locality should be searched for composite fragments. Epidotic seams are present everywhere, but the roadside about 140 yards north-east of the Smithy may be mentioned.[1]

Sweeping steep isoclinal folds are displayed about 233 yards north of Llanfflewyn Church on the crags that look down upon the lake (Fig. 132, *e*), also about the rock-encircled little tarn east of the church (Fig. 132, *a*), about 300 yards south-west of Creigiau-mawr, and on the north side of Mynydd Mechell are the sections given in Fig. 132, *b*, *c*, *d*, *f*. Symmetrical folds occur on the mountain-side west of the Smithy. Some of the minute folds are shown in Plate XXI, Fig. 2. But there is no lack of folding-sections. Where it is not perceptible the limbs are simply longer, their dip often broken by minor folds, as at the old mill-tower north of Gwaen-ydog. At the double pitch-arrow north of Coeden stretching-lines cross the overdriven anticlines obliquely, indicating a spiral movement. Crumpling of the fine partings within the larger isoclines is well seen on the north of the large dyke near the 'c' of 'Creigiau-mawr.' Strain-slip in the same fine beds is to be seen south of 'L. B.,' Llanfflewyn, but best of all on the south side of the road between the Windmill and Llanddygfael-hir, at the glacial arrow, where it is finely developed. The dip, determined by hard beds with lamination, is low, and between them the fissile schists, highly crystalline, show two series of divisional planes, neither of them parallel to those of the hard beds (Fig. 70).

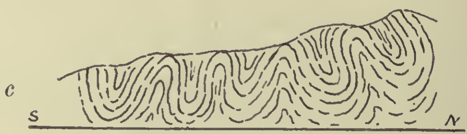
This is close to the junction with the Amlwch Beds, along which line there is a lowering of the dip of the isoclinal axes. Here also thinner-bedded rocks come on, well seen between the Windmill and Maen Arthur; and the passage by alternation (see p. 161) into the Bodelwyn division of the Amlwch Beds may be studied about Clegyrog-blâs.

At their west end, the Coeden beds are cut off by the Geirian fault, where they are pitching westward; and as the Amlwch Beds there are of the Lynas type, there may also be a rise in the angle of the Caerau thrust-plane, or a lowering of the bedding-dip. At their east end, they strike at the Amlwch Beds by the railway, but a strip (or strips) referred to them reappears beyond Gwredog, so that there must be an undulation of the pitch, a phenomenon of which there are cases all along the tract.

[1] The slides of these beds are E. 8512—6, 9312, 10284, 10401—8.

Tarn east of Llanfflewyn Church.

South of 'h' of 'Mechell.'



Mynydd Mechell, north side.

Mynydd Mechell, north side.

Slope opposite Geirian spoil-bank.

Mynydd Mechell.

FIG. 132.—MINOR FOLDING IN COEDEN BEDS.

THE AMLWCH BEDS.

As this series has a great length of rocky coast-line, and also gives rise to very rugged tracts in the neighbourhood of Amlwch, it is one of the best exposed in Anglesey. Even the ·0004 maps admit only of a mere abstract of its wealth of detail, so that the following account is but a condensed abstract of an abstract. The coast will be described first, from west to east; and then the interior, in a similar direction.

The Coast.

Where the series first appears, driven up along the Mynachdy thrust-plane (Fig. 222), the alternating type, with strong, hard epidotic grits, is pronounced; but these are succeeded in about 50 yards by phyllites, locally contorted, though rapid folding is not common in this part of the region. Beyond the serpentine, flaggy phyllite, probably of the Bodelwyn beds, forms most of the shore for some 600 yards, interrupted by a massive grit that gives rise to a cliff buttress. Alternating beds then come on and extend as far as Henborth. On two stacks of the foreshore [E. 10385, and analysis, p. 52] these grits are curiously epidotised, sometimes in concentric shells, sometimes in the manner shown in Fig. 133, where the bedding is horizontal, the foliation of the fine phyllite at a moderate inclination, while thin epidotic bands in the grits dip at a still higher angle. On the foreshore of Henborth is the first considerable development of purple phyllite, beyond which are green alternating Lynas beds, and upon them rest (see pp. 159, 177) the Skerries Grits which here interrupt the Amlwch Series. Over them the alternating beds are thrust, but in the bay by Craig-yr-iwrch is much disturbance, with a strong line of brecciation running west-north-west, outside which a small stack is an outlier of Skerries Grit. Parallel with this, and opposite the south end of the reefs of Craig-yr-iwrch, is another zone of brecciation, giving rise to a gap in the foreshore no less than 100 feet in width.

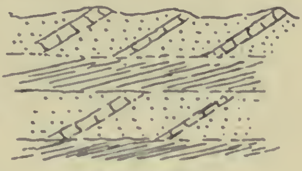


FIG. 133.
EPIDOSITE BANDS.
Henborth.

The pleasant low promontory of Trwyn Cemlyn consists of the alternating group, with bands of purple schist (cut by thrusts) at the point. But some of the grits are thicker (to six inches), darker, and coarser than usual, and contain little fragments of pink felsite and scarlet jasper, as do the Skerries Grits, thus binding the groups together. On the eastern coast of Cemlyn Bay the same alternating group reappears, with occasional thicker and coarser grits, and a great many bands of jaspery phyllite and bedded jasper [E. 10415—6], thirteen being mapped in 200 yards west of the reefs of Cerig Brith. Just at the east end of the great pebble ridge are some 20 feet of a compact, pale, flinty rock [E. 10412]. As it contains phyllitic partings and becomes gritty at the top, it would appear to be a cherty band in the alternating group. Folding is still subordinate to thrusting, but in the northern part of the cliff there is a bend in the strike, and a pitch to the north-east appears for about a quarter of a mile. Opposite the reefs of Cerig-brith is a massive grit, about whose eastern end wrap some 20 feet of breccia, like those of the crushes west of Cemlyn, and probably of Post-Ordovician date. It wedges out rapidly between the grit and a plane of sliding. Alternating beds then come on again.

On the moor above the cliffs are many more bands of jaspery phyllite, and eight small stout nips of sheared spilitic lava [E. 10419] which retain traces of the variolitic structure. On the coast at Cestyll is another zone [E. 10420] of the pale cherty rock. The alternating group [E. 10410—11, 10413—14] (interrupted only by the wedge of Gwna Beds that crosses the neck of the headland west of Porth Wnol) forms the coast all the way to that point, on which there is a great development of the jaspery phyllites, finely exposed. In Porth-y-gwartheg is a spilitic lava, truncated in a confusing manner by a Palæozoic basic sill. On a stack in a creek immediately to the south are some coarse grits [E. 10418] with three-quarter-inch pebbles of quartz-felsite, albite-trachyte, grit, and Gwna quartzite. They seem (see p. 158) to be involved with the Amlwch Beds, but may possibly be a broken infold of inverted Skerries Grits. Small fragments of a felsite also occur in the alternating beds about 150 yards east of Porth-y-gwartheg, on the north side of the spilite. There is now more folding, but thrusting along planes nearly parallel to the old bedding is still dominant. (Figs. 65, 66).

The Amlwch Beds as a whole now turn inland below the Wylfa thrust-plane, which is exposed in the cliff at Porth Wnol (Fig. 96), but there is a wedge of them on the western cliffs of Mynydd y Wylfa. They reappear for a few yards in the semi-circular cove at Wylfa ; and again on Cemaes beach, where, among bedded jaspers, they contain a good spilitic lava [E. 10507] with ellipsoidal structure. It is full of epidote and actinolite, but the variolitic radiating texture is well preserved.

Where the group once more emerges on the coast in Bull Bay, the alternating type is pronounced, and continues all the way to the Carmel Head thrust-plane beyond Point Lynas. The junction of the Lynas beds with the Skerries Grits is perfectly exposed on the headland north-west of 'Cave.' It has been described on p. 158, and is a complete passage by change of material, the two types alternating for some little way.

South of that chasm begins an excellent section, below the grassy bluffs, in the alternating group, which is much more gritty than in the Cemlyn country, for much of the schistose element between the hard bands is really grit. Folding increases, but thrusting nearly parallel to the bedding, never permitting any one bed to range for more than a few yards, is still the dominating structure. Jaspery beds appear, increasing eastwards, and there are some small nips of basic schist. The metasomatic limestone (see Chapter XIX) lies a few yards west of the southernmost inlet of the bay. Beyond that, the jaspery phyllites and bedded jaspers become very numerous (Fig. 134), 40 having been laid down upon the ·0004 maps along 400 yards of coast, which, measured across the strike, is a proportion of one in every four yards. Nowhere in Anglesey are the nature and relations of these beds better displayed than [E. 10535 and analysis] upon the cliffs at the chasm about 60 yards north of the path which comes down from the Coastguard Station. A few yards north of this chasm (opposite the dip-arrow in Fig. 134), an ellipsoidal spilitic lava some 10 feet thick, lies in the cliff between the jaspers. It is the one that was analysed (p. 55), [E. 10259], and although less well-preserved internally than those of Llanfwrog, is of the first importance, this being the only section in the New Harbour Group where the whole of a spilitic flow is laid bare from top to bottom, together with its relations to the embedding jaspers. It is partly schistose, but ellipsoids, with epidotised varioles, are well seen at the seaward end. About 120 yards further east are the structural sections given in Fig. 67, showing the processes of lenticular disruption of the grits and carding of them in with the softer schists. They are best seen by getting down the main cliff on to a platform a little further out. Another 120 yards eastwards again, on an escarpmental ridge across a chasm, are the conglomerates [E. 10540] described on pp. 51, 159. There is not the slightest doubt of their being well within the Amlwch Beds, in spite of the identity of the pebbles with those of the Skerries Group. Some of the pebbles, especially those of the old sediments, retain their smooth rolled form, and are about an inch and a half long, but those of the igneous rocks are often considerably sheared. On Graig Ddu are sills of venous quartz containing a felspar, partly albite, partly anorthoclase. Gritty matter continues to increase, and as we turn round the headland to Porth Offeiriad the Amlwch Port facies comes on, hard white-weathering bands lying between fissile green beds [E. 10559] almost as hard and gritty, and indeed rather coarser. On the ice-moulded cliffs as we approach the Port there is good folding, and the beds are cut across by the foliation.

FIG. 134.
JASPERS AND SPILITES IN AMLWCH BEDS.
Coast near Coastguard Path end Amlwch.
From the ·0001 (1/2500) maps.

On Llam-carw the rocks are driven southward on powerful thrust-planes. East of the chasm comes a space in which the hard bands are much thinner than usual, and the jaspers do not reach the coast. At the wild ravine of Aber-cawell, folding (crossed by the foliation) again becomes conspicuous, and east of it is a strong development of the schistose green grit between the hard bands [E. 10560—1] which are finely developed at the cove a quarter of a mile further on. At the rugged gap of Ffynnon Eilian is again schistose green grit, folded on steep isoclines, and here the jaspery phyllites [E. 10534] once more emerge upon the coast. Bending a little to the south, numbers of them appear in Porth yr Ychain, with a sheared spilite, confused by the presence of a metasomatic limestone, and very complex. The whole cliff becomes extremely gritty as it bends round; and just south of the 'y' is a zone of brecciation that is evidently a late movement of the Mona Complex, for the matrix of the breccia has itself become schistose, though very slightly reconstructed. On the west cliffs of Porth yr Ysgaw are spilitic lavas [E. 10443] and jaspery phyllites ; and on the west cliff of the buttress which divides the cove, is about a foot of white saccharoid limestone, associated with a thin basic schist, folded over in a crumpled anticline. It seems to be unique, and is probably an ancient reconstructed calcite-vein. On the western cliffs of Point Lynas, near the 72-foot level, in alternating beds [E. 10448—50] is one of the finest folding-sections in Anglesey, with the long straight limbs shown in Fig. 52. On the eastern side of the Point, nearly opposite this place, bedding dipping at 30° to 40° is crossed by foliation at a lower angle. Just before Porth y Corwgl is reached are several bands of sheared spilitic lava [E. 10442]. Then, on the north cliff of the cove, are typical bedded jaspers [E. 10444], and at the cliff's foot the Amlwch Beds are driven southwards upon the Carmel Head thrust-plane.

The Interior.

Inland, the Amlwch Beds are very unequally exposed, the centre of the region being obscured by great drumlins (see Chapter XXXI), while the eastern parts about Amlwch Port are among the most rugged in the Island. There seems more fine material than on the coast. The wide phyllite zone of the shore west of Henborth has been traced to Nanner, and the lines for it (which are only approximate) are engraved on the published one-inch map, but have been left uncoloured. Uncoloured lines for similar phyllites will be found south and north of Llanfechell, and a train of them runs through Rhosbeirio to Hafod-llin. The best exposures may be found by means of the drift-lines, but these fine beds do not furnish rocky land, and it is likely that more of them are hidden by the drumlins. The largest tract is that which lies along the Carmel Head thrust-plane between Gwredog and Bryn-Eilian.

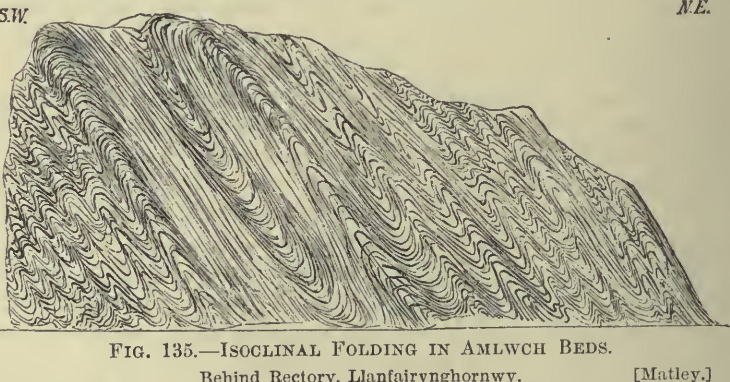


FIG. 135.—ISOCLINAL FOLDING IN AMLWCH BEDS.
Behind Rectory, Llanfairynghornwy. [Matley.]

The beautiful folding shown in Fig. 135 is at a spot 320 yards north by east from Llanfairynghornwy Church, in phyllites with fine thin hard seams, and the folds are sharper than is shown. The tract among the basic intrusions east of Caerau is interesting because of the preservation of the ancient bedding in the indurated aureole.

The Bodelwyn beds are well exposed from Maen Arthur to Clegyrog-blâs, and again at Bodewryd (though more gritty there). Like the Celyn beds of Holy Isle, they are full of sheets of venous quartz, and are more crystalline than the fine seams in the Lynas beds to the north. There are some nips of a thin basic schist near their junction with the Coeden beds, the same horizon, in fact, as that of the thin basic schist of Holy Isle. The whole thickness of Lynas beds, with lavas and jaspers, does not appear between them and the Skerries Grits of Bwlch, and much of it must be cut out by thrusting. The large phyllites near here, and the largest of all, the Llyn Llaethdy phyllite, are probably in reality the Bodelwyn beds, which had not been recognised as an horizon until after the completion of the map. Flaggy but not hard beds, with jaspery phyllites, prevail about Rhosbeirio [E. 8502—7], and there are some obscure basic rocks that may be spilitic tuffs. The dynamical structures that simulate *Oldhamia* are by the barns east of Ysgellog, near the dyke. There is little doubt that the phyllites that range from Tre-gele to Rhyd-y-groes are also on the Bodelwyn horizon.

Near Gadlys and Neuadd, Cemaes, the Amlwch Beds are exposed close to the shattered Gwna Beds, as on the farm lane east-north-east of Neuadd. Yet their isoclinal folding is not shattered, showing that they are brought up from a lower tectonic zone. At the 200-foot contour, north-north-east of Bettws gate, they contain a 2-foot lenticle of Gwna quartzite. To account for its position by earth-movement is almost impossible. It is more likely to have been a floated block, like those mentioned on pp. 51, 304.

Alternating Lynas beds, with one or two small basic schists, are well exposed all along the north side of the road from Cemaes to Amlwch, the bedded jaspers developing finely on the south side from Bryn-llywd eastwards. At the west end of Amlwch town are several masses of spilitic lava, some of them containing fine saccharoidal calcite mixed with epidote. There is a still better group of them to the east of Amlwch Port [E. 10531—2], very fully exposed. They retain traces of ellipsoidal structure, but are all more or less deformed, and the southern margin of the largest one (south of Aber-cawell), with which jaspers are interbedded, is converted into a chloritic schist with granular ternary albite. The alternating facies is pronounced in this district, except in a large crescent-shaped zone to the north of the word 'Llaneilian,' which is a tolerably homogeneous grit-schist. There is fine isoclinal folding, with slightly oblique foliation, about the 'B' of 'Bryn-Eilian' (Fig. 49).

The rugged moor east of Amlwch Port (Plate LV) is perhaps even a better locality than the coast for the study of the Amlwch Beds with bedded jasper, as they are here intensely folded. Beautiful steep isoclines are to be seen everywhere, especially just outside the town, a few yards north of the end of the street called Ednyfed Hill (where, as shown in Fig. 40, they become locally symmetrical), and by the pool east of that. The repetition of the jaspers [E. 10536—8] (Plate II, Fig. 3 ; Plate XXI, Fig. 1) to the east of this pool on the

Port Moor is wonderful (Fig. 136), 40 nips having been laid down on the ·0004 maps in $\frac{1}{64}$ of a square mile. The pitch undulates, and it is probably this which keeps the jaspers away from the coast at Aber-cawell. Close to the 100-foot contour east of the 'l' of 'Brickpool' is a four-inch oval boulder of granite, and a small one of Gwna quartzite. They are not in coarse, but in fine siliceous flaggy beds, and were doubtless floated to this place (pp. 51, 303).

FIG. 136.—FOLDED JASPERS IN AMLWCH BEDS.
On Amlwch Port Moor.
From the ·0004 or 1/2500 maps.

THE GWNA BEDS OF GYNFOR,[1] PANT-Y-GASEG, AND WYLFA.[1]

Along the rugged and often lofty sea-board the Gwna Beds are finely exposed, and at Hell's Mouth are cut back into sea-cliffs 200 feet in height. The special features of the district are: the waning of their vulcanism; the fine development of the quartzite, limestone, and black beds; the low grade of anamorphism, and the feeble schistosity of the Autoclastic Mélange. The western wing, from Porth Wnol to Cemaes, may be called 'Wylfa'; the narrow eastern wing between Porth Wen and Bull Bay, 'Pant-y-gaseg'; and the central and principal portion between Cemaes and Porth Wen, by the ancient name of 'Gynfor.'

General Characters.

1.—*Vulcanism.*—The Gwna vulcanism is here at a minimum, especially in Gynfor and Pant-y-gaseg, where only one spilite is known, and that a very small one. Concurrently with this, the alternating beds (and the resulting mélange) lose the green tint which they possess everywhere else in Anglesey, and become ordinary grey grits and phyllites without any sign of pyroclastic dust. That these grey beds are but a facies is certain, for not only do the quartzites and limestones appear among them in the same relations as usual, but the green colour does not wholly disappear, green zones remaining (see below, pp. 308, 311) at

[1] Pronounced 'Gunvor,' and 'Wylva.'

Penrhyn and Porth Wen. There are a few rather coarse diabases, decomposed and ferrified, and as one of them cuts the limestone, it is probable that they are intrusive, and were albite-diabases of the spilitic suite.

2.—*Survivals of Original Structures.*—In spite of the extraordinary break-down of the group, the original bedding of the Gwna sediments is more often to be seen here than anywhere else. From Hell's Mouth to Graig Wen the continuity of the great quartzite [E. 10953—5], though its width is modified, is unbroken, and low down on the escarpment a thinner quartzite, that seems unlikely to be the same repeated, also ranges for nearly half a mile. Between them, the bedding of the Alternating group is often well preserved, and the rocks are seen to have been for the most part exceedingly even-bedded fine grits [E. 10520] with partings of grey shale. The grits are usually an inch or two in thickness, but there are many quarter- or even one-eighth-inch seams, and they often show good lamination internally as well. Near the quartzite they are whiter, and we have rapid alternations of shale and thin quartzite. The shales themselves are finely laminated, but may be gritty.

Bedding is well preserved in thin quartzites with fissile partings at the foot of the great cliff at Ogo Gynfor, just where the Ordovician conglomerate rests unconformably upon them, as will be seen by turning to Plate XXIX. Thin-bedded quartzites again survive near the end of the headland west of Llanbadrig Church, and also about 400 yards to the south of the church. On the low cliffs of Penrhyn, Cemaes, grey grits and phyllites can be seen in rapid alternation.

The limestone is for the most part wonderfully massive, especially in the large old quarry west-north-west of Gadlys (Penrhyn-mawr of the six-inch and ·0004 maps), but is finely bedded and even laminated along the south wall [E. 10518—9], where it alternates with the graphitic phyllites. The same is the case on the sea-cliff buttress to the south of Penrhyn-mawr, and in the quarry at Llanlleiana farm-lane gate [E. 10946].

3.—*Grade of Anamorphism.*—This is lower than in any other part of the Mona Complex in the Island, lower even than in a few of the Palæozoic intrusions (see Chapter XVIII)[1]; connected with which fact is the rarity of folding, a phenomenon hardly to be seen save in the graphitic phyllites and laminated limestones. Even in the autoclastic mélange, it is remarkable how much the quartz of the grits has escaped from optical strain. In Gynfor and Pant-y-gaseg, the finer material hardly passes beyond the phyllitic stage, except at the places mentioned above, where there was a little

[1] A certain amount of difficulty arises from the fact that, in Gynfor and Pant-y-gaseg, powerful Post-Ordovician movements are superimposed upon those proper to the Mona Complex. The Gwna Beds, however, are vastly more broken than the Ordovician, which without doubt rest (see p. 243, and Chapters XIII, XIV) unconformably upon them; so that the effects of the two great movements can, in most cases at any rate, be disentangled.

spilitic dust, which evidently lent itself to re-crystallisation, the product [E. 10521] being then an ill-developed Gwna Green-schist. In Wylfa, this condition is much more prevalent. It is noteworthy that when the matrix is green, it is invariably more fissile, the volcanic dust having yielded chlorite more easily than the pelitic matter yielded sericite.

4.—*Characters of the Autoclastic Mélange.*—The mechanics of this differ from those of other Gwna districts, the fragments, especially in Gynfor, being rarely lenticular, but comparatively short, blunt, sub-angular, or sometimes rounded. At the fine sections on Cemaes Bay, west of Gadlys, they are ellipsoidal or even rudely spherical, and the mélange is a characteristic pseudo-conglomerate, whose phyllitic matrix displays relatively feeble, though always some, trace of shearing. Even here, however, there are [E. 10923—4] lenticular cores, with phyllite sweeping past them, so that the rock is but a variety of the usual mélange produced under a less compressive stress. The compression towards the west was greater, but all over the district, even in Wylfa, there is a tendency to the blunt and the sub-angular.

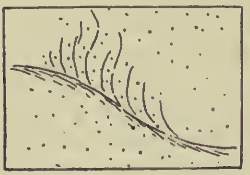


FIG. 137.
SHEARS IN GWNA QUARTZITE.
Graig-wen.

On the escarpment below Graig Wen, where bedding is well preserved, a stage in the production of the mélange is revealed. There is a cleavage at a narrow angle to the dip, yet when the beds break up, it is chiefly along a series of later thrusts at a lower angle (see p. 193), and this may happen so quickly that mélange is developed in a few yards. In the massive quartzite at Graig Wen the process begins by the development (Fig. 137) of divaricating schistose films, from which others branch off into it. In rare cases (Fig. 138) the old bedding of the thin grits holds together in a fragment. No good evidence has yet been found of a schistosity later than the brecciation.

FIG. 138.
NINE-INCH BEDDED AUTOCLAST.
Llanbadrig.

In the extended sense indicated on p. 66, the autoclastic general mélange includes not merely the alternating grit and phyllite, but every other member of the group. At many sections, especially on the headland west of Llanbadrig Church and on the heights above Porth Wnol, quartzite, limestone, diabase, and jasper, ripped away from the beds between which they originally lay, and torn and rubbed into phacoids or ellipsoids, have been driven in among the wreckage of the alternating grits and phyllites; producing a many-coloured mélange that is really indescribable, and must be seen in the field to be envisaged.

Wylfa.

The first appearance of the Gwna Beds is on the western side of Porth Wnol, where a belt of green mélange, with a little quartzite and limestone, runs across the neck of the headland between two ruptures, the Amlwch Beds being clearly thrust over them from the north. In Porth Wnol there is probably a fault with a downthrow to the east, against which the Wylfa thrust-plane runs out at a very narrow angle. The thrust (Fig. 96) is clearly exposed in the cliff, and the two green series are well contrasted.

On a great projecting buttress (Plate XXII) about 70 feet in height, which is cut by a late basic dyke, is an amazing lenticular mélange, giving a vivid impression of the disrupting forces. The resistant quartzite is seen in the act of breaking down into great rudely phacoidal masses, between which the wreckage of the thin-bedded grits and phyllites is being driven along the lines of shearing. On the heights above is a mélange hardly less extraordinary (shown in an unpublished photograph, No. 1721), large ellipsoidal cores of quartzite, limestone, and jasper, lying in a dull Gwna Green-schist with torn strips of jaspery phyllite. Similar phenomena may be seen all along the western cliffs of Mynydd Wylfa, save where a wedge of Amlwch Beds 60 yards in width is driven up through the Gwna Beds. A zone of quartzites and limestones, many of which are large enough to show upon the six-inch maps, is traceable across the headland, and there is much purple phyllite. On its high northern cliffs the phyllite-and-grit mélange is developed upon a great scale, and is intermediate in character between that of Gynfor and of the other parts of Anglesey.

In the southern of the two chasms at the 'M' of 'Mynydd' (Fig. 139) are 10 feet of a crushed spilitic lava, with two-foot ellipsoids well preserved, and plenty of scarlet jasper in the interstices. The texture in the slide cut [E. 10504] is not thoroughly spilitic, and it is possible that an albite-diabase and a spilite have been crushed together. In the northern chasm[1] is a similar rock [E. 10505], and near the north-east point of the headland are masses of dull chloritic schist with jasper.

FIG. 139.

NORTH-WEST CLIFFS OF MYNYDD WYLFA.

From the ·0004 or 1/2500 map.

MG = Gwna Mélange.
Qt = Gwna Quartzite.
G = Granite.

An unexpected feature of the Wylfa mélange is the presence of three small granites. One is on the heights above Porth Wnol, the others lying to the south and north of the southern band of spilite on the western cliffs (Fig. 139); and they are 51, 90, and three feet thick respectively. They are [E. 10422] albite-granites with a good deal of white mica, and are greatly crushed. The original junctions are destroyed, and no thermal alteration has been seen. Being albite-rocks, it is probable that they belong to the Gneisses, and are shattered nips like those of Llanrhyddlad and Mynachdy (pp. 284, 296).

[1] The sheared Palæozoic dyke (see Fig. 139) must be distinguished from these rocks.

Some clue to the extraordinary complex near the north-western point will be afforded by Fig. 139, but even the ·0004 map is but an abstract.

On the beach to the south of the Lifeboat Station are some light-coloured and decomposed felspathic beds with grey films, which closely resemble the Fydlyn rocks; and there seems no serious rupture between them and the green mélange. Eastwards by Wylfa house, the same green mélange contains dull basic schists, with a little jasper, and some jaspery phyllites.

Gynfor.

The Coast west of the Hell's Mouth Fault.—At the back of the beautiful semi-circular cove the Amlwch Beds touch the sea, and on its eastern side the Wylfa thrust-plane is exposed, the two green groups being well contrasted as before. Just above the thrust is a small nip of quartzite and limestone; and the Wylfa type of sedimentation continues as far as a point north of the 'rh' of 'Penrhyn,' where an uncoloured line runs out at a little chasm in which is a small thrust. Here the grey Gynfor type of sedimentation comes on, and the Penrhyn section is one of the best and most accessible for a study of that type. The grey grits and phyllites are largely in the state of mélange, a range of lenticular limestones and quartzites being driven into them. Yet the bedding is not utterly destroyed, and opposite the house on the cliff-edge are some overfolds from the north (figured by Matley: *Quart. Journ. Geol. Soc.*, 1899, p. 662) which only just survive disruption.

Towards the east end of the Penrhyn section, the grey beds become rapidly dull-green, at the same time shearing more, until, among the dykes, the fissile partings [E. 10521] are a true Gwna Green-schist like that of other parts of Anglesey. After we round the point into Cemaes Bay, the Wylfa thrust-plane must again run out, but it is probable that the visible rupture is a Palæozoic slip cutting it, for a dyke which is injected is in its turn sheared and brecciated.

Beyond the Amlwch Beds of Cemaes Beach, the first object of special interest is the great buttress on the eastern cliff, which is composed of limestone with much black phyllite, folded, and cut by minor thrusts; the grits and phyllites of the cliff being, apparently, driven on to it. Hence, for 300 yards, is a very fine section (best approached from the north-west headland) in [E. 10293—4] the most conglomerate-like phyllite-and-grit mélange in Anglesey; a crowd of ellipsoidal and sub-spheroidal cores of dark grey grit in a rudely schistose matrix of grey phyllite.

At the headland, between this mélange and the great limestone, is a deformed spilitic lava, some six feet thick. It seems to pass below the limestone at a low angle, soon, however, wedging out. Ellipsoidal structure still survives, and in the inter-ellipsoidal skins (now schistose) are small aggregates of scarlet jasper. The spilite [E. 10929] is slightly porphyritic and vesicular, and somewhat variolitic, the fine felspars of the matrix having a tendency to radial grouping. It is the only unequivocal spilite known in Gynfor.

The great limestone of Penrhyn-mawr (six-inch map name), the widest limestone-outcrop in the Mona Complex, is cut off eastwards by a fault with a downthrow to the south-west. It is finely exposed both on the coast, and in the large old quarry below Penrhyn-mawr, in which (except along the south wall) it is wonderfully massive [E. 10518, and analysis]. On the coast it shows bedding in several places, and about 100 yards north of the quarry's mouth some of this bedded rock is beautifully oolitic. Mélange emerges in two or three places on the floor of the quarry, and again in the cove to the north, from below the limestone. The south wall of this quarry is the best exposure of the graphitic phyllite with laminated limestones.

The little bay beyond, on either side of the wedge of Glenkiln shale, is chiefly occupied by straw-coloured phyllites and quartzites, often well-bedded, but a good deal decomposed.

The quartzite at the end of Llanbadrig Point shows good bedding, cut by curving shears; and there are some thin bedded quartzites a few yards to the north of it. The extraordinary variegated mélange on this headland has been remarked upon above (p. 306), and the general complexity is added to by a number of small Palæozoic dykes, and by late silicification, pyritisation, and ferrification. All the best sections are on the north crags. Besides the alternating beds, quartzite, and limestone, there are phacoids of typical scarlet jasper [E. 10506] (to be distinguished from some ferrified grits which are there) some of which are three feet in length, doubtless torn out of a spilite that is not now seen. Diabase of the intrusive type is also involved in the mélange. Large limestones then come on, the disruption is mitigated for a while, and between them, some 200 yards west of Llanbadrig Church, are the best exposures of the peculiar black quartzite [E. 10508] (p. 80), in beds about a foot thick.

By the old limekiln, black phyllites appear, and great lenticular masses of limestone sweep down the cliff along the foliation-dip. On their eastern margin, at the Wishing Well, is the best development of oolite [E. 9176, 10816] (Fig. 8), a lenticle 30 feet thick, and very massive.

The cliffs thence to the Ordovician are chiefly phyllite-and-grit mélange, with a faint greenish tinge. In it, north of the church, is a large, dull, basic mass, rudely ellipsoidal and probably a spilite, though no jaspers have been seen in it. Just above it a three-foot quartzite shows folding, an unusual circumstance in Gynfor. Further on, a great quartzite undulates horizontally for some 200 feet in an inaccessible position.

The Gwna rocks that underlie the Ordovician at the great Ogo Gynfor section are grey mélange with quartzites. They are illustrated in Figs. 220, 221, and Plate XXIX. But where the Complex rises once more *en masse* upon the major thrust-plane it is represented by the long limestone that runs inland to Llanlleiana farm. On the cliff, the massive parts are cut into great phacoids by innumerable curving minor thrusts at rather high angles from the north, but the thinner beds are isoclinally folded more rapidly than any rocks in Gynfor, the folds pitching westward and being traversed by a cleavage. It is locally dolomitised. One of the small but coarse diabases appears within it, the junction being transgressive and probably intrusive. On its northern margin the limestone graduates into phyllite-and-grit mélange, some of whose grits are pebbly and should be searched for composite fragments, though it is not always easy to distinguish between true and pseudo-pebbles. In the deep nook a powerful-looking thrust (Fig. 140) brings, by a curious accident of the tectonics, quartzite on to quartzite, both being contained in mélange. The end of the long quartzite on which the Ordovician conglomerate rests wedges out against the fault before it gets down to the sea.

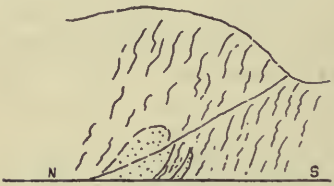


Fig. 140.
Thrust north of Ogo Gynfor.
Cliff about 100 feet.

Between the Ordovician rocks and Porth Llanlleiana, the cliff is a steep dip-slope, and the circular limestone seems to be a cake resting upon grit and phyllite. Then comes the great headland of Dinas Cynfor with its large quartzite, which widens from 30 to 220 yards as it crosses the headland. At the western end it contains a limestone, but at the eastern end (where its bedding is perceptible) no less than eight appear in it. This is probably due to repetition, for at Hell's Mouth beach a large wedge of mélange is driven up into it. The eastern section in the quartzite is nearly 200 feet in height, and is very grand, but is visible only from a boat. The Gwna grits of the escarpment below this quartzite are in places pebbly, and contain [E. 11038] fragments of ancient schists.

Inland Sections west of the Hell's Mouth Fault.—These are both numerous and excellent, and a few only, of special importance, can be mentioned. The lines are often difficult to draw, and are also obscured by Ordovician infolds. Grey mélange is finely seen to the north of Neuadd, near the boundary, and to the west-north-west of Llanlleiana farm. The larger bands of limestone are all well exposed, being for the most part massive, but in the quarry by Llanlleiana farm-lane gate there is laminated limestone with black phyllite. The quartzites are lenticular, except the long band on which the Ordovician rests west-north-west of Llanlleiana, and even this is interrupted. About 200 yards to the south of that farm one of them contains two little limestones. On a boss at the 'd' of 'Llanbadrig' (Pen-terfyn of the six-inch map) is the best example of the coarse diabases, but even this one is poorly preserved.

Gynfor, east of the Hell's Mouth Fault.—The Hell's Mouth fault, which divides the district, and is marked by alluvium and a long boggy hollow, must be a downthrow on the west, as Ordovician infolds occur nearly a mile further to the south-west on that side. But its behaviour is anomalous, for it hardly shifts the Ordovician purple conglomerate. It is discussed on p. 219. At Hell's Mouth beach, its breccia, several feet wide, is exposed in a deserted mine-level.

The junctions of the one large and two small Gwna wedges that are let in among the Church Bay Tuffs and Amlwch Beds on its eastern side inland are not exposed, but must be ruptures. The large one, being among Amlwch Beds, must be either very deep, or be thrust southward as well as ruptured. The characters of the Gwna Beds are the same as on the west.

At Hell's Mouth itself there is a junction with the Church Bay Tuffs, which is discussed on p. 160. The section in the mélange and quartzite is a magnificent cliff 200 feet in height, but, though visible obliquely from Dynas Cynfor, can be seen in its true proportions only from a boat. The quartzite, about 90 feet in thickness, runs up the cliff at a very high angle. Its junction with the grit and phyllite needs further study. Thence it is continuous all along the heights, but at Graig Wen its width is rapidly increased to 200 feet, and some green phyllites of the Gwna Beds, as well as purple ones of the Ordovician purple conglomerate, are driven into it, and its southern side (which is flaggy) is traversed by the divaricating shears shown in Fig. 137. Just beyond Graig Wen it is cut off altogether, but reappears at the natural arch on Porth Wen, where it is well bedded, and contains thin phyllites. Evidently, therefore, the widening is due to movement, which must be in part of Post-Ordovician, but is probably also in part of Pre-Cambrian date. The grits and phyllites of the escarpment, though often in the state of mélange, display bedding at intervals all the way from Hell's Mouth eastwards, as mentioned on p. 305.

At Porth Wen works all the rocks are decomposed, and, but for the purple conglomerate, it would be well-nigh impossible to separate the cleaved and sheared Ordovician rocks from the Mona Complex.

The cliffs along the south side of Porth Wen are dip-slopes, so that the rocks of the beach may rise inland. At a cave 160 yards west of Castell one may walk at low water through the quartzite, and find the grit and phyllite beyond it in an open chasm where the roof has collapsed. The eastern cliffs of the bay are sections in mélange with thick bands of limestone. One of the green bands alluded to on p. 304 in connexion with vulcanism [E. 10523] is seen in the cove south of the limestone headland near Castell. East of this headland the cliff is, for about 100 yards, a dip-slope with 'cakes' of limestone and mélange. The second green band [E. 10524—5] is well seen in a cave a few yards to the north of this cliff. Following it are flaggy brown schists, and variable mélange full of lenticular fragments of nearly all the Gwna rocks, as far as the base of the Ordovician. On a boss about 100 yards south of Castell, adjoining a large limestone, is another of the diabases, but in very poor preservation.

That the Gwna rocks of Porth Wen are bounded by a fault on their eastern side is certain, but its course and nature are uncertain. A fault that runs out in the nook east of the little limestone headland cannot bound them north of Castell ; and the boundary might be drawn along features as a winding line a little further east, and regarded as the outcrop of a nearly horizontal thrust-plane, save that the course of such a thrust in the Church Bay Tuffs to the south-east would be difficult to understand.

Pant-y-gaseg.

The Gwna Beds driven over the Glenkiln shales in the cove south of Trwyn Bychan (Fig. 95) are chiefly mélange in the cliff, but quartzite comes on at once above, and there is a black quartzite [E. 10949] at the cliff's brow. A few yards to the north, the Church Bay Tuffs are driven over them on the Trwyn Bychan lower thrust-plane.

The long narrow ridge of Pant-y-gaseg Hill is composed of grey mélange with many small nips of quartzite and limestone. This Gwna band fails to reach Bull Bay, and seems to be cut off by a small thrust which is exposed in a little cove.

Another compound zone like it lies about 160 yards to the south, but wedges of schistose tuff are driven into it ; and between the two zones lie a number of detached strips of quartzite and mélange, with purple schist, that are involved with the schistose Church Bay Tuffs. At the farm south-east of Pant-y-gaseg is a curious rock that recalls the purple conglomerate of the Ordovician, but it seems to belong to the Mona Complex. These broken Gwna bands also fail to reach Bull Bay. They are undoubtedly nips of the Gwna Beds let into Church Bay Tuffs, but it is doubtful whether the lines are drawn at the correct horizons, for some of the green rocks are bedded and may be Gwnas. They need further study, especially as light might be obtained on the local relations of the groups.

Almost on their strike, a white felsitic-looking schist is let in between thrust- and shear-planes in the Bull Bay cliff. It recalls the Fydlyn rocks (as do the white beds of the Lifeboat Station at Wylfa), but ruptures of sufficient magnitude to bring in that horizon are difficult to postulate here, and this rock also calls for further study.

The Skerries Group in the Trwyn Bychan Tract.

Hell's Mouth to Porth Wen.—Where they first appear at the Hell's Mouth fault, these rocks do not present their characteristic appearance, having passed into pale green schists, which, however, have the usual homogeneous character of the tuffs, and resemble those of the southern part of the Church Bay section towards Trefadog. At Hell's Mouth itself they rise from below the Gwna mélange. The nature of the junction, which is accessible at low water, has been discussed on p. 160. The change is rapid on the (rather high) reefs, and slower in the rocky chasm of the cliff a few yards to the east of them. A well-rolled pebble of quartzite of Gwna type [E. 11251], about three-quarters of an inch long, was obtained from the tuff on the beach. Near Bryn Llewelyn a few bedded jaspers and thin basic bands appear as we approach the Amlwch Beds.

From Hell's Mouth to Porth Wen they are well exposed on a high bossy tract; and, as Bryn Llewelyn is approached, the foliation diminishes, and the rock rapidly assumes its massive aspect, with characteristic epidosite clots of irregular shape. At the gate between Bryn Llewelyn and the chapel, also by the lane just east of the 'n,' overlooking Porth Wen [E. 10513], scraps of pink felsite can be found in the green tuff, often with re-entering curves, as of lapilli. By the roadside north of the 'a' of 'Gardwr' it contains a block of Gwna quartzite about six inches across which cannot be an autoclast, being 240 yards from the Gwna mélange. Here and there along the junction, especially at the back of Porth Wen where the formations are seen close together, the tuffs take on somewhat of the aspect of the Gwna Green-schist, as if there were a passage by increase of pyroclastic dust. Beyond the Castell fault (or thrust—if such it be—see p. 312) the tract is split by the two narrow bands of Gwna rocks, around which there are again signs of passage (see p. 312), especially on either side of the Burwen road. Between and south of these Gwna bands the tuffs vary a good deal, being sometimes a good epidosite, sometimes a green schist, sometimes rather siliceous, details of which are noted on the six-inch and ·0004 maps. Whether these be true variations in composition and states of reconstruction, or whether they be isoclinal nips and rolls bringing in the passages to the beds above and below is not yet known. All along the southern margin from the Hell's Mouth fault eastwards intermediate types are found, and the line is arbitrary within limits of some 50 yards, as might be expected from the nature of the zone of passage exposed on the cliffs of Bull Bay (see pp. 158, 315). These intermediate types are seen about Bryn Llewelyn and Bod-hunod. The tuffs are well exposed in bossy ground. The Skerries Grits have not been recognised with certainty west of Llechog-isaf. Whether they be cut out by thrusting, replaced by tuff, or overlapped by the Amlwch Beds, is uncertain.

Trwyn Bychan to Bull Bay.—Between Trwyn Bychan and the junction in Bull Bay, two miles of rugged sea-cliff afford an almost uninterrupted section of these rocks, and their great structural features are strikingly displayed upon the lofty northern crags. The dominant type is a dark-green schist with a platy foliation dipping northward at high angles [E. 9316, 10527, 11039], but it is often feeble and the epidosite scarcely sheared.

The Tuffs first appear (Fig. 95) upon the major thrust-plane which drives them southwards over grey Gwna mélange with lenticular quartzites. By descending a northward-pointing spur of cliff this thrust-plane can be finely seen in a cave, whose floor, inclined at 30° to 40°, is its bare sole, the thrust also forming a small outlier on the north end of the spur. A few yards to the north is a much greater cave, beyond which another buttress juts out, accessible by climbing down obliquely (with careful regard to foothold) along some narrow ledges above the cave's roof, and from this buttress a fine view can be obtained of the Trwyn Bychan thrust-plane, on a cliff about 100 feet in height. It is here inclined at about 8°, and is cut by a minor thrust at a higher angle, while another seems to displace it south of the cave. But these thrusts can be seen in their true proportions only from a boat (Fig. 95). On the eastern shoulder of the headland the cliff is cut back a good deal, and by descending there and turning to the left the great thrust-plane itself is accessible just where its outcrop turns round the extreme point. It is here horizontal, and the sole has a thin floor of quartz, on which are slickensides indicating that the movement was from north-north-west. In some parts there is about an inch of mylonite. For 80 yards eastwards the cliff is cut back, and the gently sloping floor of the recess, rudely triangular in plan, is the sole of the thrust with a few small outliers upon it. Then the cliff suddenly turns northward, ending the recess, and the Trwyn Bychan thrust-plane passes out of sight along its foot. Beneath it, instead of mylonite, is a zone, six to 12 inches deep, of minor thrusting (Fig. 141).

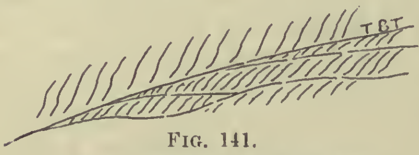


FIG. 141.
DETAIL AT THE TRWYN BYCHAN THRUST-PLANE.

Thrust after thrust now appears in the northern cliffs, and in the space of half a mile from Trwyn Bychan four more great recesses with triangular floors and vertical eastern cliffs expose their soles in the same way as at the headland. Movement is persistently from north-west or north-north-west. The outcrop of the last one turns round inland and re-appears in a chasm 147 yards further east. Between these major thrust-planes, the great sigmoidal curves into which they bend the foliation sweep grandly up the cliffs, and minor thrusts produce the same structure in miniature. On some eastward-facing crags 30 yards beyond the disappearance of the Trwyn Bychan thrust-plane, the little thrusts between the sigmoids are only a few feet or inches apart (Fig. 64), and the sigmoidal cores are traversed by still smaller ones at intervals of a quarter or even an eighth of an inch. Similar sections may be seen at many places, a good one being in the lane at Bull Bay village, south of 'L.B.' Sheets of venous quartz that lie along the foliation have been bent sigmoidally and thrust in the same way, and a two-foot sheet a little above the fifth of the great thrust-planes has been converted into a granoblastic schist [E. 10528]. This, and the fact that the thrust-planes are 'healed up' so as to become in their turn planes of foliation, show that all these are true ancient structures of the Mona Complex; though the mylonite at Trwyn Bychan points to Post-Silurian movement having taken place along a pre-existing rupture. Towards Bull Bay little is to be seen but the old foliation dipping at high angles, except certain zones of silicification, also of ancient date.

Of lithological variety there is little to record, indeed the accumulation must have been extraordinarily homogeneous, and but for the foliation it would appear almost as one solid mass, merely a little coarser here or finer there, with some short epidositic grits. Bedding is hardly to be seen, but can be traced, at a crag just east of Trwyn Bychan, for a few feet, like the local bedding of the tuffs in Church Bay. As in those tuffs, however, there are a few short purple seams, best seen at, and half a mile west of, Porth Llechog. They are to be distinguished from the zones of recent oxidation to which these tuffs are liable. The clots of epidosite, which first suggested that these rocks were a facies of the Church Bay Tuffs, are to be seen everywhere (sheared out into thin short green bands in the more foliated parts), but specially good localities are the crags a little east of Trwyn Bychan, 100 feet or so above the thrust-plane; and some bosses about 70 yards south-east of a deep coast-chasm, north of the 'll' of 'Windmill.'

Little scraps of pink felsite are generally to be found if searched for; but larger fragments, all of Skerries types, have been seen at the following places. A well-rounded pebble of granite (preserved in the Museum) about an inch in length, was obtained from schistose tuff [E. 10526 : matrix only] 60 yards south-west of the eastern 'cave.' Similar fragments, but sheared, may be seen 270 yards to the west, around the great stone chair. Fragments of pink felsite occur above the most easterly of the triangular 'soles.' Felsite and Gwna quartzite pebbles are not rare at the cliff's brow over the great cave of Trwyn Bychan, one pebble being bisected (Fig. 142) and thrust up a third of an inch along the foliation.

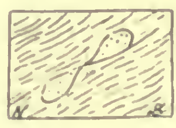


FIG. 142.
QUARTZITE PEBBLE BISECTED ALONG FOLIATION OF TUFFS.
Trwyn Bychan.

Towards Porth Llechog the tuffs [E. 1545—6, 10990] are more schistose, and there are some short pale purple phyllites, but green grits of Skerries type appear on the northern crags of the point. The western cliffs of Bull Bay afford a continuous and easily accessible section. At Porth Llechog are highly sheared tuffs that simulate phyllites, but thin grits of Skerries type soon begin to appear, and after we pass the narrow chasm about 100 yards to the south, massive Skerries Grits come on in force, with here and there a few thin fine ribs that seem to herald the Amlwch Beds, while the schistose tuff keeps on recurring in bands. On the south side of a chasm some 30 yards north of the felsite dyke a white felsitic schist (p. 312) is let in between shear-planes. It is on the strike of the wedge of Gwna Beds. South of the dyke, the Skerries Grits are again well developed, and are very massive. Then follows the fine section displaying the passage to the Amlwch Lynas Beds (pp. 158, 300), which closely resembles the passage at Llanrhwydrys cliff (pp. 158, 317).

The Skerries Grits between Llanfechell and Llanrhwydrys.

Their first appearance inland is at a knob at the south end of the Rectory garden of Llanfechell, where there is a little flagginess at the top, as if the Amlwch Beds were near. Then, just beyond the bridge at the west end of the village, is a range of good exposures, in which are [E. 11005] fragments of micro-pegmatite like those of The Skerries. That these are not on the main infold is shown by the appearance of Amlwch Beds at one or two places between them and the Bwlch road. The tract at Cromlech seems also to be isolated, but its relations are obscure.

Where the main infold is nearly wedging out, there is a section on the south side of the road at the 'Ll' of Llanfechell, which is of stratigraphical importance (cf. p. 158), for on the southern escarpment is a clear passage by alternations into the Amlwch (Lynas) Beds. Some of the best places for a study of these grits are about Bwlch [E. 8442, 9309, 10409]. There is a little bedding, crossed by the foliation at a higher angle ; but most of the grit is massive, and the fine bands are impersistent, some, indeed, being merely sheared mud-galls. At the roadside quarry the unrolled rhyolite-quartz may be obtained in quantity, there are three-quarter-inch fragments of salmon-coloured felsite, and it was from this quarry that the pebbles of old schistose grit (Fig. 2) were obtained. On the little moorland west of Groes-fechan the grits are extensively exposed [E. 10933], and there are again some impersistent fine beds. There is a southerly roll-over in them near the southern end, and as this reaches the margin of the grits for some 200 yards, it is probable that a thrust-plane runs in obliquely there. As these dips are quite local, normal northerly ones being resumed at once in both directions along the same junction, they point merely to disturbance, and are no evidence for the grits rising *en masse* on an anticline from below the Amlwch Beds. At the interesting ancient farm-house of Mynydd-ithel are good exposures, and across the river to the north-west Amlwch Beds appear in their turn on a southerly dip as if rising on an anticline within the grits. Southerly dips occur again to the north of Pen-yr-orsedd, but the usual northerly direction is quickly resumed. These dips to the south may be due to a refusal of the stubborn, unstratified mass to conform to the general isoclinal folding of the region. But there are south-easterly bedding-dips at Caerau, so they are more likely to be due, as is the case in Holy Isle (see pp. 208, 262, 277) to deflection about large unseen basic intrusions, of whose existence here (see p. 321) there can be no doubt. Between Pen-yr-orsedd and Plâs-cemlyn are pebbles, usually deformed, attaining a length of three-quarters of an inch, most of which are salmon-tinted felsites, but with hypabyssal acid fragments like the great boulders of the Skerries, and fine quartzites of Gwna type, as well as films of grey schist which appear to be reconstructed mud-galls. Some of the grit is like the epidositic Trwyn Bychan tuff. There are good exposures also at the east end of the lagoon [E. 10937]. On the stack in the bay near Craig-yr-iwrch the grits are very pebbly, containing [E. 10384] Gwna quartzite and jasper as well as the acid igneous fragments, and also old mica-schists with a foliation oblique to that of the enclosing rock.

The finest section through the Skerries Grits upon the main Island is where they run out to sea below the drumlin on Llanrhwydrys cliff. They are not so coarse here as they are inland, but the usual fragments can be recognised. The section is of the first importance, and has been briefly described on p. 159, on account of the conclusive evidence to be seen at its southern end of a passage from the Skerries Grits into the Amlwch Beds. The position is in the north cliff of a creek, just beyond a dyke and a small fault which drops the Skerries beds a little. Along the cliff's foot emerge the Lynas beds, flaggy grey-green phyllites with alternations of thin hard grits. Then the coarse massive Skerries Grits come on, with flaggy phyllites in them at intervals. Further up, at the turning of the cliff, there are still some fine beds, but they are now impersistent, ending irregularly by contemporaneous erosion. Towards the east end of the section the phyllites reappear, but the coarse grits are thrust on to them again. Finally, at the end of a beach, there is (beyond an obscure dyke) a crush at a cliff's foot, and the Amlwch Beds come on *en masse.* But the thick phyllites of Henborth are not present, and there is no sign of passage, so it is evident that the Amlwch Beds are driven over on a thrust-plane. How the grits have narrowed north-westward from Pen-yr-orsedd can be seen upon the map. Now, at the south end of the sea-section the dips turn round upon the foreshore, and become south-easterly, so it follows (see pp. 177, 218) that the great compound isocline of the main infold is rudely boat-shaped, and that its base is rising seawards.

The Three Mouse Islets.

The Middle Mouse.—As this differs from the other two, it will be considered first. Most of it is composed of pale green phyllite [E. 9318, 10509—10] with bands of hard fine green grit, and a few seams of jaspery phyllite ; undoubtedly the Lynas division of the Amlwch Beds. The foliation crosses the bedding, and as it is rather feeble, the original nature of the sedimentation of the series can be studied better on this islet than at any other place. As well as the fine grits, there are some rather thicker and coarser purple-green ones. At the east end a very massive bed of the same type (mentioned on p. 158) rises, but it is pebbly, and very ashy-looking, with mud-galls and fragments an inch or two in length. The matrix is chloritic, but the galls and many of the pebbles are purple-stained ; and the rock recalls the Tyfry Grits, as well as those of the Baron Hill outlier, or even the Arenig conglomerates of the Tywyn Trewan, which often resemble them. The fragments include spilite, albite-trachyte and keratophyre, rhyolitic albite-felsite, bedded gritty tuff with fragments of keratophyre, micro-pegmatite with porphyritic albite, Gwna quartzite, and quartzose schists with an old foliation [E. 10511, 9319—24]. This grit must be regarded as an exceptional development of the Skerries Group.

The West Mouse consists of a massive, hard, grey-green grit, of much the same type as that of Llanrhwydrys. There are patches with small pebbles of the kinds always found in the Skerries Group, but most of the rock is comparatively fine. North of the Beacon good even bedding is to be seen, while a rude foliation dips in the opposite direction, and there are a few purple streaks. The grit belongs without doubt to the Skerries Group [E. 10572—3]. Two lines of late crushing cross the isle from east to west.

The East Mouse is composed of a schistose but massive epidositic ashy grit of the type found at the junction of the Church Bay Tuffs and Skerries Grits, showing that the zone strikes eastwards along the sea-floor towards Point Lynas. There are a few purple seams, like those about Porth Llechog. The greater part is rather fine, but on the southern escarpment the greenish mudstone clots run together into rude anastomosing bands [E. 10539]. The foliation dip is high, but there are southward thrust-planes at lower angles, producing sigmoidal curves like those of the Trwyn Bychan tract, though less powerfully. Here and there the fine tuff contains curiously isolated pebbles, but on the southern escarpment is almost a conglomerate, with many pebbles [E. 11253—65] an inch or two across, and ranging up to a foot or more, among which are quartz-felsites, micro-pegmatites, hypabyssal granitoid rocks of the kind so abundant on The Skerries, old greenish grits, and Gwna quartzites. The grits and quartzite, one of which latter [E. 11253] is six inches in diameter, are much more numerous than in the Skerries conglomerates. The igneous pebbles are deformed, but the sedimentary ones often retain their original rounded water-worn form. There are bands of coarse grit with fragments of quartz-felsite about as big as peas, and many that are merely felsite-quartz with a little matrix adhering. A very little more disintegration would furnish the unrolled felsite-quartz (p. 59) so abundant in the Skerries Grits.

The Skerries.

This remote and rugged little archipelago (Plate XXVI and Folding-Plate XIV, from which the place-names here used are taken) comprises no less than 17 islets, all but two of which are accessible at low water (some, however, for a short interval only) from the lighthouse island, and that is connected with the other large island by a footbridge. No one who knows the rocks of Anglesey can have a moment's doubt that the Skerries rocks belong to the Mona Complex, or that they, the grits of the Llanrhwydrys infold, and those of the Trwyn Bychan tract belong to one and the same member of the series. All three have the same petrological peculiarities both on the large scale and the small, and the same peculiar pebble-contents. But as The Skerries are

The Skerries. From near Carmel Head.

[*Face page* 318.

by far the most interesting of the three, and have furnished much more decisive evidence as to the chronological order of succession, their name is the best that can be given to the group.

The rocks are intermediate in character between those of Bwlch and Trwyn Bychan.[1] Those of Bwlch are ashy grits, those of Trwyn Bychan gritty tuffs. In these, the gritty and the epidositic-ashy matter are more nearly balanced. The typical grit of The Skerries is extremely massive and tough, with tints varying from grey to dull olive-green, but is nearer to the Bwlch than to the Trwyn Bychan type. The greater part of it is perhaps not quite so coarse as that which is prevalent at Bwlch, but both coarser and finer varieties are frequent. Sub-quadrangular rhyolite-quartz may often be observed, and volcanic fragments abound in all the slides. The matrix is full of epidosite and white mica, with crystalline grains of epidote as well. The massiveness of the formation all over the islets is remarkable ; but local bedding has been observed in some five places, where short bands of mudstone or the disposition of pebbles render it perceptible, especially on the little northern peninsula and on Ynys Arw, dipping at high angles to the north. By the deep cleft in Ynys Arw these mudstones are undoubtedly true beds, and in place. But elsewhere (and they are seen in many places), especially in the conglomerates, they are broken up, rolled, and cut off in such a way as to show that contemporaneous erosion is the cause, not cataclastic deformation. The best locality is on the south cliffs of Ynys Arw.

Four series of dynamical divisional planes can be distinguished, viz., foliation, thrusting, jointing, and faulting. The foliation is, except in certain zones, rather less intense than it is at Bwlch, but is accompanied by good mineral reconstruction in epidote and mica, dips being at high angles to the north. The most powerful deformation is at the Lighthouse garden, where boulders of granite have been rolled out into long lenticular strips as in Fig. 3, p. 61, and internally sheared as well. On the western cliffs north of the footbridge a one-third-of-an-inch quartz-vein that cuts the foliation at right angles is itself shifted many times along it, thus revealing a second movement along the same planes. Thrusting, also from the north, but at lower angles, crosses this foliation. Two thrust-planes traverse Ynys Arw, and others may be seen on the Lighthouse crag (Fig. 143), but the most powerful thrust-plane is that along which a little sound has been eroded, isolating the Toucan, the peninsula, and Berchan. The grits are mylonised upon it, their epidosite flowing into streams in which the deformed quartz-grains float.

Fig. 143.
THRUSTS CUTTING FOLIATION.
The Skerries.

[1] A suite of 19 slides [E. 10579—98] (Plate II, Figs. 4, 5) has been cut from the grits and boulders of The Skerries.

The most conspicuous series is a system of jointing with south-easterly and north-easterly dips, that simulates bedding. It is not a pure jointing, for at the north end of the large 'footbridge' island and on the northern peninsula some feeble crushing has been observed, and it is older than the Palæozoic sills, which are injected along it. Finally, there is a system of late faults trending approximately north and south, which have initiated several of the little sounds.

Isolated pebbles may be found anywhere, and beds of conglomerate occur all over the islands. The nature of the pebbles is much the same everywhere, but it may be mentioned that the two-inch pebble of Gwna quartzite was found on the south slope of the Lighthouse crag, and the best one of Gwna jasper under the wall on the eastern side of the garden. Ten beds of conglomerate have been laid down upon the '25-inch' (·0004) maps; a broad one on the southern cliffs of Ynys Arw and on Flood Point islet, five thinner ones at the Lighthouse and garden, one on the south point of the footbridge island, one on Cave Point, one on the little northern peninsula, and one on the Toucan. The broad zone on Ynys Arw is the great boulder-bed alluded to, and is the most remarkable zone in the islands. On the west cliffs of the deep cleft internal bedding can be seen in it, but the great granitoid boulders are upon the brows of the southern cliffs.

Basic Intrusions of the North.

These include serpentines, ophicalcites, dolerites, and amphibolites, and are known at 13 places in the Northern Region. The intrusion of Mynachdy is exposed on the coast, at a pit north-east of the house, and by the stream that comes out of the marsh. It is really a small complex, composed of true serpentine, ophicalcite, amphibolite and dolerite. On the coast amphibolite and serpentine cling to a cliff of baked Amlwch Beds, and in the floor of the nook serpentine and variegated ophicalcite rudely alternate in five- or six-foot bands, often schistose. It is here that the garnet-serpentine [E. 10996] with stars of antigorite is found. In the pit, green serpentine again alternates with ophicalcite, and there are obscure dolerites. The pit was worked for asbestos, which may still be seen there and in blocks in the farmyard walls. Three specimens examined had the refractive index of chrysotile, but the serpentine may contain tremolite as well. By the stream the Amlwch Beds are powerfully baked, and as contact-spots in the baked rocks on the coast [E. 10939] are slightly frayed out and cut by strain-slips, the intrusions must be ascribed, as in Holy Isle (pp. 109, 208—11), to an interval in the great movements.

The four intrusions of Caerau [E. 10948] are dykes, with chilled selvages. They were coarse dark ophitic dolerites, but their augite survives only as cores within green hornblende. Their felspar, now very decomposed, was an andesine-labradorite. The two intrusions west of Cefn-coch resemble them, but seem still more amphibolised. These intrusions also are surrounded by induration-halos, well seen at Caerau. The indurated sediments [E. 11343] are highly altered. Clastic quartz survives, but the matrix is almost wholly transformed into white and brown micas, in well-formed plates as much as ·25 millimetres in diameter, which lie in all directions, accompanied by cubic iron-ores and a little tourmaline. Some beds are crowded with pseudomorphs that resemble andalusite, but they are indistinct in thin section, and are now chiefly composed of white mica. This alteration is much too intense and too extensive to have been produced by the visible dykes, and must be ascribed to a much larger (and probably gabbroid) intrusion of which they are apophyses, now either buried or completely removed by erosion. The original bedding of the Amlwch Beds is well preserved, the indurated rocks are but faintly schistose, and small shifts that cut the junctions are 'healed-up,' so these dolerites must also belong to an interval in the great movements, are probably connected with the serpentines, and may be equivalents of the gabbros of the Strait of Holy Isle. The preservation of their augite is doubtless due to the protection afforded by the wide indurated mass in which they enclosed themselves. To an unseen member of the same suite of intrusions is to be ascribed a zone of schist at the foot of the north cliff of Porth-newydd (six-inch map), the beach at the north boundary of the Ordovician of Mynachdy [E. 10383], full of pseudomorphs about one-eighth of an inch in length which lie in all directions, but are sometimes frayed out along the foliation. They are now composed of mica, chlorite, and delessite, with some quartz, but show good cross-sections as of an orthorhombic mineral with combinations of pinacoid and prism, and are zonal, so that they may be referred with confidence to andalusite.

At Cefn-coch Mill there is a good tremolite-schist, on the strike of which an ophicalcite has been quarried. About half a mile south-west of Llanfechell is a green serpentine intimately associated with a purple-red ophicalcite [E. 10938, 11018—20, 11025, 11034], which comes on in mass along its northern side and contains antigorite-stars among the carbonates. Two more ophicalcites lie to the south of it and are exposed in the lanes. All these rocks are schistose in parts. At Tre-gele there is a massive limestone [E. 515], purple-red but variable, with serpentinous patches and a bright green antigorite, best exposed in the garden of the chapel-house. At Hafod-onen is a similar limestone full of grains of serpentine, with a little talc. Some of it is bright red and rather hard, simulating jasper. Parts of the carbonate-mosaic [E. 10388] show very clearly the mesh-work structure of serpentinised olivine, picked out in hæmatite, thus revealing that the limestone is a second pseudomorph of a peridotite. At Tyddyn-dai is a larger mass of the same kind, in which is a band of tremolitic serpentine. The carbonate is (see analysis) dolomite, so probably all these hæmatite-ophicalcites are dolomitic. The intrusions of this suite are on or near the horizon of the Bodelwyn beds.

THE MIDDLE REGION AND ITS INLIERS.

Gneiss of the Middle Region.

The Southern End.

The only place where this is known to the south of the Holyhead Road is in the ravine at Bryngwran, and the exposures are poor. At the Treban fault by the main road north-east of Fach is a strong feature, at whose foot the gneisses are crushed. Between Treban and Caerglaw, opposite the alluvium, a feature again overlooks the road, but on the southern side, and the crag is composed of mica-hornfels, considerably crushed. This locality is important (see p. 162), for, only 65 yards away on the north side of the road, gneiss appears, with abundance of granitoid matter. On the south side granite is sharply delimited from hornfels, but on the north graduates into gneiss. This gneiss [E. 9189] is thoroughly foliated, whereas the structure of the hornfels is crystallisation along bedding. Finally, the gneiss is an albite-oligoclase-biotite rock, rich in sphene and apatite, thus differing completely from the composition of the hornfels. Just east of this, a wedge of acid gneiss runs up into the basic. It is quartzose, with sillimanite [E. 9807, 11393] 'faserkiesel' being visible on the rough weathered surfaces. A high boss 350 yards north-north-west of the 170-foot level is the place where sillimanite was first found in Anglesey, but much richer localities are now known.

Allor.

Between Treban and Clegir-mawr (which may be called the Allor tract, from the conspicuous Craig-yr-allor or 'Altar Crag' a little north of the alluvium) is the finest development in the Island of the hornblende-gneiss, all whose phenomena can be studied with perfect ease upon its crowd of rugged bosses. Some sections have been already described on pp. 131—3; but it may be convenient to add here a list of the best localities for study. The old unfoliated mottled rock [E. 9905] (Plate XII, Fig. 4) is best seen 500 yards north by east from the road-fork at Clegir-mawr and on the top of a large boss at the south end of Werthyr alluvium; and its drawing-out, with tracts of white albite (Fig. 12), at the 'T' of 'Pandy Treban,' near the north end of a long crag, facing the alluvium. Typical banded gneiss is everywhere, but the summit of Craig-yr-allor [E. 8479—82, 9803, 10729] (Plate XII, Fig. 1) shows it grandly; folded, on a north-west strike, with epidote, knots of coarse albite, and a little microscopic pyroxene [E. 10729]. Another excellent section is at a quarry 320 yards north by west from Clegir-mawr. The strips of biotite-gneiss [E. 11187—88] are frequent, and the largest are shown upon the one-inch map. On the eastern side of the south bay of Werthyr alluvium a gneiss with pale biotite

[E. 11378] contains abundant sillimanite in its quartz, and there is a similar band west of the road-fork of Clegir-mawr [E. 6101,] which points to these inclusions not being products of the basic magma, but xenoliths of the gneiss-proper. Perhaps the best exposure of an albite-pegmatite is at a small quarry (Plate XIII) close to the fork in the lanes west-south-west of Clegir-mawr; and the borders of coarse hornblende are well-developed on the boss west of this one, as well as at the quarry 320 yards north by west from Clegir-mawr. For others see Figs. 13, 14, 15. The great 'plutonic breccias' of Figs. 16, 17, 18 are on the south-eastern side of a lofty boss about 320 yards west of Clegir-mawr. Though the basic mass as a whole has a north-east to south-west trend, the strikes within it are extremely variable. The terminating fault on the north-east is conjectural, and an alternative line is added on the six-inch maps. Late mylonitic films may be seen anywhere.

Llandrygarn and Gwyndy to Llechcynfarwydd.

At Llandrygarn, the primitive black basic nodules with shells of pegmatite are at a boss 160 yards south-south-west of the Church, and the rude hornblende-gneiss produced by their drawing-out [E. 6102] is seen at an escarpment near the south end of the farmhouse just across the little alluvium to the north-west.

The only place where potassium-felspar has been found in the gneisses is at a large quarried boss 100 yards east by north from the church, in a biotite-gneiss of most unusual character, containing porphyroblasts an inch or more in length of clear white orthoclase, which are Carlsbad twins. The felspar of the body is albite-oligoclase. This rock has therefore affinities to the Coedana granite, and, as that is exposed on the strike to the south-west with only half a mile of covered ground between, is likely to be due to permeation from an apophysis of it. Turning for a while westward: in the long train of knobs to the south of Clegir-gwynion almost every variety can be seen, with amphibolitic lenticles as well. Whether the granites in it belong to the Coedana group or to the gneissic series is not yet certainly known, but that of the great boss at Clegir-gwynion is an albite-rock. Another granite sill is exposed at Treferwydd. A quarry by the roadside at Pen-yr-orsedd, though not very good as a structural section, owing to late crushes, is perhaps the best collecting-spot in the region for the normal quartz-albite-biotite-muscovite gneiss [E. 9951], which is very fresh (though the biotite is chloritised). There are white-mica pegmatites, and a little sillimanite. North and east of this are good exposures, with 19 lenticular hornblendic masses, the larger of which are shown upon the one-inch map, but they often simulate the biotitic rock, and only a drastic search will reveal the true proportions of the two, especially as there is a light-grey type containing both minerals [E. 1637—8]. South of the road, between the two farms, are hornblende-pegmatites with albite-oligoclase; and the most southerly bosses near the dyke afford very clear sections with irregular inclusions (Figs. 19, 20) in a coarse oligoclase-granite. The lines about here were often perplexing to trace, on account of the variable dip and strike, together with the uncertainty of the types themselves. North of Gwyndy, between the roads by the School, is heavy crushing, both mylonitic and brecciating, and some hornfels is involved with the gneiss in this, so that the granite wedges probably belong to the Coedana intrusions. But most of the rock seems to be crushed gneiss.

The large bosses to the south of Gwyndy are of gneiss, coarse and granitoid, with a few siliceous seams. The granitoid matter frequently graduates into the gneiss, among which it may make its appearance along the strike by decrease of quartz and micas, and increase of albite. The strike changes rapidly. The best sections in the whole Island for a study of the structures of the gneiss are the escarpments that overlook the Llynfaes road immediately to the south-east of Gwyndy. They have been described and figured on pp. 141—2, and display perfectly the four highest stages, i.e. lenticular interfelting, permeation, granitoid gneiss, and gneissoid granite. It is hoped, however, that collecting will not be attempted here. Clear though the exposures are, the rock is decayed, so that good specimens will not be obtained, and the attempt will merely injure one of the finest sections in Anglesey.

On the slopes below Llechcynfarwydd Church the gneiss is but moderately exposed; but the large boss at the 'yd,' 617 yards east-south-east of the church, in the angle between the road and the farm-lane, from which came the specimen analysed [E. 9939], and also E. 1635, is one of the most interesting in the Middle Region. Lenticular interfelting is well seen, with albite-oligoclase-pegmatite. But the body of the gneiss is richer in sillimanite than any in the Island except those of the Nebo coast. It is chiefly in 'faserkiesel,' and large parts of the rocks are much richer than the specimen that was analysed. Garnet also is more plentiful here than anywhere else, the crystals weathering brown, and into hollows.

Henblâs to Mynydd-mwyn-mawr.

The picturesque rocky tract about Henblâs is notable as the great locality for the banded gneisses. The material [E. 9666—71] into which the granite-bands [E. 9458] have come, is chiefly 'B. C.,' *i.e.* the granular and flaky biotite-gneisses, but some 150 to 200 yards west of the house a good deal of the siliceous 'A' type [E. 9950] is present also. On a steep escarpment about 150 yards north-west of the house, overlooking a deep drain, is a fine section in lenticular interfelting with an approach to permeation [E. 6106]. Though banding is seen to the west, the great banding sections are on escarpmental bosses looking southwards (Plate XV), which will be found between 100 and 250 yards north of the bridge where the lane from Sherry crosses the brook. All the banding phenomena of pp. 139—140 are here clearly seen, but the rock is not as fresh internally as it looks, and the banding sections should not be injured by attempts to collect from them. The albite-granites are very simple (those laid down upon the map are exceptionally thick, and are not the bands of the 'lit-par-lit' injection), but the intervening gneiss varies, being locally garnetiferous and containing abundant apatite. Much of it also is a pale hornblende-gneiss, in which are some of the large crystals of sphene. About 320 yards north of the bridge the regular, even, 'lit-par-lit' injection disappears, and the granites anastomose, running together into knots, in which they are apt to become coarser. In these there are inclusions of the gneiss (both biotitic and hornblendic), but the granite-margins are here somewhat nebulous, and permeation is beginning to set in. Lewisian and Eastern Sutherland types are both present. There is a little folding, but not on any ascertained plan. The dips about Henblâs are for the most part northerly and low, but the direction varies a good deal in places. The basic mass west of the farmhouse contains [E. 9945] a zeolite which Dr. H. H. Thomas refers to natrolite. It is a true anamorphic product, and may be almost original.

The small basic masses west of Mynydd-mwyn-bach are pale foliated diorites [E. 9986, 11383] with the large sphenes. Good exposures occur again at Mynydd-mwyn-mawr, the types being largely granular with some flaky, and many small hornblendic lenticular masses. Garnet, unusually fresh [E. 6107—8, 11384], with well-preserved brown mica, is abundant in some albite-gneisses [E. 9991—2] that contain also oligoclase. Lenticular interfelting is the chief mode of granitoid injection. The dips are high and the strike changeable.

Gneissic inliers of the Middle Region.

All of these are essentially of the same nature as the main tract itself.

Cae-howel.—Lenticular interfelting and incipient permeation prevail here, the granitoid element being rather coarse; and there are a few small amphibolites. In several places there is an epiclastic aspect, as though remains of the Ordovician conglomerates were still adhering to the surface, especially between Cae-howel and the alluvium. But the fragments may be cataclastic. *Penrhiw.*—This is a micaceous permeation-gneiss, granitoid in parts. A coarse vein south-east of the house contains large crystals of pink orthoclase, as if the Coedana granite were present. *Ty-hên.*—There is a good deal of the fine siliceous type, and also some very micaceous bands. *Tai-uchaf.*—The inlier to the north-east is of coarse gneiss. *Llyn Traffwll.*—The perplexing little 'complex' on the western shore, near the church, contains two inliers of granitoid gneiss, with a sill of gneissoid granite in the northern, and knots of amphibolite in the southern one. As the difficulties of the sections arise from the relations of these to the Arenig conglomerates and the diabase sill, the 'complex' is discussed under those heads (see Chapter XIV). *Llanerchymedd.*—The large inlier of Bryn-gwallen [E. 1632—4, 9800, 10722, 9808] is composed largely of the lenticular flaky type, with both micas, but the granular type is also present, and there are granite sills. Near the south end there is banding. East of the north end of Ty-croes lane a hornblendic gneiss contains very fresh brown biotite. Where the lane joins the Llanerchymedd road abundant sillimanite is present, and in a quarry by the roadside at the bend a granitoid gneiss contains green pseudomorphs probably after garnet. The two small inliers east of this one are obscure. The three to north and west resemble it, there being good banding at the south end of the north-westerly one. The one north of Chwaen-bach is granitoid, as is the small one in Chwaen-goch farmyard. The last one of all, west of this, is a gneissoid granite.

Basic Gneisses near Llangwyllog.

The long train that follows the margin of the Coedana granite from the railway to Llanfihangel-tre'r Beirdd [E. 6099, 6103—5, 10735—6] is not well exposed, the best exposures being by the railway, by Ynys-goed, north-west of Bryn-goleu, and south of Plâs Llanfihangel. By the railway strikes are locally north-west. The rest of the way the dips are for the most part at high angles off the granite, but the relations with the adjacent rocks are not seen, save that south of the Plâs a quartzose gneiss appears on its southern ridge, which may be a re-action rock with the Penmynydd schists. For the most part the basic band is fairly foliated, and should be called a hornblende-gneiss, but is a massive diorite at some places near the north-east end. Near Plâs Llanfihangel it is a hornblende-albite rock occasionally rich in sphene, rutile, and apatite, and with large decomposing garnets. It is thus allied in composition to the basic gneisses of the Middle Region and the Nebo Inlier. But epidote and zoisite abound, and the albites are partly saussuritised, so that its condition resembles that of the basic gneiss of Holland Arms.

Gneiss of the Nebo Inlier.

In this inlier, conveniently named from the great smooth hill of Nebo, the gneiss attains its greatest elevation (550 feet), but the hill itself does not furnish good exposures, decomposition being strangely advanced for a mass that has been able to survive as a monadnock (see Chapter XXXIV) ; and there are far better crags on the 300-foot platform between it and the sea. The coast, however, is an excellent though not lofty section, interrupted only by the wedge of shale at Porth Helygen. All the gneissose types are well represented, the flaky ('C') type being dominant as usual.

The Interior.

The best section in basic gneiss is by the alluvium south-west of Pensarn,—a foliated biotite-diorite, passing into hornblende-gneiss with pegmatitic seams. A foliated granite lies beside it, and the small one to the north of that shows transgressive junctions. The great sphenes described on p. 130 are in a hornblende-albite-biotite-gneiss [E. 10850] (Plate XII, Fig. 2) rich in ilmenite and in large broad apatites, collected by Blake, who remarks on the sphenes. The locality is given simply as 'East of Parys Mountain,' and has not been identified. None of the large granite sills reach the coast, but can be studied easily, a good locality being by the Nebo thrust-plane at Plâs-uchaf. They, and also the thin sills on the coast, are albite-granites with much oligoclase, and are therefore, like those of the Gader Inlier, to be referred not to the Coedana but to the gneissic suite. The Gneisses are well seen between this and the Rhos-mynach farms, unusually fresh rose-coloured garnet [E. 10267] being abundant on a small boss 300 yards south-east of Rhos-mynach-fawr. Graphite can be found at the farmyards of Rhos-mynach-isaf. The forsterite-limestones [E. 204, 10264—6 and analysis, 10568, 10842] are exposed at some barns south of the 'B' of 'Bryn-fuches,' also at a quarry[1] 300 yards west-north-west of that house, and at three bosses on the limestone band that runs from Rhos-mynach-isaf to the northern boundary of the inlier.

The Coast.

The Coast (which should be visited at low water) will be described best by beginning first at the south end and then at the north end, proceeding in each case as far as the wedge of Ordovician shale at Porth Helygen beach. It is unfortunate that, except the siliceous bands, the rocks are deeply decomposed all along, for they are the most beautifully crystallised and mineralogically the most interesting in Anglesey.

So soft are they as to be easily crumbled by the fingers, and hammered fractures are absolutely useless, but the structures and many of the minerals can be clearly seen and studied on the sea-washed face. In addition to this decomposition they are, for nearly a quarter of a mile on either side of the Old Red Sandstone, stained to a deep red colour (see end of Chapter XXI).[2]

Southern portion.—The rock that rises on the Nebo thrust-plane is a straw-coloured flaky gneiss with lenticular pegmatites, among which thin siliceous seams quickly appear. Then, banded granular ('B') gneiss develops, and keeps on alternating with the flaky ('C') type as far as the stream's mouth north of the Old Red beds; some sharp folding repeating the bands. There is not space here for the details, but all can be clearly seen at low water, and are of the nature indicated. Sillimanite can generally be found in the flaky gneiss, usually in the micas rather than in quartz, but good localities are:—270 yards from the Nebo thrust-plane, in a straw-coloured micaceous gneiss [E. 10269]

[1] It is nearly certain that E. 204 came from this quarry, as it is labelled 'Bryn-fuches.' It was collected many years ago, probably during the one-inch surveying.

[2] Nevertheless, the slides E. 9527—52 have been made with such care and skill by Mr. Rhodes that the characters come out with unexpected lucidity.

(nearly all whose white micas are, as all along this coast, bleached biotite); and a reddened gneiss [E. 9529] (Plate XII, Fig. 3) at the end of the fir-tree fence that comes from Bryn-fuches, just a quarter of a mile from the thrust-plane. The latter is perhaps the richest sillimanite rock in Anglesey, and the mineral occurs in sea-green aggregates quite unaffected by the staining and decomposition. Beyond the stream's mouth aforesaid, the rocks are rather less interesting, save that the pegmatoid lenticles are well seen. There are some that seem to have been diorite, but utterly decomposed; and the section is traversed by a zone of brecciation, as well as by many mylonising thrusts. The graphitic gneiss alluded to on p. 136 is close to an old copper mine, which raises a suspicion that the graphite may be metasomatic and of Palæozoic date. At the south end of Helygen beach is an ill-foliated rock, with green pseudomorphs, probably after idocrase.

Northern portion.—Beginning again at the north end of the inlier, the rock that rises from the great Gwichiaid slide is a rough granular ('B') gneiss, which, beyond a heavy rock-fall, is driven sea-wards on a very steep thrust over a flaky one with sillimanite. The two types (with lenticular pegmatites) keep on being brought against one another by thrusts and slides as far as the headland, where the zone of calcification (see Chapter XIX) is about 100 yards in width. South of this, beautiful sillimanite-gneiss comes on, in which a zone of hard siliceous ('A') type (some of which is dark with hornblende) occurs. Granitoid matter now appears, and we pass into a permeation-zone, in which (as on the coast of the Gader Inlier) all the four higher grades are developed in the course of a few yards (Fig. 144). But here the sills of gneissose granite are never more than a few feet thick.

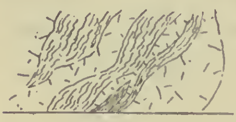


FIG. 144.
SMALL GRANITOID SILLS IN THE GNEISS.
A few yards north of Porth Helygen.

South of this, is the most interesting part of the whole coast-section. The positions may be obtained by reference to the mouth of a streamlet, not shown on the one-inch map, which is nearly opposite the top of the 'P' of 'Porth.' On the north side of this little stream is the first of the beautiful sillimanite-biotite-idocrase gneisses [E. 11391], and at its mouth is another zone of granitisation. A yard or two southwards is the most beautiful crystalline rock in Anglesey, a coarse flaky gneiss with large micas, and full of sillimanite, rose-garnet, and green idocrase. Some seams are almost half composed of silky sillimanite, but through much of the rock it is in radial groups, whose crystals are almost columnar. The outcrop is not convenient of access, being chiefly on the floor of a little nook. Similar gneiss, in which are pegmatoid augen with biotite and sillimanite, but without the rose-garnet, follows; and about 70 yards from Porth Helygen beach a group of thin siliceous bands of the 'A' type rises, some of which have a very clastic aspect, though no clastic grains are to be seen in thin section. They lie between seams of the highly crystalline idocrase-gneiss.

In these remarkable crystalline zones[1] (Plate XII. Fig. 5) are one or two gneissoid granites two or three feet thick, and many thin ones, which constitute a yard or so of banded gneiss at one place. The section ends, at the north end of Helygen beach, with a reef of most beautiful sillimanite-idocrase-gneiss, brilliant with large bleached biotites, and full of thin lenticular pegmatites. The sillimanite is in stellate groups.

The Coedana Granite.

The only places where this granite is visible on the western coast are the north side of Careg-lydan, a reef accessible only at dead low water; and the little crags to the south of the 'Ff' of 'Fferam,' where a ten-foot sill [E. 9904] (with some isolated phacoids) runs through the hornfels. It is heavily crushed. At Pensieri [E. 9907], and again by Drudwy mill, are two of the marginal white-mica-granites. Near the north end of Llyn Maelog are inclusions of dull-green hornfels. By the lake-end the granite is porphyritic, and this is a good place to study the peculiar nature of the phenocrysts, but in the railway cutting close by the same type [E. 9460] is in a fresher condition—fresher, indeed, than at any other known exposure. Porphyritic structure is also frequent about Plâs Maelog and Neuadd. Thence there are frequent exposures, the type being for the most part normal [E. 9943—4] (though a fine pink white-mica-granite with orthoclase, microcline, and albite occurs 540 yards north by west of Dyfria), as far as Ceirchiog and Tre-ddolphin, at which place are some obscure dioritic rocks that may be xenoliths.

The xenolith west of the Ceirchiog Smithy is cut by countless veins and sills of granite, ten being laid down upon the six-inch maps, and the relation of several exposed in the quarry east of the farm-house. On the bosses between it and the Smithy thin fragments are enclosed in the granite. On the heights that overlook the south side of the Holyhead road about half a mile west of Caer-glaw, the great xenolith of mica-hornfels is traversed by some 14 sills, and on the westward slopes the relations of the Coedana granite are to be

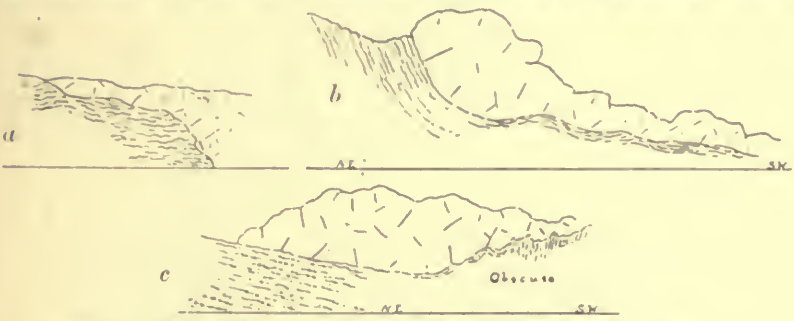


FIG. 145.—GRANITE SILLS IN MICA-HORNFELS.
Heights on south side of main road, quarter to half a mile west of Caer-glaw.
Lengths: a. six feet; b, c, ten feet.

[1] E. 9533—4, 9527—8, 10835, are some of the best slides, with sillimanite.

seen in admirable sections (Figs. 145—8), the best that are known in the Island. The sill-relation is dominant, but veins also cut the bedding of the hornfels at high angles. The granite [E. 9804] is an albite-white-mica type, and is not porphyritic, but it is here

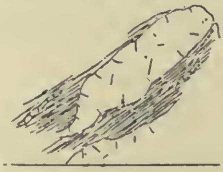


FIG. 146.
FOUR-INCH GRANITE SILL IN MICA-HORNFELS.
Same locality as Fig. 145.

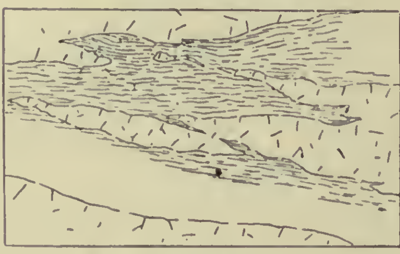


FIG. 147.
GRANITE SILLS IN AN INCLUSION OF MICA-HORNFELS.
Length: Two to three feet.
Same locality as Fig. 145.

FIG. 148.
SIX FEET OF GRANITE VEIN IN MICA-HORNFELS.
Same locality as Fig. 145.

that the felspar of a micro-pegmatite has been pseudomorphed in white mica, suggesting that orthoclase has been present. By the riverside east-north-east of Y Werthyr a sub-basic diorite appears in the granite, which again traverses and includes mica-hornfels (Fig. 149). At and north of Caer-glaw are many inclusions, and on a crag-face 250 yards north of the cross-roads by Gwalchmai Inn the junction shown in Fig. 150 is seen.

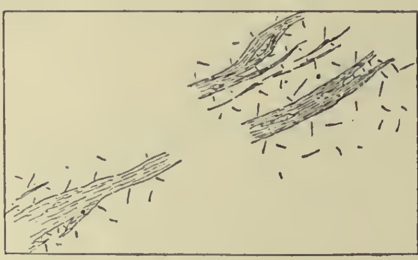


FIG. 149.
FOUR-FOOT PLAN OF GRANITE SILLS IN MICA-HORNFELS.
Werthyr bend of River Caradog.

FIG. 150.
SIX-INCH GRANITE SILL IN HORNFELS.
Gwalchmai, 250 yards north of Inn.

The finest exposed tract of this granite is the rugged moor of Gwalchmai, traversed by the footpath which leads to Clegir-mawr.

Here all its characters may be studied: the normal rock, the porphyritic, with the peculiar character and capricious distribution of the red phenocrysts of orthoclase, occasionally the old foliation, and everywhere the late planes of mylonisation. A little south-west of the place where the path enters the granite-moor, by a forked drain, is one of the rare aplitic veins, and a quarter of a mile north-west of Bryn-ala [E. 9910] is a white-mica variety with original foliation. All along the western flanks from the Holyhead road to Gwyndy, apophyses penetrate the mica-hornfels, excellent sections being seen south-east both of Bryn-crogi and of Gwyndy. Thence to the base of the Ordovician the Coedana granite comes against the Gneisses without any intervening zone of hornfels being visible, but the nature of the junction is unknown.

Along the lane at Y-foel are good intrusive junctions in folded mica-hornfels, and there is a faint foliation (Fig. 151). Albite and orthoclase are both present, with albite-micro-pegmatite, and white mica [E. 9975]. In the rocky tract about Eirianell there is extensive exposure, second only to that of Gwalchmai moor. The granite is often coarse, and in the northern part of the tract is porphyritic, with occasional old foliation (as at the glacial arrow and by the road south of the large felsite), and a few small xenoliths of hornfels at the farm due north of the same felsite and elsewhere. At Plâs Coedana granite rises over an anticline of mica-hornfels. From Neuadd to beyond Coedana Church is a long rocky tract, and the granite shows all its leading characteristics. Among the Palæozoic dykes towards Neuadd the porphyritic orthoclase is admirably seen, with the late mylonisation of the Complex; and west-south-west of the church are some of the best examples of the ancient foliation (Fig. 9). In the Coedana district is also a system of vertical planes coated with silvery films that seem to be minute white mica, but the original micas of the rock are not pulled out along them. About the farm at the 'oed' (Maengwyn of the six-inch map) there are sills with slight marginal foliation traversing the hornblende-hornfels; and in the farmyard (when tolerably clean) both sills and veins can be seen (Figs. 152, 153), the granite in its turn containing xenoliths of mica-hornfels. It is here that the margin of the intrusion [E. 10721], which is of the usual texture, contains a little tourmaline.

FIG. 151.
TEN INCHES OF BEDDED MICA-HORNFELS TRUNCATED BY GRANITE.
Laneside, West of Y-foel.

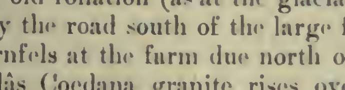


FIG. 152.
GRANITE SILLS IN HORNBLENDE-HORNFELS.
Maen-gwyn Farm, at 'oed' of 'Coedana.'

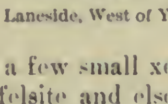


FIG. 153.
TRANSGRESSIVE MARGIN OF GRANITE.
Maen-gwyn.

From Coedana to its final disappearance in the north-east the granite is tolerably normal, but by the lane side south of the 'Ll' of 'Plâs Llanfihangel' are nests of greenish white mica. The shift at Cwyrt is, on account of its suddenness and of the trend of the features, considered to be due to faulting. The termination at Maen-addwyn is drawn from features. At its last exposure [E. 9996] about 500 yards south of Hebron, the granite, which is red (probably from Old Red staining), contains hypo-porphyritic orthoclase in rather small crystals.

Hornfels.

The Coast, Llanfaelog, and the Marginal Aureole.—The best section in the most prevalent type of the crypto-crystalline hornfels is on the western coast opposite Careg-lydan, a cliff about 18 feet in height, easy of access except at high water. The hard lenticular cores and schistose seams that sweep past them are very clear, some cores being internally banded, the banding in one case turning round and being truncated by the schistose seam. The hornfels, as a whole, shows no bedding. At the next section, about 140 yards to the south-east, the rock [E. 6118] is more micaceous and schistose. At the last one, south of the 'F' of 'Fferam,' the hornfels, which is but slightly micaceous, is distinctly bedded in places. This is the rock that was analysed [E. 10188, p. 95]. A yard or two further on a granite sill about 10 feet wide runs out south-westward, and some phacoids of sheared granite occur near the south side of the rocky knoll close to the glacial drift. The hornfels here bears a marked resemblance to the Church Bay Tuff, and is full of small clastic grains of quartz [E. 11190, 6117]. In a gap south of this crag is a strong mylonising crush, just before reaching which the change into fine mica-schist of the Penmynydd Zone comes on, unbrokenly though rapidly (pp. 127, 342).

Along the lake side crypto-crystalline hornfels is fairly exposed, and again around Llanfaelog Church, 170 yards east-north-east of which is a quarry in the analysed variety [E. 9888] with spots of chloritised xanthophyllite. This higher grade of alteration is found almost at the end of a great wedge that runs for more than a mile into the granite. At the seaward end of the long marginal tract schistose crypto-crystalline hornfels is well seen by Pensieri marsh and at Bryn-du, after which exposures are somewhat scanty (though the type remains the same) [E. 6116] as far as Penrhyn, Llanbeulan.

The rock then becomes very bare, and so continues all across the moors of Gwalchmai. Just beyond the Holyhead road the band ceases to be marginal, though the granite is very narrow on its eastern side. In the tract between Penrhyn and the Holyhead road good banding is visible, and at a spot 275 yards south-south-east of the tenth milestone are the thin quartzites [E. 9185—8, 9856]. They are two to twelve inches thick, and graduate by quarter-inch seams into the hornfels. About 190 yards to the east, a purple phyllite occurs within the zone. The aspect of the hornfels in this tract continually recalls that of the Church Bay Tuffs. A clear junction of crypto-crystalline hornfels with granite is to be seen at the large boss at the south end of Caer-glaw marsh, in the angle between the two lanes, on a little crag facing south, where the granite contains inclusions. Both rocks are typical, and there is no chilled selvage. North of the Holyhead road is a good deal of the siliceous adinolic type [E. 9857], and where a lane crosses the high moor towards the Clegir-mawr footpath this is beautifully bedded for many yards at a time. Remains of clastic texture can be detected here and there [E. 6113]. There is no better locality in the Island for a study of the original nature of the hornfels. Good exposures are seen again between Bryn-ala and Bodfeillion, where, 400 yards north of Bryn-ala, is the banded hornfels with encarsioblastic spots of chloritised xanthophyllite [E. 9972 and analysis], which is rich in small tourmalines and leucoxene. It is noteworthy that where this long tract ceases to be marginal, its grade of alteration distinctly rises, as in the Llanfaelog wedge, though never attaining the condition of the inner xenoliths. The tract at Fach may be marginal, as gneiss appears in the ravine beyond. Much of it is siliceous, with fine micaceous seams, but it is rather obscure.

Passing to the northern end, the hornfels that wraps round the granite as a great aureole to the east of Llanerchymedd is for the most part crypto-crystalline and of the usual grey-green type. It is well exposed from the Old Windmill to Bachau [E. 6119], at Cwyrt, Ynys-fawr [E. 10003 and analysis], and Bodafon-glyn. Much of its chlorite is probably after xanthophyllite. Epidote-hornblende-hornfels occurs at the farm south of the 'h' of 'Bachau' [E. 10001], and in the south-east angle of Maen-addwyn cross-roads [E. 6112], and a calcareous epidote-hornfels north-west of Clorach bridge. The important section at the south end of Mynydd Bodafon [E. 10341—7, and analysis] (Plate X, Fig. 1) (pp. 96, 160, 336) where bedded hornfels with original structures dips under the quartzite, is just above the road, 300 yards east by north from the 329-foot level north of Maen-addwyn. As would be expected from this section, the line drawn to separate hornfels from Bodafon moor-schist is merely provisional, though necessary.

The Xenoliths.

Turning now to the great xenoliths within the granite, that of Ceirchiog is siliceous, rather like the Fach tract; that north-west of the Smithy is crystalline biotite-hornfels, with unusually large idiomorphic sphenes in the boss north-east of the farm [E. 11191]. The xenolith on the south side of the Holyhead road west of Caer-glaw is of great importance, being the finest exposure of the mica-hornfels, traversed by some 14 granite sills (see Figs. 145—148). The specimen analysed [E. 9806] came from here. The xenolith, like the Fach hornfels, is brought against the gneiss by the Treban fault, which must be Pre-Ordovician; and it is evidently faulted on the south also. The hornfels is most beautifully crystalline [E. 10361, Plate X, Fig. 2], with micas one-eighth of an inch across, and tourmalines [E. 11395, 6115] easily visible to the unaided eye, while the original bedding, picked out by fine granoblastic seams, is often perfectly clear. This is the only place where the large oval groups of orthoclase have been seen [E. 9901].

Mica-hornfels, again well bedded, and with thicker siliceous beds, occurs among the small basic sills by the river east-north-east of Y Werthyr (Fig. 149). It also borders the Coedana granite from Clegir-mawr to Gwyndy, and runs past the Glan-yr-afon road for 300 yards, between two granite sills. It can be seen also on the western side of the western sill, and must therefore adjoin the Gwyndy gneiss. The junction is concealed, but as each rock (see p. 162) maintains all its own characters in full, and as the gneiss is brecciated in the hollow, there is evidently a fault. Mica-hornfels occurs at Gwyndy itself, and runs a few yards north-east of the cross-roads, but at the quarry 200 yards from thence [E. 9948] the hornfels is crypto-crystalline, and so are most of the xenoliths from there to Cwm. At Y-foel there are once more fine exposures of mica-hornfels [E. 9974] dipping under granite, which cuts an old pre-intrusion folding.

The epidote-hornfels of Cwm [E. 9949 and analysis] (Plate X, Fig. 4) is the finest development of that type in the Island. The spot where bedding in it, and the passage into it from bedded mica-hornfels are best seen is on the side of the crag about half-way from the farmyard to the pool. Some veins of a red granite whose felspar is albite-oligoclase cut this hornfels. At the 'e' of 'Coedana' the strip shown is mica-hornfels, which appears also [E. 6120] at the boss 240 yards north of the 'o' (near Maen-gwyn of the six-inch map). But it is there quite subordinate to, and passes into, the much more exceptional hornblende-hornfels [E. 10002 and analysis] (Plate X, Fig. 3 ; Figs. 152, 153), of which this is the only considerable mass known in the Island. It is well bedded, and there are seams with unorientated mica, so that the union of the types is complete. Granite sills, with slight foliation, occur in this boss, and veins at the farmyard.

The Deri Inlier.

The rocks of this inlier are well exposed on Pen-y-graig-wen, at other places indicated by the drift-lines, and in the two stream-sections. Its outer boundaries are obscure except at Pen-y-graig-wen. By far the most conspicuous rock is the granite, but the section in the Deri water leads one to suspect that the mica-schists, being less durable, may occupy considerable drift-filled hollows within the granite area. The granite, which is unusually white, and of medium grain, is an albite-white-mica-rock, no orthoclase having been seen. But, as it produces hornfels-alteration, it would seem to be a portion of the Coedana granite. To the south of Deri-isaf, and to the east of Llaneuddog, it is locally foliated, and at the 'y' of 'City' this foliation is cut by an albite-white-mica-pegmatite with micas an inch in diameter. There are some fine white parts that simulate quartzite, and appear to be silicified. The included strips at Pen-y-graig-wen are composed of a chlorite-leucoxene-hornfels, but the inclusions west of Deri-isaf are crystalline mica-schist of Penmynydd types, and in the Deri water east of the house there is almost as much mica-schist as granite, but the bands cannot be traced on. Mica-schist appears to occupy most of the inlier towards the river, but is not well exposed, except in the channel by the mill (in dry weather) and at a roadside quarry west of 'P.' It is fissile [E. 6098, 10272] with well-developed white micas, and some alkali-felspar as well as quartz in long granules, the foliation being sometimes beautifully corrugated. In it are bands of rather fine quartz-schist or quartzite, now granoblastic, with some grains of albite that seem blasto-psammitic. The group is evidently that of Bodafon, somewhat more foliated. At the roadside quarry the quartzite is split by lenticular seams of mica-schist near the junction, which is visible, and in the bed of the river at the mill the mica-schist contains long phacoids of quartzite. Both rocks are purple with hæmatite, doubtless a staining derived, as on Mynydd Bodafon, from the Old Red Sandstone.

The Foel Inlier.

This inlier emerges on a compound isocline in the hill east of Llanerchymedd. It is composed of mica-schist with some bands of quartzite. The mica-schist [E. 10679] (unlike the schistose hornfels across the valley to the south) is finely fissile, with micas occasionally well-developed, and is of a grey tint. The quartzites [E. 10170] are also fine, though massive, and are granoblastic, with zircon and garnet. Their micas have been replaced by delessite, which forms also stars in the quartz-veins. Both rocks (though here unstained) are of the same character as those of the Deri Inlier. Towards that they strike, and are evidently on the same zone of metamorphism; suggesting that the Penmynydd Zone has wrapped round the hornfels of Bachau, to come between that and the great zone of gneiss.

Mynydd Bodafon.

The Quartzite, Hornfels, and Moor Flags.

Mynydd Bodafon rises in a promontory of the Middle Region, to which Graig-fryn and four smaller inliers among the Old Red Sandstone also belong. A curving line runs from Bodafon-glyn to the Old Red Cornstone east of Maen-addwyn, coinciding for some way with a fault that passes through the quartzite, but for the rest of its course merely indicating a zone of metamorphic change. West of this line is crypto-crystalline hornfels, already described on p. 333. East of it, the rocks that emerge from below the quartzite are but partly hornfels, and east of the Bodafon-glyn fault two strips only of it have been separated out, near the farm.

The rocks of the tract east of this fault vary a good deal, but being fine flaggy mica-schists, and best seen on the wide moor north of the mountain, may be conveniently called the 'Bodafon Moor Flags.' Their flagginess is imparted by films of lepidoblastic mica, but between these films the minute micas that crowd the rock [E. 10042] lie in all directions, as in the hornfels, to which they are therefore closely related. Indeed, the rock with pseudomorphs of andalusite, referred to as a hornfels (p. 93), is a pale band among the moor flags [E. 10043] about 100 yards north of the 'n' of 'Bodafon.' And in the junction series (pp. 96, 160) at the 'base' of the quartzite, though the slides [E. 10341—7, and analysis] (Plate X, Fig. 1) were selected to bring out the hornfels characters, the alternating schistose beds have the characters of the moor flags. One exceptional rock [E. 10048] about 200 yards north-east of Bodafon-glyn, is much more highly crystalline—a corrugated schist with large muscovite, chloritised biotite, idiomorphic pseudomorphs after garnet, tourmaline, zircon, and other minute minerals of high refractive index. The moor flags often have the same purple staining as the quartzite. About 400 yards west by south from Fedw-isaf they contain small curving lenticles of purplish grit, in which clastic grains just survive; so there can be no doubt that they are in great part sedimentary, though the horny bands with a felsitic aspect may be pyroclastic dust. For a yard or two above its apparent base the quartzite becomes a little flaggy, and graduates into them by alternations. Now at the south end of the mountain the beds on which it rests are largely hornfels, at the north end they are the moor flags. It is evident that hornfels and flags are one and the same formation, stratigraphy thus confirming petrology as to the clastic (if in part pyroclastic) origin of both. The flags are to be seen here and there all over the moor, but the best exposures are between the little moorland village and the north end of Plâs Bodafon woods.

In the quartzite, on dip-sections and along the north-west escarpment, divisional planes can be made out which are undoubtedly stratification, for they dip always at the same angle as the 'base' wherever that is well exposed, and to the 'basal' flagginess of the quartzite near that. The beds were thick, and the rock uniform on the whole. Clastic grains are best seen near the east end of the southern escarpments, about 90 yards from the gap where some cottages are; also on the north-east parts of the Graig-fryn Inlier, which seems on the whole a little less reconstructed than Bodafon.[1]

Tectonics.

Reference was made on pp. 184, 221 to this chapter for detailed field-evidence in support of the views there set forth as to the structures, expressed also in the sections (Figs. 156—8). The quartzite mountain, 583 feet in height, rises from the moor whose

[1] The Bodafon rocks can be studied in the following slides: [E. 10038—45, 10048, 10706—10, 10341—7, 6132—3] (Plate X, Fig. 1).

levels are about 300 to 400 feet, and which in its turn ends off in a steep feature overlooking the Old Red and Ordovician country. To east and north this feature is enforced by a rampart of quartzite, forming a circlet of bold crags. Bedding is clearly visible in this quartzite, dipping always away from the flags of the moor at angles varying from 20° to 30° ; while the moor flags themselves, whenever exposed at all near (and along the northern rim the junction is almost visible), dip under it at corresponding angles, the direction changing with the curve of the quartzite rampart, which presents low sinuous escarpments to the moor. Further, in its course north of Plâs Bodafon woods there are three gaps in this rampart (the third of which, greatly exaggerated on the one-inch map, is only seven to 17 yards wide), in which the moor flags are seen to pass down upon the dip under the quartzite (Figs. 154, 276, 278). About a quarter of a mile west of Fedw-isaf. some small faults, running south-west, break the rampart, and on the upthrow sides of two of them little inliers of moor flags appear, one of which is very small. At the north end of the moor the rampart suddenly ends, and a rugged escarpment of quartzite, facing due west, runs right down the steep feature. The moor flags, as at the gaps, pass under the quartzite, but the junction is often obscured by a tangle of thorns and gorse. About 200 yards further on a small outlier of quartzite clings to the face of the feature, dipping now north-west. There is therefore clear evidence that Bodafon Moor is a broad symmetrical anticline with a pitch to the north-east. The quartzite on its western limb has been removed by denudation, that on its eastern limb strikes not for Mynydd Bodafon but for the Graig-fryn Inliers. But this great anticline is far from simple. The moor flags are locally corrugated, and their dips (for foliation is evidently not far from bedding) indicate many undulations. About the little village these appear to be symmetrical, but further south to be isoclinal, with three narrow nips of quartzite.

FIG. 154.

NORTHERN PARTS OF BODAFON MOOR.

From the six-inch maps.

M — Bodafon Moor Schist.
MQ — Bodafon Quartzite.
b — Ordovician Shale.
c — Old Red Sandstone.

Now the great quartzite of Mynydd Bodafon itself is a complicated group of synclinal outliers upon the eastern limb of this broad crumpled anticline (Fig. 155). That of the northern summit seems to be a simple isocline, but for a sharp uprise of the flaggy base just before the eastern side is reached (Fig. 156). The western faces of the mountain are escarpmental all the way along, with the flags dipping under thick-bedded quartzite. In the middle of the rugged hills, east of the tarns, the moor flags rise on a broad subsidiary anticline (Fig. 157). West of this the main ridge, though elsewhere an isoclinal, is for a while a symmetrical syncline, with a small nip of quartzite on each side. The broad anticline of moor flags carries on it five small nipped outliers of quartzite among the cottages (Figs. 155, 157), so it must be corrugated in its turn, as well as cut by some small faults. Quartzite comes on again to the east, but the form of its northward termination, just

FIG. 155.—THE CENTRAL PARTS OF MYNYDD BODAFON.
From the six-inch maps.
M = Bodafon Moor Schists.
MQ = Bodafon Quartzite.
C = Old Red Sandstone.

before it is overstepped by the Old Red, suggests that the moor flags are about to rise again and that this ridge is a sharp compressed isocline. On the broad southern summits all the dips observed are easterly, at an average angle of not less than 24°; in spite of which the 'base' of the quartzite on the southern face only drops 100 feet in a distance of 1,950 feet. It must therefore be folded, and the folding must be isoclinal. One of the principal folds must be on the strike of the central anticline of the mountain, by the little tarn. The others are inferred from the rises and falls of the 'base' along the 400-foot contour. There must also be a syncline of pitch, taking in this tract of quartzite between the tract of moor flags in the middle of the mountain and the southern margin. The depth to which the isoclines descend in it can only be conjectured, but from the solidity of the mass it is probably considerable, as indicated in the section Fig. 158.

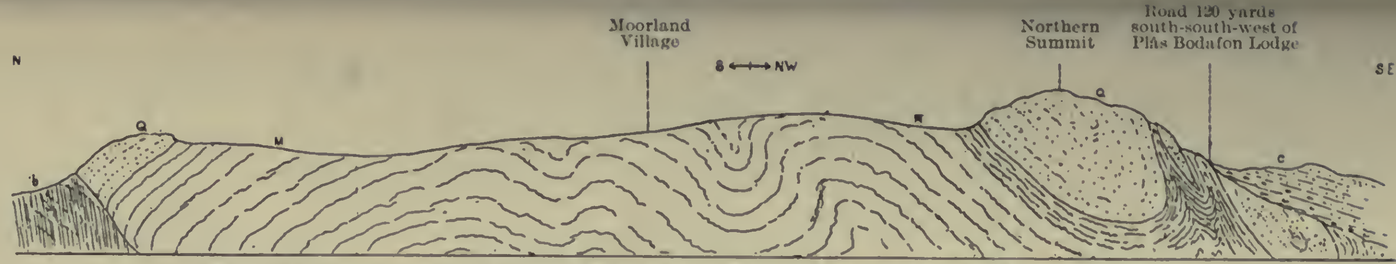


FIG. 156.—SECTION ACROSS BODAFON MOOR AND THE NORTHERN SUMMIT OF MYNYDD BODAFON.

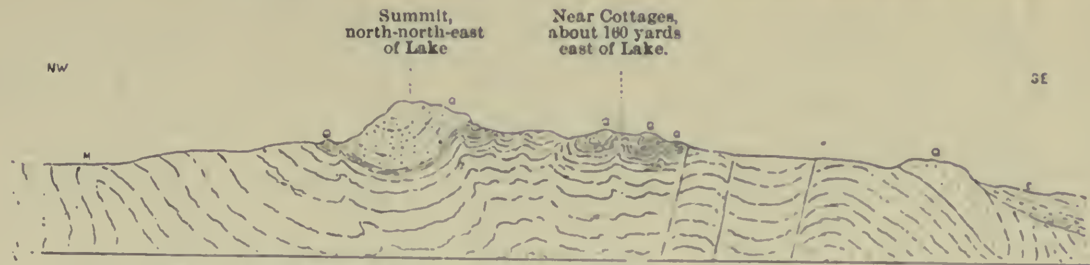


FIG. 157.—SECTION THROUGH THE CENTRAL PARTS OF MYNYDD BODAFON.

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

Scale:

Eight inches = one mile.

Symbols:

M = Bodafon Moor Schist.
Q = Bodafon Quartzite.
b = Ordovician.
c = Old Red Sandstone.

The amplitude of the main Bodafon anticline cannot be less than 1,000 feet, measured upon the apparent base of the quartzite in the visible part of the fold, and, with the rise of the pitch and the plunge to the adjacent complementary synclines, must be several times as great. The whole of this ancient folded mass is driven over the Ordovician rocks (Fig. 156, north end. See also Figs. 154, 276, 278) on the Bodafon thrust-plane.

The Penmynydd Zone of the Middle Region.

The coast section will be considered first, then the western margin, then the rest of the inland tract, and then the eastern inliers.

The Coast.

The main junction of Braich-llwyd, which has been described on p. 124, is at the north-west brow of a chasm. Though an unbroken passage from Gwna to Penmynydd schist, it is very rapid, and is complete in only a few yards from the chasm's brow. Moreover, the Penmynydd type that is developed is one of the most highly crystalline of the Middle Region, a flaser, undulose mica-schist comparable with that of the Aethwy Region, and with quartz-augen ; the band being 400 yards in width, and the widest one of that type known in the region. At Porth Cwyfan the flaggy type comes on, and in it are a number of bands of the pale green variety of hornblende-schist [E. 10179], which are highly epidotic but contain true zoisite as well. Thin acid seams adjoin them ; but there is folding, and too much evidence of movement for the original relations to be ascertained. At the church islet reefs the flaser type appears again, and also on both flanks of the rugged Porth China headland at the bay's end. Near the outer end of the summit, however, it takes in a nip of the oft-repeated quartz-schist, limestone, and graphite-schist group [E. 10178, 10182—4]. There is powerful folding at high angles, overdriven somewhat from the south, and doubtless thrusting, for the limestone is a curved and split lenticle some 20 feet wide, and the graphitic schist, only an inch or two in thickness, frequently nipped out. The limestone is calcitic, light-grey with dark bands, foliated and saccharoid, though fine ; and besides the true graphite-schist is much dark mica-schist, full of seams of quartz. Limestone appears again in Porth China, where the flaser mica-schist is highly crystalline. But along the cliff westward it becomes finer and more flaggy.

On Ynys Meibion are many destructive thrust-planes (Fig. 159), probably the latest movements of the Complex. Caethle begins with micaceous flaser schist, but most of the rocky bight is occupied by a somewhat unusual type, siliceous, but massive, and greenish, as if epidotic. Then flaser schist comes on again, succeeded, where the dyke skirts the coast between two chasms, by a large mass of flaggy schist, almost a quartz-schist in parts. The high headland called Trwyn Euphrates consists of highly crystalline flaser schist with quartzose augen. About 150 yards further on, a chasm runs in, and on the north brow is the rock with surviving felsitic structures [E. 9184], (p. 123). It has decomposed along the joints, is banded, locally foliated, and stripped into thin seams, which lie in a decomposed basic schist, and are sharply folded. About 100 yards to the north, on the low cliff-top, among hard-banded mica-schist, are the beds [E. 11086] (p. 123) of albite-grit. Their clastic quartz can be seen in the field with the hand-lens. That there should be two survivals of original structures here may be due to old thermal effects of the basic intrusions making the rocks more resistant. On and about Ynysoedd Duon 16 small basic masses

FIG. 159.—LATE THRUSTS ON YNYS MEIBION.
Height: about nine feet.

have been laid down upon the six-inch maps, partly unfoliated, partly hornblende-schist [E. 10174—6]. The best junction-sections are on the islets (accessible at ebb), the best zoisite-amphibolite is 200 yards to the east. The mica-schist in which they lie [E. 6137] is variable, but mainly flaggy, with bands of quartz-schist. On the south cliffs of the large cove west of Gate House is the most quartzite-like of all the quartz-schists of the Penmynydd Zone [E. 9183] but it is completely granoblastic.

About the Telegraph Cable Hut are the best exposures of the triple group—quartz-schist, graphite-schist, and limestone, which are here considered in order from north to south. The Hut is built upon a ridge of flaggy quartz-schist, and on the south cliff of the little cove, composed of highly crystalline flaser mica-schist, a very thin slip of graphite-schist appears just at the corner of the beach. On the seaward strike of this, in the same cliff, is the limestone, a range of overlapping lenticular nips, one of which is about three feet thick and about 15 feet long. It is a white calcite-marble (slightly dolomitised in places) with plates of mica, like that of Bodwrog, but finer in grain, graduating into the adjacent rock through thin zones of calc-mica-schist very poor in felspar [E. 10689, 8518—22]. The 60-yard quartz-schist that follows must be broadened out by repetition, for the preceding rocks are driven into it ; besides which there is a fine section in true inter-bedding, bands of quartz-schist two to six inches thick lying in mica-schist at intervals of a foot or so, forcibly recalling the sections on the northern coast (pp. 305, 309) where thin quartzites alternate with Gwna phyllite, save that the rocks here are highly crystalline. Then mica-schist rises on a corrugated anticline, cut off by a nearly vertical thrust at a little chasm, so that locally the limestone group seems to lie below the quartzite. In the chasm is the best as well as the most petrologically interesting exposure of the graphite-schist [E. 10030], (Plate X, Fig, 6), rich in rutile and xanthophyllite, a corrugated group of black seams whose total thickness may be about three feet, lying in mica-schist. On the south cliff of the chasm are two small nips of limestone. Quartz-schist then appears once more above, and comes down, but with heavy crushing, in the large cove west of Gate House already mentioned.

Returning to the north of the Cable Hut, the marginal fine flaggy type appears on the Barclodiad headland, and is strongly developed. A thin limestone is driven into it in the chasm where the sheared dyke outcrops (Chapters XVI, XVII).

But on the southern foreshore of Porth Nobla comes a local rise in crystallisation with reversion to the flaser type [E. 6136, 9900, and analysis], (p. 112). Biotite as well as muscovite is plentiful and in good preservation, partly intergrown with, partly penetrated by the muscovite. Garnet and pyrite are present. The felspar is an untwinned albite, ill-preserved. There is probably a rupture in the cove, as indicated by the features, for the schist of the reefs beyond is fine and flaggy, falling in crystalline grade up to the junction with the hornfels (p. 127). This is at the crag south of the 'Ff' of 'Fferam,' where there is a glacial arrow. A few yards from the south-east side of it is a gap, in which is a strong mylonising crush, and at first sight this crush (a steep thrust from the north-west) appears to be the boundary. But inspection of the north-west side shows that, for a yard or two, the rock is still Penmynydd mica-schist, though fine; and that there is an unbroken passage into it from hornfels. On the south-east side the Penmynydd type is evident. The passage is therefore a real one, and the thrust, which outcrops within the Penmynydd Zone, fictitiously accelerates it by bringing a marginal part of the Zone on to an inner part.

The Western Margin.

No other section across the junction is known, but all along the boundary the two rocks exhibit the same changes where near together as they do at the coast. The best sections where granitoid matter can be seen in the mica-schist are as follows: a high boss 330 yards west-south-west of Fferam, Llanfaelog; the east side of Tre-ruffydd farm-lane; the quarry by the eleventh milepost at Gwalchmai; and the knobs just below the road at Bodwrog Church [E. 8484]; also at a farm at the south-west end of the granite sill that lies within the Zone at Gwalchmai. The breaking-down of the granite into granoblastic matter can be seen at the lane-side in the same sill, north of the Windmill; at a crag 140 yards north of Gwalchmai Inn; at Bodwrog Church; and at the figures '263' near the church. At the last place, granite and Penmynydd schist interdigitate (as shown on the six-inch maps), and are seen only four feet apart, the schist being almost a quartz-schist (see p. 127).

The flaggy marginal zone is about half a mile wide, and well-marked as far as Gwalchmai, but narrows at Bodwrog, and then becomes indistinct. The type is exposed on many isolated bosses, but the best sections are at Gwalchmai, especially in and about the little ravine of Penrhyn, where a speckled variety is occasionally seen [E. 9858]. The specks are biotite, the rock is rich in alkali-felspar, and minute garnets are plentiful.

The rest of the Inland Tract

is but moderately exposed except at the railway cutting of Ty-mawr, and along some ridges between Grugor-bach and Bwlch-y-fen ; but is evidently composed of the same types as those cut by the sea-section. The railway cutting goes through the main junction with the Gwna Green-schist, but unfortunately a bridge wall and a large dyke come just at that place. There are, however, the usual indications of a passage. West of this is a continuous section for 450 yards, in which the type is mainly flaggy, so that the passage cannot be at quite the same horizon as at Braich Llwyd. There is also much of the flaggy type about Erddreiniog, but on the whole the micaceous flaser type appears to be the more prevalent. At Grugor-bach is a highly crystalline schist [E. 9940] with lavender-polarising chlorite after biotite, abundant epidote, leucoxenised ilmenite, and some tourmaline (a rare mineral in the Penmynydd Zone) which has a curious habit, being chiefly in bundles of needles that appear to replace biotite. The porphyroblastic albite-schist [E. 10177] (Plate X, Fig. 5) is seen at a boss at the first 'r' of 'Aberffraw,' and 250 yards from the outlet of Llyn Frogwy there is another [E. 10066] full of delessite and epidote. The garnet-schist [E. 9993] of the north-east end of Llyn Hendref, (partly analysed) contains chloritised xanthophyllite (crowded with rutile) which had a considerable axial angle.

The hornblende-schists are chiefly dark, and usually contain porphyroblastic albite and abundant zoisite, suggesting derivation from zoisite-amphibolites like the intrusions of Ynysoedd Duon. Feathery hornblende-porphyroblasts are well-developed at Pen-yr-allt, and the remarkable variety with foliated pyrite was found in a pit on the east side of the road 500 yards south-south-east of Gwalchmai-uchaf cross-streets [E. 9859, 9994—5].

The rutiliferous schist [E. 10058] is at 141 yards south by west from the 268-foot level at Bwlch-y-fen. Its iron-ores do not appear to be ilmenite, so the titanium seems to have all gone to the production of rutile. The relations of the granite at Bryn-goleu are not visible. About three-eighths of a mile east of Erddreiniog what seems like an acid gneiss is obscurely seen, and 140 yards to west-north-west a basic rock has a somewhat gneissose aspect. Folding is not conspicuous as a rule in this zone in the Middle Region ; and though locally sharp folds are frequent, they hardly disturb the dip, and there is no good pitch. Local bends in the strike will be noticed on the map, the greatest of which is at Bwlch-y-fen.

The Triple Group.—Detail of the triple group of quartz-schist, limestone, and graphitic schist is of much more than local, it is of stratigraphical importance (see p. 125). But an outcrop of all three together will be looked for as but a rare occurrence by those who realise the vast number of thrusts which traverse the Mona Complex, yet seven triple (and six double) outcrops are known, in the main tract, and in its inliers. Graphite schist is associated with the quartz-schist west-south-west of Llangwyfan New Church. The long bands of quartz-schist which range through Gwalchmai-uchaf and Bodwina to Bwlch-y-fen are generalised from, probably, ranges of shorter, overlapping outcrops. The black schist is not yet known actually with them, but occurs 200 yards north-west of Tyddyn-gwyn, only 250 yards away. About Bwlch-y-fen 15 bands of quartz-schist have been laid down upon the six-inch maps; and with them, at the 'B,' also west and south of it, are four nips of limestone [E. 6134] one of them 40 to 50 feet in width, partly light, fine, and dolomitic, but partly darker. Dark schist lies close by, so probably the graphitic schist is present. The rocks are very siliceous west of Bodwrog Church, and ought perhaps to have been separated as quartz-schist, of which three bands have been mapped (on the six-inch scale) near the limestone, among highly crystalline flaser mica-schist. Of the beautiful Bodwrog marble [E. 10057, 10690, 8523—5, 8445 (b), 8557] (Fig. 160), 12 bands are known, one of which is sharply folded round. Both groups are well, the south-westerly very well, exposed. Besides the snow-white marble analysed [E. 10057] there are red varieties, in some of which are green silicates. In the large quarry at the north end of the southern group are several bands of graphite-schist, some of which yield a strong black streak; and on the south-east side the limestone is dark, thin-bedded, and interleaved with seams of graphite-schist, very much as in the large quarries at Cemaes (pp. 85, 305). The group may therefore be safely correlated with those of Cemaes and Llanfaethlu. The marble of Erddreiniog, which is so rich in accessories [E. 10080—1, 11396, and analysis], was, at the time of the surveying, only to be seen in an abandoned quarry about 17 yards long, south of the little square wood. About 10 feet of rather massive beds were visible, foliated, and with thin partings of mica-schist.

FIG. 160.
THE BODWROG MARBLE.
From the six-inch maps.
G = Coedana Granite.
M = Mica-schist.
D = Palæozoic Dyke.
⌣ = Cors Bodwrog Alluvium.

The Inliers.

These are chiefly composed of the flaser type, and sharp folding, with a good pitch to north-east, is more conspicuous, but some of them have a close external resemblance to the adjacent Gwna

Green-schist. About a score of lenticular inliers run in a double train from the sea to the Old Red Sandstone, passing on both sides of the great Engan zone of spilite-schist. Many of the lines are conjectural, and adjacent inliers may be continuous in some cases. In and at the foot of the cliff north-east of Braich-llwyd, Aberffraw, an inlier of mica-schist is cut very obliquely by the sea. The zone of passage on the buttress has been described on p. 124, but that on the other side is to be seen on the cliff wall. Calcareous bands in the mica-schist graduate into a 20-foot bed of crystalline grey limestone, with which is a one-foot bed and many seams of good graphite-schist, and at the north-east end are thin bands of quartz-schist, so that the whole of the triple group is present [E. 10181, 10185, 10191—2]. On the foreshore about halfway to Aberffraw Sands is another inlier of mica-schist. In the cliff on its west side, close to the little chasm, is a decomposing graphite-schist. There seems to be a small fault at the streamlet, but not enough to break off the wedging of the inlier into Gwna mélange, with a small foliated limestone [E. 10182, 10186].

In the large inlier east of Hen-ysgubor, are thin fine dolomitic limestone [E. 6135] and quartz-schist, and as blocks of dark mica-schist lie near, the graphite-schist is probably present also. The limestone [E. 10056] just east of the dyke rises from under mica-schist on an anticline seven feet wide. In the Druid Farm inlier, 300 yards south-west of the house, grey crystalline limestone [E. 10691] is folded in with quartz-schist, and the basic rocks are hornblende-schist. In the mica-schist adjacent to the limestone there are thin graphitic seams. Just west of the farm the Gwna rocks contain clastic grains, and 366 yards south of the house there is a suspicion of clastic albite in the mica-schist [E. 10024—5]. North of Druid and east of Tros-y-rhos is a small inlier seen only on the east side of one large boss. But at that boss the types are seen only four feet apart, and there seems to be a passage [E. 10064—5]. The clean grey limestone of the large inlier south-east of Bodwrdin [E. 10079] is foliated, with films of graphite, as in the Cemaes limestones. In the same inlier, between the dykes, are several signs of passage from the Gwna Green-schist, and at one of them, south-west of the 115-foot level, by a dip-arrow, a two-inch phacoid of jasper lies in a micaceous variety of this [E. 10069—71].[1] The inlier that is crossed by the road from Llangefni to Bodffordd south-west of Ty-gwyn contains a grey dolomitic limestone with calcite veins, a thin quartz-schist, and some graphite-schist [E. 10204]. Grey limestone lies just at the north-east end of the inlier east of Tregaian, and there are thin quartz-schists in the one south-east of this. Along the first one are exposures very near the boundaries. As limestone and graphitic schist occur several times close to the margins of these inliers, it is evident that the Zone develops at different horizons from those of the principal tract (pp. 220, 343).

[1] At some such place as this, the Bodorgan thrust-plane may yet be picked out from among the other foliation-planes.

The Gwna Beds and Tyfry Beds of the Eastern Middle Region.

The coast will be considered first; then the south-eastern margin as far as Llangefni; then the inland lying between that margin and a south-west to north-east line drawn through Cerrigceinwen; then the Ceinwen volcanic zone; then the Engan spilites; then the western tracts.

The Coast.

Aberffraw.—On the south-east side of the chasm where the Penmynydd Zone comes on is typical Gwna Green-schist. At Braich-llwyd clastic grains are visible, and as we pass up north-east from the point, the rock is purplish, with little red fragments. Then follow the zones of change on the flanks of the Penmynydd inlier, whose rapidity is remarkable, so close to schists with surviving clastic textures. Beyond the inlier are typical Gwna Green-schists, in which clastic matter, though present, is inconspicuous. Then comes the other Penmynydd inlier, and then the Gwna Green-schist of the river's mouth. This Aberffraw section would repay very careful study.

The Bodorgan Headlands.—Where the section begins again beyond Aberffraw Sands we are just on the strike of the Ceinwen spilites, and these, converted into chloritic schists and accompanied by a limestone, appear among Gwna Green-schist, which is not normal, but full of sheared fragments torn from them. The rugged coast from here to the great headland of Twyn-y-parc, is the finest section across the Autoclastic Mélange in the Island (Plate VII). To describe it in detail is impossible, the wealth of structural evidence is practically inexhaustible, and it must be visited to be envisaged. So no more will be attempted here than to indicate points of special interest. The grade of metamorphism is low, the schistose matrix being dull-green; but there is relatively little matrix, the greater part of the rock being hard grit, often crowded in closely overlapping phacoids, and the larger lenticular masses are for the most part quartzite, limestone and spilite being rare. Small strips of partly bleached jasper, torn away from their native spilite, occasionally lie between the grits, with a few of jaspery phyllite. Some of the grits are coarse and should be examined for old composite fragments. Opposite the word 'Bay' are several large quartzites, one of which forms a conspicuous ridge, and then, folding, runs in on another parallel ridge. It shows bedding, is unusually rich in albite and tourmaline, and contains old compact fragments that may be felsite [E. 10169]. On the cliff 100 yards to the north-west of the high ridge the quartzites are partly split, and the base of one of them wedges

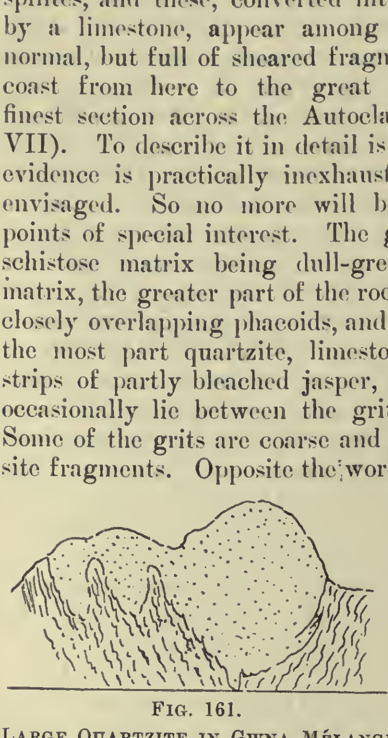


Fig. 161.
Large Quartzite in Gwna Mélange.
(Several yards high.)
300 yards north-west of Porth Cadwaladr.

in and out, the foliation of the mélange remaining at high angles (Fig. 161). The structures recall those of Porth Wnol (Plate XXII, and p. 307) on the northern coast, but the mélange here is far more strongly foliated. It can be seen unusually well close to these quartzites. Bedding is rarely visible, but can be seen, overfolded from south-east, on a boss just above the cliff on the west side of Porth Cadwaladr. A little inland is a small limestone, and there are others in the cliff south of the cove, with a sheared spilitic lava. Beyond them are some rather massive grits. The low cliffs of the next sandy cove afford excellent sections of the mélange, which is also [E. 10277] magnificently displayed all over the crags of Dinas Trefriw. In the north-west corner of Porth Tywyn-mawr bedding has been preserved in the act of breaking down. The basic sills now begin to appear. They are described below.

Phyllite, both green and purple, increases as we approach the headland, and on the craggy brow south of Porth-ro the sections are of great importance, for clear passages of the Tyfry phyllites into mélange can be seen both along and across the strike. In the deep chasm beyond is a rose-limestone. The great headland of Twyn-y-parc itself, more than 100 feet in height, is a rugged mass of mélange, with nips of quartzite, limestone and diabase. Near the seaward end are some 20 feet of unusually coarse grit, with fragments that resemble jasper, but the rock should be further searched. Oligoclase as well as albite has been found in these grits [E. 10241—5].

The sections hence as far as Dinas-lwyd are highly complex, and cannot be followed on any but the ·0004 or at any rate the six-inch maps; mélange with quartzites and limestone alternating with phyllites in which are beds of grit, and the whole traversed by sills of epidiorite partly schistose, in which are inclusions of grit and hornfels. The outer islets appear to be of massive diorite. These phyllites have been provisionally coloured with those that occur in the zone of passage to the Tyfry grits, but the whole group needs further study. On the eastern side of the semi-circular cove and at the old quarry, they show bedding, besides a venous banding. On the south-facing cliff before Dinas-lwyd is reached, schistose diorite, hornfels, phyllite, grit, and quartzite have all been sheared together, and the complexity of the rock is at a maximum. Dinas-lwyd is another fine crag of mélange, which then occupies the coast all the way to the Millstone Grit, and reappears in the Bodorgan inlier, but contains more nips of limestone than on the western coast. At Bone Twni cove the grits, less torn up, contain the bodies referred to on p. 151 as castings of annelids.

The epidotic epidiorites [E. 10233—5, 10279] (p. 75) are well exposed at many places both on the coast and on the slopes among the dunes, passing often into chlorite-schist upon their margins. Coarse diorite forms a high knob just above the 'd' of 'Bodowen,' and occurs also in Porth-ro, where its pale augite survives. It is possible that some deformed spilitic lavas have been coloured with these intrusions; for some 300 yards north-east of Porth-ro is a curious chlorite-schist with what seem to be remains of ellipsoids and jasper ; and studded with small white bodies [E. 10236] composed of interlacing colourless needles, apparently an amphibole, in which are veinlets of clear albite. The rock may be a variolitic lava that has been thermally altered. Inclusions, more or less thermally altered, are to be seen at Porth-ro, at the south-facing cliff near Dinas-lwyd, already mentioned, at a cove a quarter of a mile north-east of Dinas-lwyd, at Bone Twni Cove, and indeed at all the good sections. In Porth-ro, one of the sills passes down to north-west at moderate angles, in spite of the high foliation-dip. At the foot of the south-east cliff, its chilled selvage can be seen, with inclusions of purple phyllite converted into pink epidotic hornfels. Both rocks have been in places torn up, sheared, and incorporated into the mélange ; yet in parts of the hornfels old folded bedding is preserved, and an old cleavage, with small slips along it, healed up and welded by the thermal action [E. 10237, 10240, 10278]. At Bone Twni Cove the original sill-relations are visible, the diorite slightly transgressing the bedding of grits and shales, which have been locally converted into true adinoles [E. 10238—9]. The bedding is overfolded from the north-west, and there is again an old cleavage, and yet a shearing of the diorite. On the south-facing cliff south-west of Dinas-lwyd, tongues of the basic rock have been sheared out until as thin as paper, and it is noteworthy that, though the thicker tongues contain inclusions that are in the condition of hornfels, no thermal effect has been induced upon the Autoclastic Mélange *as such*. It is evident, therefore (see also p. 76) that these intrusions must be later than the earliest folding with its resultant cleavage, but older than the production of the Autoclastic Mélange. It would seem as if they belonged to the same interval as do the dolerites of Caerau (see pp. 103, 321), though those are labradorite rocks, which these do not seem to have been.

South-eastern Margin.

Along this the chief interest is the train of infolds letting in the beds regarded (see pp. 63—4, 160) as a zone of passage from the Gwna Group to the Tyfry facies of the Skerries Group. Though coloured with the Skerries Group, they include not only true tuffs, but grits and phyllites ; and the lines drawn are but provisional, coinciding probably rather with 'dynamical horizons' of escape from autoclastic break-down than with stratigraphical horizons. The whole zone calls for more minute petrological research. From the Bodorgan inlier to the railway, mélange comes to the margin, well exposed east of Hermon Church site, where some coarse grits contain albite [E. 10688] and blue quartz, beyond which are some three-eighths of a mile of obscure ground. Then : in the cutting between the tunnels, appears a clearly and rather thinly bedded group, fine flinty green grits (containing broken laths of albite) with green and purple phyllites. Similar beds are exposed in the eastern tunnel (which is not wholly bricked in), and can be seen plentifully in the débris taken out, now lying over the tunnel's roof (Fig. 162).

In the cutting there is a vertical cleavage (probably that which is older than the diorite intrusions) and a folding on vertical axes (Fig. 41). Similar beds appear again at the tunnel's eastern mouth, and it may be that the group should be given more space upon the map. In the next tract is a rock of great importance, quarried 170 yards north-north-east of Trefdraeth Church, and used for the walls along the road. It is an epidosite-tuff, with 'clots,' and little scraps of pink felsite, of whose identity with the Trwyn Bychan and Church Bay Tuffs there can be no doubt. Mélange then forms the margin all the way to the Henblâs Water, finely exposed along the strong feature which bounds the Carboniferous Series (see Chapters XXII, XXIII).

FIG. 162

FOLDING AND CLEAVAGE.

× ¼

Tyfry Bed Blocks from Bodorgan Tunnel.

Green grits and mudstones form the tracts that have been separated out about Henblâs. They are not very well exposed, but it is significant that where the Henblâs Water cuts back the Carboniferous and lays bare its floor for 200 yards, this group is the only one revealed, as if it were about to come on in force beneath the coalfield. With two interruptions, the passage-beds then continue along the margin for the remaining two and a half miles to the Llangefni fault, beyond which they have not been recognised. They are well exposed about Llangristiolus, especially below Cefncanol on the north-east side of the late dyke, where (see p. 160) there is a perfect passage from Tyfry to Gwna Beds, and as perfect a section showing the rapid breakdown of Gwna bedding into mélange. The section is about 60 yards from the Llan-fawr path. No better exposures of the passage-beds themselves exist than the quarried knobs (see p. 160) about Nant-newydd [E. 9688—90, 10198—200, 10697—8]. At the farmyard is a grit with a white felsitic matrix, and some purple ones ; but those to south and east are green, with abundant fragmental albite and an epidositic matrix like that of the Skerries Grits, in beds a foot or so thick, between which are thin epidotic mudstones. A little further on, where the boundary crosses the 100-foot contour, is a good conglomerate with pebbles an inch in diameter of spilitic lavas (often hæmatised), albite-trachytes, and pinkish felsites, as well as large broken albites, while in E. 10200 there is a fragment of granitoid quartz containing a long apatite, and another that resembles a true gneiss.

Between the margin and the line through Cerrigceinwen.

This great zone, more than 11 miles in length and a mile or more in width, is almost entirely composed of the Autoclastic Mélange, but though abundantly exposed in several rocky tracts, few features are yet known in it that are not still better seen on the coast. Any planes but those of the steadily striking and almost vertical foliation are very rarely to be seen.

The first rocky tract extends from Dinas Trefriw to the Bodorgan woodlands. Some of the grits of the mélange are quite coarse, and one of them [A.P. 238] at the glacial arrow south-east of Trefriw contains orthoclase, a rare felspar in the Mona sediments. One zone is doubtfully separated as a Tyfry grit. In the railway cutting west of the tunnels the mélange is less full of grit than usual, and bedding is visible about 150 yards from the tunnel, dipping west at moderate angles. The quartzite of Bethel, though well known from having been worked, is of less petrological interest than many, being almost wholly quartz. The rocky tract from Trefeilir woods to Capel-mawr contains many nips of quartzite, some of limestone, that of Ty-calch [E. 10197] being white and calcitic, and its coarser grits may yield composite fragments. To the north of Henblâs the quartzite nips are unusually large, and the one south-east of the school contains little fragments that may possibly be jasper. The top of the plateau and the slopes from the 258-foot level to the ravine up which the late dyke runs, are very bare and display the mélange finely; in which, 200 yards south of Cefn-canol, is a schistose breccia of grit and fine siliceous matter. By Nant-newydd a rose dolomite with jasper shows that the Llanddwyn Group is just caught in. At Cefn-cwmmwd is a nip of reddish Tyfry grit [E. 10009] very rich in albite and spilite, and with many fragments of tourmaline-mica-schist in which is alkali-felspar. The plateau is again very bare between the branching roads to the north-east. Several quartzites which are involved in the mélange are not as white internally as usual.

Llangefni.—About Llangefni there are ten quartzites. The white crags of the one cut through by the river are conspicuous among the fir trees from the station. It contains [E. 10196] albite, spilitic lava, and a fragment of ancient mica-schist such as is found in the Tyfry Grits. The inlier in the Carboniferous at the Old Windmill contains [E. 9954] tourmaline, rutile, zircon, and fragments of ancient quartzose and micaceous schists. The mélange is well seen beyond the church [E. 10063, 10193, 1541—2], and in the railway cutting at the station; while the Dingle, in which several fine sections are conspicuous, demonstrates its continuity all across the belt. Alongside the path, about 570 yards north-west of the station, was found (see p. 160) a one-and-a-half-inch pebble [E. 11249] of deformed hypabyssal albite-rock, identical with those of the boulders of the Skerries Conglomerates. Quarter of a mile north-west of Pen-lan a tributary ravine comes in from the east, a little to the south of which two zones of jasper, jaspery phyllite, and purple grit have been incorporated. Yet at its mouth is bedding, well preserved, in rocks that recall those below the Graig Wen quartzite of the north (p. 305). At the great curve between Pen-lan and the Dingle a broad band of compact rock is passed through, best seen just inside the wood and in the railway cutting opposite. Greenish internally, but weathering white, it has the aspect of a felsite, or of the silicified rocks of Parys Mountain. But it is [E. 10173] finely clastic, with little albite fragments, and the mosaic is largely composed of crypto-crystalline alkali-felspar, so it would appear to be an albite- or quartz-albite-dust.

In the cutting it graduates laterally into grits of the mélange, and is sheared along with them. That it should be an adinole is improbable, no intrusion being visible. Similar rocks, though more siliceous, are seen at a cottage 533 yards east of Tre-Hwfa, at the Cromlech crag by Henblâs, in the cutting at the Station, and in a Tyfry grit south-east of Plâs-bach [E. 10172, 10194—5, 10073]. They recall the rocks of Tyfry and Newborough (pp. 355, 373). A narrow rocky tract of mélange [E. 6125], with some small quartzites [E. 6124], runs along the base of the Old Red Sandstone, from Llangefni by Rhos-meirch to a point east of Pen-y-cefn, beyond which this belt becomes obscure.

The Ceinwen Volcanic Zone

is identical with that of Newborough and Llanddwyn, the ellipsoidal spilites, ashy rose-limestones, jaspers, and jaspery phyllites, all being present, as well as the Tyfry grits. It is finely exposed at Cerrigceinwen and Taldrwst, and the high steep knobs at Cerrigceinwen Church would be a complete reproduction of those of Llanddwyn but for being thickly draped in vegetation. The ellipsoids are of the smaller type, seldom a foot in diameter, and are well seen all along the tract, but there is a degeneration into chlorite-schist at the south-west end as well as in the outlying strips west of Trefeilir and at Aberffraw Bay. Indeed, even at the best, the rocks are not quite so free from deformation as in the type-area. Some degree of hæmatisation is usual, but the great mass is green. Jasper is common in the interspaces, with some limestone south-east of Bodrwyn. About 250 yards west of Cerrigceinwen Church there is a vesicular spilite [E. 10017] with signs of variolitic structure, in which are the jaspers that have been searched for pseudomorphs of vesicles; while in a rock three-eighths of a mile west of Parc-glas the structure is still stronger between a crowd of objects that look like amygdules [E. 10062]. West of Hendre-bach is a curious porphyritic variety. Hæmatised fragments of the lavas are common in the limestones, as in the one south of Taldrwst [E. 10075], often, when deformed, simulating jaspery phyllite. The felspar had been pseudomorphed in all the specimens cut. Albite-diabases [E. 10016, 10076] are present, but have not been delimited on the one-inch map. The larger limestones [E. 10693—4] are well exposed, and often jaspery. The one 330 yards south-west of Hendre-bach is a mottled rose-dolomite. It contains the jaspery phyllite and spherulitic jasper [E. 10011—12] that were analysed. There must be a small serpentine at Bodrwyn, probably resembling that of the Pentraeth eastern Inlier, for many years ago some asbestos was found there which (Mr. J. J. Ffoulkes, of that farm, informs me) came from about 200 yards below the house. A specimen preserved in the Museum of the University College of North Wales has the refractive index of tremolite. Further information on this volcanic zone will be found on the ·0004 maps: and the whole suite of sections will repay study, for they are very complex.

Tyfry Beds.—Tyfry Grits, rather fine but rich in albite [E. 10010], are seen on the high boss west of Cerrigceinwen Church; but the most interesting is a coarse one [E. 10074] by the end of the lane that goes north-west from Tan-lan. It is full of broken albites, fragments of keratophyre, spilitic lavas often hæmatised, old grits and quartzite, and is the one that contains a fragment of mica-schist with nine little tourmalines. Yet it is highly sheared, and has developed more new mica than many parts of the mélange, in which it is therefore incorporated.

That mélange is, on the south-east side, the country in which the Ceinwen zone lies; but on the north-west side is Gwna Green-schist, and the zone is brought within 170 yards of a Penmynydd inlier of western Gwna facies at Plâs-bach, and almost as near at many other places. The existence of a thrust-plane, therefore, need not be doubted; and it must be folded sharply. But it has been considered better to leave the line undrawn upon the maps, as it may not coincide with the outcrops of the inliers, and would in that case be conjectural in our present knowledge.

The Engan Spilites.

The great Engan zone of spilite-schist, nine miles in length, is best studied along the five miles of steep and rugged bosses between Coron lake and Mona House. The rock is remarkably uniform in character, and the petrological descriptions given on pp. 77—8 [E. 10019—20] apply everywhere, with mere slight local variation, so that intrusive diabases are likely to be very rare, if not absent. Ellipsoidal structure is now barely discernible, for the deformation has been very powerful. Possibly it was never as marked as in the Llanddwyn spilites; but the presence of the jaspers and the chemical composition (p. 78) leave no doubt of the rock having been a spilite. The characteristic hæmatisation also survives in many places [E. 10360]. The condition of the jaspers, now sheared-out into long lenticles and bleached [E. 10013—15], has been described on p. 88.

Long thin strips of a siliceous schist are also numerous, and, in places, large enough to be shown upon the maps. Here and there, as on the Ty'n-dryfol bosses, they contain cores with clastic grains, and are evidently caught-up inclusions of the Gwna sediments. But they are compact, and have a baked aspect, as if slightly altered thermally by the great lava. They need further investigation (see pp. 121, 368). It is very difficult to believe that the Engan spilites can be intrusive. The continuity of the basic schist is more seriously interrupted by many bands of Gwna Green-schist, often of considerable size. Some of these are due to folding, but the occasional alternating sections point to the existence also of several flows on slightly different horizons.

Unusually fine sections are afforded by the conspicuous great boss west of Tre-ddafydd-isaf, with shearing of the jaspers. A quarter-inch vein was noted, with epidote and transversely set fibres of pale actinolite. About Soar many strips of Gwna Green-schist lie within the spilite, but the broad tract at the 'B' of 'Bodwrdin' is poorly exposed, though sufficiently to show that the cross-faults must exist. The bleaching of the sheared jasper lenticles is easily seen on the Soar knobs. Hæmatisation survives on the steep lofty boss of Dinas, at whose south-eastern foot also some original igneous textures are visible. The siliceous seams are numerous all across the spilite at and south-east of Ty'n-dryfol, and are shown (much exaggerated in width) upon the one-inch map. Some of the clearest exposures are afforded by thin ones on the boss between the channels of alluvium. At the 'w' of 'Prys-iorwerth' the foliation passes obliquely through a jasper that has not been drawn out into a phacoid (Fig. 163). Very fine exposures occur again at Cerig-engan. On the escarpment below Craig-lâs spilite-schist alternates with Gwna Green-schist, and one such band rises (Fig. 164) from below some of it on a little anticline. All the characters are again finely seen about Mona House, especially on the peninsula that runs into the alluvium, which is the best of all the localities for a study of the bleaching of the jaspers, here sometimes in phacoids a yard or more in length and six inches thick. The spilite-schist itself shows what seem to be survivals of ellipsoids, and a banding, with dark green seams that probably represent their dark outer skins. There are also about here hard salmon-pink seams, and the whole is cut by post-foliation movements. At the cottage among the crags north of the little alluvium beyond the road, Gwna Green-schist seems to both underlie and overlie the spilite, passing down on a north-east pitch which can be seen in the siliceous bands. Good exposures are found again near Tre-hwfa-bach, the usual characters appearing, as is also the case to the end of the line of strike near Trefollwyn, and at the extreme south-west end at Aberffraw.

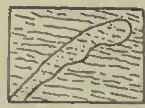


FIG. 163.
FOLIATION CROSSING JASPER.
200 yards west-north-west of Prys-iorwerth.

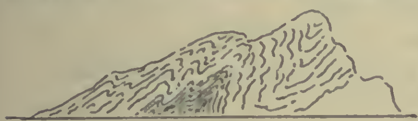


FIG. 164.
FOLDING OF A LOWER ENGAN SPILITE.
CRAIG-LÂS.
Five feet high.

The Western Tracts.

The Gwna sediments have been converted into green-schist on both sides of the Engan spilites. On the south-east, original textures survive occasionally, as at a knob north of Prys-iorwerth close to the spilite [E. 10023], and other places along the strike to the south-west, the rock being well exposed south-east of Dinas. North-west of the Engan spilites clastic textures are much rarer, and most of the green-schist is completely reconstructed, mica being often well-developed, and the aspect of the rock approaching that of the Penmynydd Zone. Quartz has separated out in great quantity, imparting a rugged appearance to the bosses, just as in the western parts of the Gwnas of the Aethwy Region, which these rocks vividly recall. There are good exposures north of the railway, and again at Soar [E. 10426], whence came the rock that was analysed. At Bryn-yr-odyn it is very typical [E. 10021], and quarter of a mile to the north is fine folding. But, consistently with the high foliation-dip, it is on vertical axes (Figs. 42, 43), with nevertheless a good pitch to the north-east. From the map it will be seen that along this tract the pitch undulates considerably, being sometimes to the south-west. Near the 12—13 milestone on the main road the type approaches that of the Penmynydd inliers [E. 6126]. Another tract of good exposures is from Tre'r-gof to near Hen-eglwys, folding being visible, with pitch first to south-west then to north-east, and sometimes a distortion of the strike. Some of the quartz-aggregates in these schists contain felspar. At a little boss 300 yards south-east of the summit of Dinas [E. 10022], this is albite, but 233 yards west-south-west of the road at Tre-ddafydd-isaf it is orthoclase. About 400 yards west of Mona House a two-inch vein with pink orthoclase cuts the foliation. The extreme western parts of the tract, and most of the north-eastern, are but scantily exposed, except among the Penmynydd inliers east of Tregaian, where there are a few little limestones. But the character of the rocks remains much the same. A few outliers have been recognised among the Penmynydd schists. A little limestone of Gwna type occurs in one north-west of Aberffraw.

THE PENTRAETH INLIERS.

The Western Inlier

is but moderately exposed, though sufficiently to show that the strike of its masses is oblique to its trend; and there is a narrow rocky ridge between Ty-coch and Tan-y-graig. Gwna Green-schist without original structures, and rapidly folded with an inconspicuous north-easterly pitch, is well seen at Bryn-gwallen [E. 6140], much jasper and purple phyllite of local Tyfry type being incorporated in it. The little inlier of Penmynydd rocks is visible in three quarries on the western side of the road near the Smithy, but its relation to the Gwna Beds is not seen, though the changes of type in the middle quarry suggest a passage. It is crystalline, with well-developed mica, and is [E. 11437—9] a true porphyroblastic albite-schist rich in epidotes and other minerals like that of Aberffraw, though less regular in structure.

The broad basic band, visible in a scattering of small exposures, is chiefly chloritic schist, much of which appears to be deformed spilitic lava; but diabasic texture survives in some of the green schists, and a rock [E. 9851] 220 yards south-south-east of the 103-foot level is an ophitic albite-diabase with pale augite. It has not yet been possible to delimit spilite and diabase in this band. At Ty-coch is a beautiful ashy rose-limestone with spilite fragments. Spilitic lavas (into which some Tyfry Beds [E. 11250] are wedged) follow along the ridge.

Tan-y-graig high boss is composed of the remarkable glassy variolite (p. 72, Plate V, Fig. 3) [E. 11222—3]. Its ellipsoids are a foot or two in diameter, with re-entering curves as if plastic when rolled over. Often they have concentric bands of varioles. The matter between these ellipsoids, usually a darker green, is highly complex, and full of banded and angular bodies. This is the fluxion-banded spilite-glass that was afterwards brecciated. Jasper occurs in some of the interstices.

The rest of the inlier appears to be chiefly Gwna Green-schist with a northerly pitch. It is well seen below Ty-coch, and at Hendre, where purple phyllite is incorporated.

Rhyd-y-saint.—Between the tongues of alluvium at Rhyd-y-saint some crushed calcareous schists are seen, showing that a thin wedge of Gwna rocks rises between the Ordovician and the Carboniferous.

The Eastern Inlier,

except at its south-western end, on which are broad spreads of drift, is extremely rocky, and the natural clusters of trees about the bosses render it one of the most charming tracts in Anglesey.

Dyffryn to Tyfry.—As the country rock of the Western Inlier, and of this one where well exposed, are known to be Gwna Green-schist and mélange, the obscure tracts in the south-west and the smooth bluffs that run on from them above the river as far as Pentraeth Mill have been coloured as such ; but there is no direct evidence of this, the few knobs that stand out of drift being chiefly spilite-schist and limestone.

The Serpentine [E. 9852], half a mile west-south-west of Tyfry, is compact and purple-green, with veins and aggregates of fibrous tremolite [E. 11387]. It shows no trace of pyroxenes, but the mesh-work after olivine, with some corroded crystals of chromite. The parent rock must have been a pure dunite. Nothing else is exposed at this boss, but a few yards to the south, a high knob of deformed jasper, chloritic schist, and phyllite contains a few seams that appear to be schistose and fibrous serpentine, and if so, the peridotite is involved in the mélange. It is probably, therefore, of the same age (see p. 211) as the larger peridotites.

Tyfry Beds.—About 200 yards from the serpentine is a steep craglet composed of hard, pale, flinty rocks [E. 9822—3] that recall those of the Cefni Dingle (p. 350), but well bedded and with some slate and fine grit. The flinty beds are clastic, and appear to be quartz-albite dusts, as do certain rocks at Newborough (p. 378), so it is possible that those of the Middle Region may be infolds of the Tyfry Beds. These now form a succession of straight ridges for a mile to the north-east. They are green and purple grits and phyllites [E. 9840, 9842], evenly bedded, the grits being comparatively fine, but full of albite and spilite. Some lateral dips indicate a symmetrical infold, but there is a steady vertical cleavage striking 20° more easterly than the bedding does. Locally they are brecciated; beds can seldom, indeed, be followed far, and at a point 400 yards west-north-west of Tyfry begin to break up into lenticles along the cleavage (Fig. 68) whose mechanics, therefore, link it with the foliation of the mélange. A thin strip of that, with a more crystalline matrix like the Gwna Green-schist, appears among the grits 200 yards to the east-north-east. The Tyfry type-grit [E. 9839] (Plate II, Fig. 6), coarser than the rest, with fragments of tourmaline-mica-schist, is in an isolated nip, well seen 120 yards east by north from Tyfry, lying between finer grits and ashy shales with hardly any cleavage, dipping at 18° north-north-west.

Tyfry to the seaward end.—All the way from Tyfry to the seaward end of the inlier there is extraordinary variety; a group of rocks with great petrographical diversity having been so cut into slips by shearing stresses that the outcrops are seldom of the same nature for more than a few yards at a time. No more, therefore, than the points of chief interest can be indicated here. The high foliation dip itself is, indeed, the only constant feature, and to this there are but few exceptions.

The broad basic band is chiefly spilite [E. 6141], but a border on its eastern side about 140 yards in width is chiefly (though not wholly) albite-diabase, in addition to which there is a train of small slips of diabase lying *en échelon* on a meridian drawn through Fferam-gorniog. As both spilite and diabase pass laterally into chlorite-schist they have been but partially delimited. Just north of the 'Ff' of 'Fferam,' the diabase [E. 9844] is coarse, with large ophitic plates of augite and small green pseudomorphs that may represent olivine. Its felspars are mere shells of albite enclosing secondary products. In the spilitic remainder of the band, pillowy structure survives well in places north by east from Fferam-gorniog between it and the road. The beautiful hæmatised variolite [E. 9843] (Plate V, Fig. 2) is from a boss 108 yards south-west of the pond at Fferam-gorniog; but variolites hardly less perfect are found at Tyfry [E. 9875], also between and in the limestones at the farm 300 yards to the north-east. They are somewhat inconspicuous in the field. Most of the spilites, however, have passed into dull, undulating green schists, full of purple streaks from hæmatisation before deformation, this colouration being often the only means of distinguishing spilite- from diabase-schist. Among them, about 133 yards north of Fferam-gorniog, is the keratophyre [E. 9874], a fine dull-green rock with little spots. The smaller basic strips along the Plâs-gwyn and Rhiwlas tract are largely spilites, but east of a line joining those houses a train of albite-diabases comes on. In one of these [E. 9830] (Plate V, Fig. 4) 500 yards north-east of Rhiwlas, though nearly all the felspars are thin shells of albite filled with sericite, a few of the original cores remain, and show that the mineral had been zonal, with centres at least as basic as andesine and probably more so.

Jasper is found everywhere, both in the spilites and the rose-limestones. An isolated boss of it measuring no less than 18 by 9 feet rises in the hollow south of the crag where the variolite [E. 9843] occurs, and there is unusually perfect spherulitic structure [E. 9877] (Plate V, Fig. 6) 210 yards west of Fferam-gorniog, close to which also the little idiomorphic quartzes are found. The typical jaspery phyllite [E. 9879], with very minute clastic micas in a siliceous base that seems almost isotropic, is from the end of the lane that comes from Rhos-cefn-hir. The limestones vary greatly, but most of them are of the rose or rose-green types, the latter often ashy. The large limestone of Tyfry shows, round the farm by the aforesaid lane, rude bedding-like structures dipping at low angles to the north-west. Here [E. 6142] it is in part a grey dolomite, but at Tyfry is rose-green with brown dolomitic and white calcitic veins. In and about the woods it contains the beautiful breccias with spilite fragments described on p. 83. Their best exposure is a little boss with two trees on it just outside the western corner of Tyfry wood [E. 6147], but excellent blocks of them abound in the old walls. On the western margin of the spilites, 400 yards west-south-west from Fferam-gorniog, is a rudely-banded, gneissose-looking calcite-limestone; but that at the farm itself is a rose-green dolomite [E. 9870] with many small fragments of spilite-glass; and on a boss 480 yards to the south-west one of the largest masses interdigitates with the Tyfry grits. By the farm about a quarter of a mile from the end of the inlier is a rose-dolomite rich in jasper [E. 9876, 9878] with the sub-spherulitic oval bodies (p. 85). The last boss of all, which boldly overlooks the low country by the bay, is a spilite-schist with much jasper and jaspery phyllite [E. 9880].

Mélanges.—A strip of Gwna phyllite-and-grit-mélange occurs within the Fferam-gorniog spilites just north of the position of the variolite [E. 9843]. But there is much more in the north, and to the east of Rhiwlas is good Gwna Green-schist. The state of anamorphism [E. 9850, 9933] is about the same as in the eastern Middle Region.

In many places are mélanges even more extraordinary (good localities for which are between Rhiwlas and the Three Leaps; by the gneissose limestone; and a little east of Fferam-gorniog) in which grit and phyllite, spilite and diabase, limestone and jasper, are all sheared out in thin sigmoidal overlapping lenticles, and so carded together that every rock may contain inclusions of every other rock. Had such a product been subjected to higher pressures and temperatures, so that the whole became recrystallised, it is easy to see that a gneiss would have resulted whose origin would have been well-nigh undiscoverable.

THE AETHWY REGION.

The Gwna Beds of the East.

This large region will be considered in the following order :—

1. The Menai coast (with the adjacent road and drive sections), from Gallows Point to Llandysilio Church islet.
2. The adjoining heights, from Cadnant to Red Hill.
3. The interior.
4. The eastern margin, from Baron Hill to Careg-onen.
5. The Llanddona highlands.

Some inliers of the Penmynydd Zone will also be described here.

The Menai Coast.

This affords a continuous dip-section (interrupted only by the Arenig Beds of Garth Ferry) from Gallows Point to Cadnant creek, after which the rocks are almost as well exposed along the shore and rocky isles for the rest of the way. The high-road and Baron Hill drive, which run just above the shore, will be considered along with it.

The best part is from Gallows Point to Garth Ferry, a cliff 20 to 50 feet in height, richly overhung by woods ; but an ebbing tide should be selected, some parts being difficult to study or even traverse at high water. From Glyn-y-Garth to Cadnant a boat is desirable, as the walls of the private grounds are an obstacle.

Gallows Point to Garth Ferry.—The first rock seen is a basic schist among Gwna Green-schist. Its western edge is ill-defined, so it may possibly be a spilitic tuff. The Gwna Green-schist is typical, its quartz-augen being venous, but some of them soon show clastic grains, though veiled by vein-quartz, and less conspicuously clastic than on the weathered bosses inland. There is good flattened folding, but the dominant structure is an undulating foliation-dip at moderate angles. The large basic band near the 'y' of 'Pen-y-parc' (split by a wedge of pale schist close to the plexus of little dykes) is a good example of its class ; heavy, dark-green, platy throughout, and containing little aggregates of granular ternary albite. Siliceous green-schist then rises, in which is inconspicuous clastic matter, and a six-foot quartz mass that seems metasomatic, as well as a thin basic schist that shows faint signs of diabasic texture. After the gap with dykes is a rather platy fine siliceous schist, but gritty matter follows, almost as platy ; quickly, however, becoming a 'pencil-schist' with venous augen. Beyond another dyke (which hades west) is true autoclastic mélange, full of lenticular grits, one of which, a yard in length, can be seen in the act of breaking up sigmoidally into smaller augen (Fig. 5), and, a little before a natural arch is reached that leads to the old bathing-house beach, are fine sections in mélange. But the matrix is far better foliated than in the Middle Region. By the arch are some red grits.

Beyond the beach the large limestone is well exposed, mostly massive, but including several feet of purple and green-schists, as well as lumps of jasper. Fig. 165 represents the base, a good deal simplified. Some purplish banded rocks are hæmatised ashy calcareous beds with fragments of albite and keratophyre. The large basic masses that now come down to the coast are of great importance, as they are evidence of the nature of the many basic schists of the region which have been completely reconstructed. The first is mostly a chloritic schist, but contains large cores in which are sheared ellipsoids with remains of concentric structure, and little spherulites. Mélange rises from beneath it, in which are basic lenticular bands a foot or two thick, some only two inches thick, but with sharp junctions. Beyond these is a flaggy grit with fragments up to a quarter of an inch in diameter of salmon-tinted acid igneous rocks. A fault bounds them, and the next basic schist has obscure ellipsoids only. Pebbly grit again follows, rich in the same fragments. They are [E. 11196] albite-quartz-felsites and albitic hypabyssal rocks like those of the Skerries Grits (p. 60), with keratophyres. The matrix is full of secondary chlorite and white mica. Beyond a spur of grit a great scree from road-widening makes a landmark; and then follows another sheared spilitic lava with lenticular jaspers and remains of ellipsoids, but with the dark skins between them now become a contorted schist. Yet only a yard away perfect little spherulites have survived in it. A few yards further on ellipsoids about a foot in diameter are perfectly clear, with dark skins in which are spherulites [E. 11194—5]. The augites have disappeared but the felspars are fairly preserved, the rock resembling the typical Newborough spilite [E. 9895]. The felspar spherulites resemble those of E. 9956, 10339, and the base was probably a glass. Then, on a spur of cliff all these volcanic structures are seen better still; yet at the foot of the spur are sheared into a platy green schist with no trace of them perceptible. Another spilite follows. Thence to Garth Ferry, along a straight stretch of coast where exact positions were difficult to get, is Gwna Green-schist with a little grit, and several basic bands, one or two of which retain traces of ellipsoids. The general structure is lenticular, with undulating dips, and a few folds.

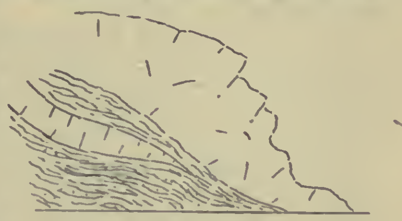


FIG. 165.
BASE OF LIMESTONE.
South-west of Pen-y-parc, at Bath House, Menai Strait.
Height: about 10 feet.

The Road and Drive.—Parallel sections at successive levels of about 80 and 180 feet are afforded by the Beaumaris road and the Baron Hill drive, besides which the wooded face of the plateau and its edge at the 300-foot contour are hardly less craggy, so that the behaviour of the rocks can be studied through a depth of 300 feet. The larger basic bands are cut by several of these parallel sections;

and we find, first, that their margins practically coincide with foliation planes, showing the foliation-dip to be locally a true dip; and secondly, that the masses wedge-out as often downwards as they do upwards.

The rocks are very fresh and good in the cuttings on the road, the analysed specimens of Gwna Green-schist and spilite-schist [E. 9911, 9913] having come from 760 and 850 yards north-east of the Ferry Inn respectively. The spilite-schist is platy here and original structures hardly visible. The sections have been altered and some of them a good deal improved since the ground was mapped, by the straightening of the road. This is the case with the fine cutting in the bath-house limestone; here a beautiful rhodochrosite-dolomite with some white mica [E. 9932]. Some of its jasper is tabular. Smaller lenticular limestones are to be seen close by (Fig. 166).

FIG. 166.—LIMESTONES IN GWNA GREEN-SCHIST.
About four feet and three feet thick.
Roadside, about 200 yards west of bathing house.

Just inside the gates of the drive a large lenticular limestone appears at the top of the cliff among Gwna Green-schist which is dipping at very low angles, and low dips, even of overfolding, are prevalent for some way. About 310 yards from the gate is a fine group of lenticular limestones (Figs. 78, 79), one of which is contorted. Just beyond, the jaspers are sheared in among a micaceous Gwna Green-schist as thin lenticular seams [E. 9965] contorted with it, forming, indeed, a member of the foliated complex, as described on p. 88. A massive green rock not far from the gates retains broken large augites and albites with traces of ophitic relations, and was evidently an albite-diabase. There are also excellent sections in mélange.

Garth Ferry to the Church Islet.—Returning to the coast beyond the Ordovician grits, the first rock is a siliceous and micaceous Gwna Green-schist in which clastic grains are just discernible. But the grade of metamorphism has risen, and original structures can hardly be made out all the rest of the way. Before Glyn-y-garth terrace interrupts the section a strong platy chloritic schist appears, but it seems only sub-basic, is interbanded with micaceous green-schist, and may be a spilitic tuff. Beyond the terrace are many torn strips of similar sub-basic schist.

The coast under the grounds of the next house (Glan-y-Menai on the six-inch map) is of importance because for nearly a quarter of a mile the Gwna Green-schist becomes so micaceous that in a region of the Penmynydd Zone it would not have been separated out. The section is troubled by a quartz-vein, which has been searched for copper, but this is not a boundary, for on its outer side a complete passage can be seen from nemablastic Gwna Green-schist into this Penmynydd type. The position is on the strike of the glaucophane-schist of the wood west of the Ferry Inn (see p. 119) [E. 9526, 11088] which rests upon mica-schist also of Penmynydd type. On the same strike is the drive of the new house immediately above the high road at the Ferry, and at the foot of this drive is Gwna Green-schist rather more micaceous than usual, followed by the same still more micaceous, until at the turn of the drive, just on the strike of the bed below the glaucophane-schist, is good mica-schist but with typical Gwna local structures. Mica-schist has lately been exposed also on the roadside by the post office. The tract is undoubtedly a small inlier of the Penmynydd Zone, with the belt of transition exposed both on the shore and in this drive.

A little point, east of Craig-y-don house, shows a good junction, with alternations, between basic and siliceous schist, and then a fine section follows in rock largely composed of lenticular, folded pegmatoid quartz-augen as much as three inches thick, in which are albite and anorthoclase. Thence to Cadnant Creek is Gwna Green-schist, with occasional basic schists, containing red albite-aggregates like E. 10031. The two Craig-y-don islets are of a rugged nemablastic siliceous type, with some similar basic rocks. Ynys Gaint (accessible by a causeway except at high water) affords fine sections of the same rugged siliceous schist, with undulating constricted augen, which on the outer summit are contorted, and the whole rock strongly gnarled (Plate VIII, also Fig. 6). The type is dominant on the succeeding islets and rocky shores under the village and past the Suspension Bridge as far as the Church Islet, where the change to the Penmynydd Zone comes on (see pp. 124, 366).

But it has already begun, for glaucophane is found in the basic schist on the shore east-south-east of the island church [E. 10208] (p. 120). The polyclinally folded Gwna rocks in the pine wood east of the islet-causeway are extremely siliceous, and the sections are some of the best for a study of the pencilly pitch that results from nemablastism. They also show signs of the approaching change, mica being better developed than in the typical green-schist [E. 6093, 10033—4]. The quartz of these augen may be studied in E. 9861—2, 9985, from the Smithy islet and from north of the 'y' of 'Llandysilio,' at both of which places it contains albite. In the pine wood are two little outliers of chlorite-epidote-schist [E. 10031—2], with the aggregates of reddened ternary albite and quartz that are generally to be found in these rocks near the Penmynydd Zone in the Aethwy Region.

The Heights from Cadnant to Red Hill.

On the high brow that looks down on the woods north-west of Plâs Cadnant are fine examples of the Mélange with lenticular grits, cases being seen of sharp folding of a phacoid on itself

(Fig. 77), and many (especially the red grits) that show clearly a development of nemablastic structure at the ends, as well as others where venous is effacing clastic texture. One of them [E. 10787] contains a little microcline, and garnet with polygonal outlines, curiously cased in chlorite and quartz. In the ravine [E. 10786] is a compact rock with generally low refractive index that seems to be one of the quartz-albite dusts. Along the rocky heights to Pen-y-parc lake are many similar sections (with grits that contain much albite [E. 10788]) and others (Fig. 167) that show basic schists and limestones lying as lenticles within the mélange. On and south of the open common of Cyttir Llandegfan are perhaps the best localities for a study of the later cross-corrugation (Fig. 80) described on p. 200, which trends here about west-north-west. At the farm 300 yards east of Bryn-meurig is a rose-dolomite [E. 6091] with jasper and purple phyllite; and a curious variety of the spilitic suite—composed of a crowd of idiomorphic augites in a faintly schistose matrix of chlorite, epidote, and leucoxene, with chlorite-albite veinlets, which may be an augite-tuff [E. 9845]. About the next farm the lavas have passed into leucoxene-chlorite-schist [E. 9846], which contains lenticular jaspers, partly bleached.

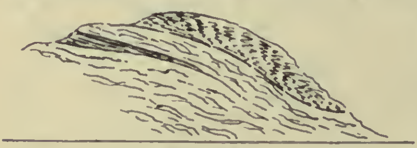


Fig. 167.
Basic Schist in Gwna Green-schist.
500 yards west of Garth Ferry Inn.
Height: about four feet.

About Pen-y-parc lake the fine banded siliceous schist [*cf.* E. 9824] is well developed, and shows the most regular folding seen anywhere among the Aethwy Gwnas, crossed by the later folds. Mélange comes on again at once, with foliated grits [E. 10792], whose foliation is occasionally folded over sharply within the lenticle, about 120 yards south-east of the lake. By the woodside farm north-east of the lake is a grit [E. 6091] containing a granitoid fragment. In the midst of this mélange lies the large quartzite of Pen-y-parc [E. 6096, 10802], a lenticle which can be traced down to the wood, followed by two smaller ones a few yards further east. The old quarry by the farm-house affords a fine section, on whose north-east cliff some isoclinal folding of schist and quartzite was to be seen 20 years ago (Fig. 168). At the edge of the wood, 233 yards east of Pen-y-parc, is a chloritic rose-dolomite [E. 9802] with trachytic lapilli and groups of clear secondary albite. The large chlorite-epidote-schist [E. 9812] with which it inosculates, is cut off by the fault that partly bounds the Baron Hill outlier. In the midst of it, just north of the road, is a singular brick-red rock [E. 9970] with a fine schistose matrix of rf. ind. about 1·536, in which are many good-sized phenocrysts of albite, evidently a sheared albite-trachyte.

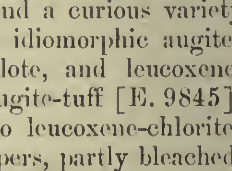


Fig. 168.
Eastern side of Quartzite, Pen-y-parc.
Height: about 10 feet.

The Interior.

The greater part of this (away from the Penmynydd march-land, which is not well exposed) is composed of mélange. Spots of special interest only will be indicated. The grey dolomite of Pedair-groeslon [E. 10801 and analysis] closely resembles the Cemaes limestones in general aspect. It lies in Gwna Green-schist, in which no graphite-schist or quartzite has been found. A train of thin purple phyllites runs from Pedair-groeslon to Llansadwrn, which are not true jaspery phyllites, but [E. 9953] the albitic type mentioned on p. 68. Good exposures of folded mélange full of lenticular grits [E. 6086, 9811, 9934, 9809, 9825, 9801, and analyses], and green-schist (Plate IX, Fig. 2) are to be seen at Llansadwrn. Their quartz includes needles of apatite and zircon, and E. 9801 which is red, contains granite and micro-pegmatite. Fig. 169, which was drawn in

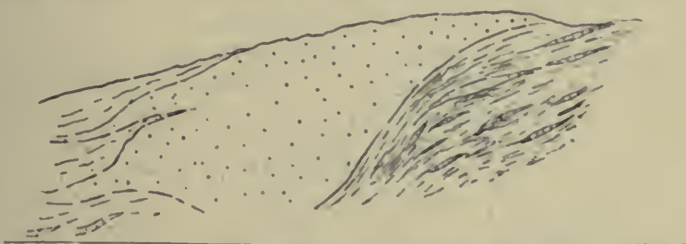


FIG. 169.—LENTICULAR QUARTZITE.
Three and a half feet long. In Gwna Mélange, Llansadwrn.

1896, by the 'S' of 'Smithy,' had become overgrown in 1911, but there are quarries by the road-fork between the church and Tai-lawr, and good bosses towards Ucheldref, where four quartzites appear. By the footpath north of the 'S' is a deformed spilitic lava with jasper, which retains traces of original structures.

An interesting group appears 266 yards west of the roadside corner of Hafotty Covert. In mélange whose matrix [E. 9968] is rather more crystalline than usual, is a chloritic rose-dolomite [E. 6097] which contains the type-jasper [E 11224] (Plate V, Fig. 5), with hæmatite aggregates in the cores of quartz-grains. This limestone contains lapilli of hæmatised spilite; and close to it is a six-inch bed of spilite-tuff, one lapillum of which is porphyritic, with a twinned albite a quarter of an inch long. The little ravine at Cremlyn is cut in siliceous nemablastic schist [E. 6088] with a large rose-dolomite containing jasper [E. 10004] now slightly schistose. A few yards to the east is a purple schist that simulates a jaspery phyllite, but is really a porphyritic spilite, hæmatised and schistose. Hæmatisation is clearly older than deformation, and some seams of granular ternary albite are unhæmatised [E. 10005]. There is another rock like it [E. 6087] south of Hafotty Covert.

The Eastern Margin.

This is a zone of siliceous Gwna Green-schist, highly nemablastic, though with ashy grits near Nant woods [E. 10799], and remarkable for the train of great sigmoid lenticular basic masses that strike north from Bod-gylched to the sea, and are well exposed about Carwad and Bryn-cogail. They are platy green-schists, which, as the rose-limestones and jaspers accompany them, are doubtless for the most part modified spilitic lavas. At Bod-gylched one of them [E. 6085] seems to be a modified albite-diabase; while another [E. 10797] is a fine epidote-chlorite schist with alkali-felspar and some amphibole; and a thin one at the north end of Cremlyn alluvium is blue, as if with glaucophane. But they need further petrological study.

The jasper [E. 9847] that underlies the limestone between Carwad and Bryn-cogail is pale, micaceous, and a link with the jaspery phyllites, but though highly reconstructed contains rhombs of carbonates. On Llaniestyn common, just west of the church, the micas of the green-schist are unusually developed, with which is doubtless connected the nature of the large basic mass running northward from the church (see p. 119), where the reconstructed lava seen at the church farm [E. 9691] strikes at the glaucophane-schists that appear on the bosses south-east of Ty-du, whose powder yields glaucophane in moderate development. The pitch undulates remarkably about Llaniestyn, and 300 yards east of the church farm the cross-folding is a distinct over-drive northwards up a southerly pitch.

The schist of the coast at Careg-onen is nemablastic and siliceous [E. 9790, 9810], but its basic bands are of intermediate character and do not seem to represent the spilites. They may be impure tuffs, but need further study. Still more doubtful are the dull-green rocks at Pen-yr-allt, Llanddona [E. 9797] which may have been somewhat silicified near the lead-veins (see Chapter XIX).

The Llanddona Highlands.

This will be a convenient name for an extremely rugged tract, 400 to 500 feet in height, with a scenery that in its wild western parts adjoining Mynydd Llwydiarth recalls that of the Lewisian Gneiss of Scotland. The Gwna Green-schists, which strike across the heights, are very siliceous, corrugated, and strongly nemablastic [E. 9848]. Untwinned albite is not uncommon.

The most remarkable feature is the extraordinary number of little lenticular strips of basic schist. In a quarter of a square mile near Ty'n-y-mynydd-'east' (to be distinguished from the western farm of the same name) 100 of these have been laid down upon the six-inch maps, and had the ·0004 scale been used many more could have been shown, yet the map would still have been but a rude abstract of nature. These basic rocks need further study. So far as is known, they are [E. 9831—2] (Plate IX, Fig. 3) chlorite-epidote-schists with some development of minute actinolite and seams rich in granular ternary albite (see p. 77) often slightly reddened, as in E. 10031. As these are characters of spilite-schists, it is to be supposed that most of them are derived from spilites. Yet (unless it be the source of their siliceous seams) no jasper has been observed in them; so albite-diabases may be largely represented.

The powder of the large basic schist above Wern yields abundant glaucophane in good development, and the rock is freely exposed. That a rise in crystalline grade appears in the siliceous Gwna schists has been mentioned on p. 125, and can be seen easily by traverses down the rugged slopes from the south. But the complete passage to the Penmynydd Zone is cut out by a considerable rupture that bounds the glaucophane-schist on the south-east, bringing chlorite-epidote-schists against it, and giving rise to a strong steep feature.

The rugged Llanddona highlands afford, on their innumerable bosses, the best possible sections for a study of the structures of the nemablastic schists. The various types of quartz that separated at successive stages of the metamorphism can be seen almost anywhere, especially by the hollow some 200 yards north of Ty'n-y-mynydd-east. North-west of Rhos the close connexion between nemablastic pencils and the corrugation of locally thickened seams of quartz may be studied. A strong straight 'slack' or hollow evidently along a fault crosses the hills at the parish-boundary, and at this, west-north-west of Ty'n-y-mynydd-east, a-clinal folding is combined with a vertical dip (Figs. 54, 55). On its eastern side, polyclinal folding (Figs. 57—60) is to be seen in many places, though often confused by the local thickening of the quartz-seams. Sometimes there is evidence of torsion, for, 200 yards north-east of that farm (and elsewhere) the nemablastic lines pass obliquely across the crests of anticlines, as if there had been some shifting along the strike at the time of the crumpling. The angle of pitch varies a good deal, as at the southward end of the great slack, where it changes from 5° to 20° in 34 yards. About 170 yards to the north-north-west a complete phacoid of basic schist is cut through as in Fig. 170, where the pitch is at a gentle angle into the crag-face. Near the middle of the slack on its western side the annexed plan (Fig. 171) shows a small basic schist crossing the strike. It is inconspicuously folded on the same scheme as the coarse and ruggedly gnarled siliceous

FIG. 170.
BASIC KNOT IN GWNA GREEN-SCHIST.
250 yards west of Ty'n-y-mynydd-east.

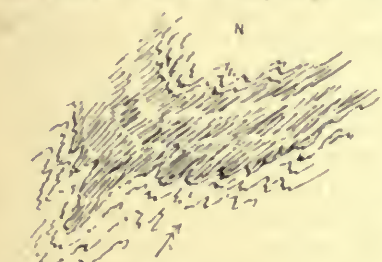


FIG. 171.
BASIC SCHIST CROSSING THE STRIKE.
About four feet.

schist. The plan and section (Fig. 172) show the effects of pitch on similar bands. One of the best sections that exhibit the relations of the masses to folding and foliation is about 150 yards north of the south end of the great slack (Fig. 173). Both basic and

FIG. 172.—SECTION AND PLAN OF BASIC AND ACID SCHIST.
Height: about six feet.
460 yards north-north-west of Ty'n-y-mynydd-east.

siliceous schists are folded together, the pitch being away from the eye at a gentle angle. It will be noticed that the true dip is on the whole in a direction opposite to the foliation-dip and to the plunge of the axes of the little isoclinal corrugations.

THE PENMYNYDD ZONE OF THE AETHWY REGION.

By far the best exposures are on Mynydd Llwydiarth, but as there are some structural peculiarities at that hill, the region will be described in the following order. First: the eastern and south-eastern margins from Llandysilio and Castellior to Newborough, then the north-west margin from Newborough to Plâs-gwyn, then the centre from Newborough to Tre-for; then Mynydd Llwydiarth. Some inliers from the Zone have already been described on pp. 361, 364—5.

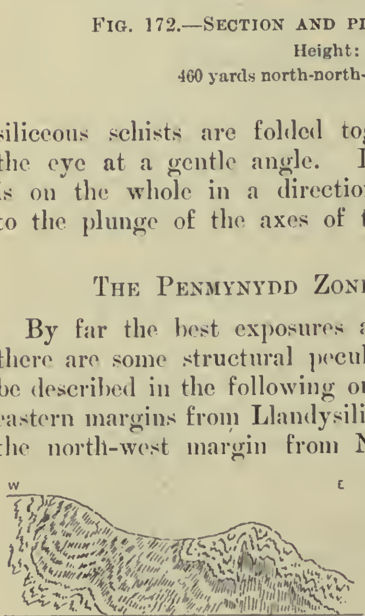


FIG. 173.
CHLORITE-EPIDOTE-SCHIST IN GWNA GREEN-SCHIST.
Foliation-dip counter to true dip.
250 yards south-west of Ty'n-y-mynydd-east.
Height: about one foot.

The eastern and south-eastern margins.

On the Menai shores by the island church the gradual on-coming of the Penmynydd Zone, though not laid bare in continuous exposure, is quite manifest on the group of rocky knolls and islets. Heralded by the increasing size of the micas in the nemablastic siliceous Gwna rocks in the wood [E. 10033—4, 6093] (see p. 124), the passage may be said to begin on the shore east-south-east of the church, where the basic schist [E. 10208, and analysis] (p. 78) contains a little glaucophane. The line, however, has been drawn where, north-west of the church, unmistakable holocrystalline mica-schist first appears, which is a compact albite-quartz type where it adjoins the basic schists. At the little headland north of the church islet those are in about the same crystalline condition as E. 10208, true transition rocks, with ternary albite [E. 10035—7]. Beyond them it has, in common with the adjacent Gwna rocks, a somewhat nemablastic structure. The shore is a good section under the woods and railway bridge as far as the base of the Carboniferous rocks. On the church islet the types are transitional, but all the other islets are crystalline mica-schist (the western ones highly so) (Fig. 174), and worthy of note because two of them are very near to Carnarvonshire and yet show not a trace of decline in metamorphism. One more transitional rock should be noted—the narrow basic mass along the road at Pedair-groeslon (see p. 119). North of Yr-allt this resembles the green chlorite-epidote-schists with reddened albite usual in the Gwna tract, but west by south of that farm becomes a good glaucophane-schist. Whether the two types are continuous is not known, but they strike at each other, and the green chlorite-epidote-albite-schist contains [E. 6092] large hypidiomorphic glaucophanes, leaving little doubt of the continuity. . The siliceous schist adjacent to the blue glaucophane-schist on its western side has the aspect and the nemablastic pencils of Gwna Green-schist, from which it differs only in a better development of mica, and is a passage-type to the Penmynydd Zone.

FIG. 174.
BIOTITE-AUGEN.
GORED ISLET.

The Great Glaucophane-schist, the largest known in the British Isles, extending over more than two square miles, is well exposed from the Column to beyond the Cromlech, at Dyfnia, Felin-engan, and Castellior. With the exceptions presently to be noted, it maintains all the characters described on pp. 115—18 with great uniformity [E. 1644—5, 9789, 9829, 9866—8, 9924, 10767—8, 10770—71]. It is powerfully folded, with a pitch (occasionally high) to the north-east, and the foliation-dips and overfolds indicate thrust from the north-west except at Dyfnia. Little cross-wrenches occur at intervals, and at Castellior near the dyke are themselves overfolds from the south-west. There are also larger cross-folds overthrust from south-west, themselves crossed by little ones at a lower angle (Fig. 175). A core with hypo-plutonic texture appears near the north end of the Dyfnia bosses by the river; and another at the first 'w' of 'pwllgwyngyll,' but this [E. 9853] contains no true glaucophane, and is a foliated zoisite-albite-amphibolite with broad plates of faintly-bluish hornblende. Small porphyroblasts of glaucophane may be found 225 yards west of the Cromlech. The large knots of glaucophane-epidosite [E. 11141] which may represent the ellipsoids of a spilite (pp. 117, 120) are well seen at Felin-engan; and on the Column crags, especially alongside the footpath going north-westward through the little wood where the crag looks down upon it. The great glaucophane-schist is nearly split by a long curving wedge of mica-schist, well seen west of Pedair-groeslon, so crystalline as to suggest that part of the zone of passage from the Gwna rocks may be cut out by a slide. Its

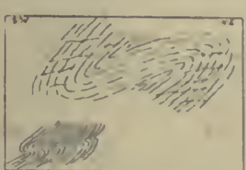


FIG. 175.
CROSS-FOLDS IN
GLAUCOPHANE-SCHIST.
Castellior.

felspar seems all albite, it is rich in epidote, and is one of the few Pennynydd rocks that contains a little tourmaline [E. 9827]. By the roadside east of the bridge at Felin-engan some hard flaggy siliceous bands occur in the glaucophane-schist which resemble the banded marginal rocks well seen elsewhere, and the loose blocks not far off show that the type must be well developed below the drifts.[1] Finally; it may be convenient to add that fresh specimens of the glaucophane-schist can be obtained from the roadside quarry 250 yards east-south-east of the Column, about five-eighths of a mile from Llanfair Station.

Trefor and Pen-hesgyn to Newborough.—From Wern to Trefor the eastern margin is obscured by drift, but the Trefor inlier is fairly exposed and contains thin glaucophane-schists. Returning south-westward, the mica-schists are well seen at several places between Pen-hesgyn and Bryn-gof, and the line is one where some overfolding from the east has taken place, though the usual westward foliation-dips are not entirely excluded by this. But this folding calls for further study. The analysed specimen of mica-schist [E. 9912], (p. 112, *cf.* also E. 11372—3), was from this tract, at the bosses on the north side of the road near Braint farm; it contains twinned albite and much epidote. The analysed hornblende-schist [E. 9914] from the large knob 400 yards west of Sarn-fraint bridge, is rough rather than platy. Beds, a yard or so thick, of the usual hard mica-schist occur in it. From the same basic band, and not far off, must have come the interesting variety collected by Blake [E. 10766], containing a blue-green amphibole with low extinction angles allied to but not glaucophane; while, further south [E. 10769] the band contains a little pale glaucophane.

The two hornblende-schists that run towards Bryn-celli-ddu are but moderately exposed. A gently curving anticlinal axis of pitch runs nearly west-south-west past the Carnedd, beyond which the pitch is southerly as far as Pont Dic, where the normal northerly direction is resumed. There are good exposures along the river between Crug and Dic bridges, the schists striking sharply at the Carboniferous boundary. A good deal of flaggy rock occurs here as well as the normal type, and hard fine seams adjoin the thin hornblende-schists, a good junction (Fig. 176) being visible on the easterly one opposite Gwydryn. By the footpath north of Pont Dic is a pink albite-mica-schist rich in garnet [E. 9918]. The great basic masses that begin at Bodlew are but scantily exposed for some three miles: indeed the tract on the south side of the river from Trefwri to Tre-anna has been coloured on hardly any

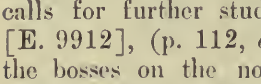


FIG. 176.

HORNBLENDE-SCHIST ON MICA-SCHIST.

Three-sixteenths of a mile south-west of Rhos-gerig.

[1] *Note just before going to press.*—Can it be that they are of the same nature as the hard siliceous bands in the Engan spilite (see p. 352), but in a much more advanced stage of dynamic metamorphism? It has already been suggested that the glaucophane-schist may represent that spilite. The specimens are not at the present moment accessible, and the point will need further investigation.

better evidence than that of the Dwyran strike and the contents of the drifts. A chain of scattered bosses ranges from Llysllew to Pont-mynach, along which the hornblende-schist has a tinge of blue and has yielded glaucophane at Bodrida by the roadside, though opposite Bryn-gwyn [E. 10764] it is normal. The adjacent mica-schist, mostly of the usual types, contains, a little south of Bodlew [E. 10747], a large broken compound felspar that is chiefly microcline. The Dwyran ground is rocky, the schist fine and blue enough to look like a true glaucophane-schist, but four powders examined yielded no good glaucophane, the amphibole being partly green, partly indefinite with low bi-refringence. These rocks call for much more examination. On the western side of the river several thin bands of compact mica-schist lie within them, and (90 yards north-north-east of a small house) there is a singular breccia that seems ancient. From Llangeinwen Church to the dunes they are obscured by drift.

Along the Braint both foliation-dip and fold-axes have been very high, but at Newborough they are first overdriven from the south-east and then roll over on an anticline. The mica-schist [E. 10742] is normal. The large basic mass of Newborough is glaucophanic in its north-eastern parts, but between the village and the southern dunes [E. 9971, 10763], where there are good sections, is a typical hornblende-epidote-schist rich in granular albite, and with singular spherical groups of epidote that may possibly represent spherulites. Perhaps a spilite and a diabase have been sheared together.

The north-western margin.

Newborough to Llangaffo.—Along the rocky hills that look down upon the Malldraeth Marsh the Penmynydd rocks are well exposed. By a little farm half a mile west of Tyddyn-pwrpas, Newborough, the mica-schist has broken down into a singular schistose breccia, probably a product of the last movements of the Complex. The marginal mica-schist varies a good deal, but contains plenty of fresh albite [E. 10743] even when fine. At Bryniau some varieties [E. 9917] are dark with oxidised biotite. The long, broken train of basic rocks is largely green hornblende-schist, but glaucophane begins to appear, and thence to the railway the broader bands all contain glaucophane. From Tyddyn-fawd as far as the Glan-morfa bosses there is most intimate interfelting of basic and siliceous rocks, the seams being only half an inch or less in thickness, the acid ones occasionally [E. 9915] not very compact, but containing rounded small porphyroblasts of albite. On the bosses north-east of Tyddyn-fawd these banded complices are powerfully folded, the glaucophane-schist being traversed by a second foliation (a very rare phenomenon in the Penmynydd Zone) which, however, almost dies out in the acid seams (Fig. 90). Connected with this may be the fact that a quartz-vein filling an old fault in the glaucophane-schist is itself crossed by the foliation (Fig. 177).

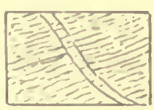


FIG. 177.
QUARTZ-VEIN in fault, crossed by foliation of glaucophane-schist.
Farm north-east of Tyddyn-fawd.

Llangaffo Railway Cutting is of exceptional importance because, between Plâs Llangaffo bridge and the marsh, it lays bare 466 yards of continuous section on whose northern cliff the relations of the several basic and acid rocks [E. 6110, 6130, 8529—34, 8543—6, 9190, 9557, 10765] are seen quite clearly. The ·0003 plan (Fig. 178, reduced from a ·0004 plan) will be a guide on the ground. The mica schists are on the whole rather flaggy, but highly crystalline. The western basic bands are hornblende-schist, but the eastern one is a tolerably coarse foliated diorite with deformed bodies that were evidently phenocrysts of felspar. On its margins (as well as along some internal planes of shearing) it passes into hornblende-schist, thin bands of which alternate rapidly with mica-schist. Rapid alternation occurs also near the other basic masses, and there is a thin acid band in the midst of the diorite. About 12 yards west of the diorite some dark knots appear within the mica-schist, which are locally thickened bands that alternate marginally with it, and are intensely contorted (in their thinner parts) on horizontal axes. Their nature is uncertain, as they are now [E. 9190] crushed quartz-epidote, and chlorite-epidote aggregates, with distorted flakes of white mica, and some carbonates. Near the west end of the larger hornblende-schist, their foliation sweeps across that of siliceous mica-schist without any disruption plane, as if they had appeared at a late stage of the Complex. With this exception, the relations of all the rocks are those of common and conformable foliation. Wedges of siliceous mica-schist plunge down from above into one of the western hornblende-schists, but they are sharp synclinal nips in a compound anticline upon which the hornblende-schist is rising. Where the mica-schist adjoins any of the basic rocks, it assumes the compact marginal modification so often alluded to (p. 121). Some of such, high up on the cliff close to the diorite, appear from below to be tongues of acid matter intrusive in the basic. But on close inspection they are found to be true bands, conforming to the foliation of the basic schist, rapidly folded along with it, and with a faint internal parallel banding that is folded also in the same way. No junctions in the cutting can be regarded as original,

FIG. 178.—LLANGAFFO CUTTING. ·0003 plan.
Hornblende-schist and Diorite shaded. Mica-schist unshaded.

but the close association of the hard bands with margins of basic rock suggest an early thermal induration that conferred powers of resistance to deformation.

Llangaffo to Berw.—At Hendre-gadog is a schist with 'spangle' micas oblique to the foliation; and about Treferwydd are coarse, gneissose-looking mica-schists with dark bands that contain a biotite with variable axial angle. The pitch here is locally high, and even vertical with sharp folding. There are cases where the overfolding of soft beds in a nip (Fig. 179) is from a direction opposite to that of the main fold.

FIG. 179.
FOLDING AT TREFERWYDD.

FIG. 180.
SHARP SMALL FOLD ON FOLIATION-DIP OF MICA-SCHIST.

Some of the best sections of the zone are between Berw and Bwlch-gwyn. On the rocky moor about Bryn-tirion are long straight trains of the venous quartz-phacoids, overlapping *en échelon* (Fig. 181), themselves often split by bays of mica-schist, but not sensibly affected by the folding (which is at intervals, in short hitches, as in Fig. 180), and on a boss 100 yards south-east of the 178-foot level one of them (Fig. 182) truncates granoblastic lenticles. At the northern cottage in the moor is flaggy moine-like rock [E. 9916] with small idiomorphic garnets; and 90 yards south of the 178-foot level are rounded porphyroblasts [E. 9919] chiefly of albite but some of micro-perthite. The hornblende-schists near Berw are of the platy type with occasional 'feathery' needles, many small lenticular albite-pegmatites, and at a railway cutting 120 yards south of Plâs-berw plates of a white mica with a wide axial angle, probably paragonite. In and alongside of these hornblende-schists, south and east of Plâs-berw, is perhaps the most minute interfelting of basic and acid schists to be seen in Anglesey, the alternating bands ranging from an inch or half an inch in thickness down to mere films, and remarkably even and parallel. The white seams are granoblastic albite and quartz with a few garnets, the dark seams chiefly straight prisms of hornblende with many of blue-polarising zoisite, some of which have cores of epidote [E. 9885].

FIG. 181.
VENOUS-QUARTZ PHACOIDS IN MICA-SCHIST.
Near Berw.

FIG. 182.
THREE-INCH VEIN-QUARTZ LENTICLE TRUNCATING VEIN-QUARTZ SEAMS.
Near Berw.

Holland Arms.—North of the main road the mica-schist is as highly crystalline as anywhere in the Penmynydd Zone, so that the survival close by of original structures is remarkable. It is rapidly folded, sometimes a-clinally, on axes pitching north-east (most of the foliation-dips being high), with corrugated quartz-phacoids (Plate XI), all well seen west of the little wood north of the church. The lenticular orthoclase-pegmatites are better developed here than anywhere, especially in the little wood itself. The important knob discovered by Dr. Callaway (p. 122) whence came the specimen E. 8485 with felsitic texture, and the analysed specimen E. 8486, as well as E. 8487—8494, 9170—73, will be easily found by the reduction from the ·0004 map (Fig. 10). The slides E. 8496—8, 8526—8, 1548—9 are from the immediate neighbourhood; as well as those of the hornblende-schist E. 8536—40, 10776, 11380—81, of which E. 8537—8 contain beautiful albite-quartz seams.

The hornblende-schist with its hard adinolic inclusions [E. 9884, 9925] can be obtained fresh (occasionally with 'feathery' porphyroblasts) from the roadside quarry close to Graig-fawr. But it is far better studied on the great natural bosses at and south-west of Bwlch-gwyn. Fine and well-foliated for the most part, its contrast with the coarse gneisses across the fault is pronounced, yet it contains cores of dioritic matter a yard wide, never, however, so coarse as the gneisses. The lenticular albite-pegmatites here attain a foot in length, and pass into seams which transgress the foliation. Some of them are, as has been remarked on pp. 115, 199, slightly foliated, indicating a pause in the anamorphic process. The hard fine inclusions that may be zoisitic adinoles (p. 121) are greatly developed close to Bwlch-gwyn, where they are sometimes flaggy with fissile partings, containing also pegmatitic eyes, and a network of thin veins that do not pass outside them. Many are large enough to be shown on the ·0004 maps. There is also a larger acid mass, which is nearer in character to the ordinary mica-schist.

The Centre.

The tract from Newborough to the main line of railway, though deeply drift-laden, seems to be chiefly normal mica-schist. There is a curious variety [E. 10745] that is albitic with vermiculite aggregates. The compact felsitic rock [E. 9480] that resembles E. 8485 but contains quartz-albite pseudomorphs of porphyritic orthoclase (p. 123) was obtained from a quarry in a field 500 yards west of Myfyrian (Myfyriant-isaf of the six-inch map) near Gaerwen Junction. The adjacent mica-schist, though rather fine, is well foliated and even folded, with quartz-augen two feet long. At and south-east of Bridin the quartz-augen [E. 9863—5] may conveniently be studied. On the boss overlooking the south side of Bridin farm-yards the three types of quartz (p. 111) are well seen; and some very thin trains of mica-flakes are sharply doubled on themselves inside one of the fine granoblastic bands (Fig. 183). On Penmynydd are fine exposures of rather massive and granular types. The Zone was named from this place because no other member of the Mona Complex is present there. On the boss by

FIG. 183.
INTERNAL CORRUGATION IN FOLDED SILICEOUS SEAM A FEW INCHES THICK.
Bridin Farm-yard

the pitch-arrow to the west of Elusendai alluvium a small vertical hornblende-schist is folded a-clinally (Fig. 56). At Bryn-eryr a hornblende-schist is finely folded (Fig. 50) isoclinally.

Between Pen-y-garnedd Inn and the marginal dioritic Gneisses the mica-schist is generally normal, except (as usual) close to the basic schists; but the basic schists themselves are interesting because, though their amphibole is chiefly green, they contain glaucophane in places. The Pen-y-garnedd band is a green hornblende-epidote-schist [E. 9828] with albite and a pale mica a quarter of a mile north of the Inn, and so minutely corrugated as to show this in thin section; but just south-west of the Inn it is faintly blue, contains glaucophane, and shows large folds. The Careg-landeg band, 475 yards south-west of the house, is green, but contains glaucophane, some needles of which also occur in the inclusions of mica-schist (Fig. 184) which it contains at the same place. Blake's slide [E. 10784], an albite-hornblende-epidote schist with delessite, and containing another amphibole allied to glaucophane, is evidently from the same band. Just outside the corner of the woods east by south from the 's' of 'Leaps' is a dark schist with a good black streak, which may be graphitic, but the dark mineral has not been investigated. It is the only such rock known in the Aethwy Region, and is unlikely to be the Gwna graphite-schist, as none of the associates of that rock have been found there. A venous origin is quite possible.

FIG. 184.

BASIC AND ACID SCHIST.

417 yards south-west of Careg-landeg. 10 feet by 1 foot.

Mynydd Llwydiarth.

Mynydd Llwydiarth (Folding-Plate VIII), which in spite of its moderate height of 520 feet is extremely rugged, far more so than many greater 'mountains,' is the best place in the Island for a study of the Pennynydd metamorphism. It rises rather abruptly at a strong craggy feature, developed along a cross-fault, the largest of a group of six that shift the main junction of the Mona Complex with the Ordovician rocks. The mountain is divided by a dislocation into two sharply contrasted parts. All its upper portions have the prevalent north-easterly strike, and are composed of acid and basic rocks of the prevalent types; but about the tarn, between them and the Gwna rocks, is wedged a long triangular tract (which may be called 'The Tarn Wedge') of compact acid schists and glaucophane-schists that strike directly at the rocks on either side (Fig. 185).

The Summits.—The mica-schist of the summits [E. 6083—4, 9849] is all coarsely crystalline and rich in well-developed white mica, the seams of which, usually thin, may be an inch or two in thickness. The dominant schist is of the lenticular type, but there is, especially about the eastern summit, a good deal of the more evenly-banded kind. Both contain abundant venous quartz, involved in the folding; that of the lenticular schist being in stout augen, often rod-like, that of the other schist being in tolerably regular thin seams. This venous quartz continually tends to become granoblastic at its edges, which is the beginning of incorporation. The mica-schists are nemablastic in thin seams only, they are for the most part granoblastic, the grains being less deeply sutured than usual, and are very rich in albite in good sized oval crystals often showing cleavage and but rarely twinned [E. 9849], with much minute epidote and a little garnet.

FIG. 185.—THE SOUTHERN PARTS OF MYNYDD LLWYDIARTH.
From the six-inch maps.
Eastern summit at the 500-foot contour.

MG = Gwna Green-schist. M = Penmynydd Mica-schist.
Mhb = Hornblende-schist. Mgl = Glaucophane-schist.
Gl-Di = Glaucophane-Diorite. D = Palæozoic Dolerite Dykes.
⋎ = Alluvium. RR = The diverging pair of Ruptures.
The symbols indicate dip, isoclines and pitch, all of foliation.

Twenty small hornblende-schists pass across the summit, east of which are two larger ones, the greater of the two ranging along the whole length of the mountain and giving rise to a dark line of rugged escarpmental crag. They are normal green-hornblende-epidote schists with granular albite [E. 11376—7], one of them [E. 10785] containing large clear porphyroblastic albites in which are needles of secondary actinolite and veinlets of epidote. At the margins of the large ones are zones of interfelting, in which the mica-schist assumes the compact adinolic modification, the finest section of which in Anglesey is below the little cottage on the crags about half a mile north-east of Ty'n-y-mynydd-'west' (to be distinguished from the eastern farm of the same name—see p. 364) (p. 121) called Gigfran on the six-inch maps (Fig. 185) where the felting resembles a strong banded gneiss. Some of the junctions are sharp, but some of the adinolic bands are shredded through and through with hornblende-schist.

The great mica-schist of the summits is overfolded from north-west, pitching to north or north-east at varying angles, often as high as 40° to 60°, so that the outcrops of bands are very curious, but the folding lacks a smooth decisive sweep. In the hornblende-schist, when visible, the folding is more decisive, and very sharp at the dip-section in the gap north-west of the cottage on the crag (Gigfran) (Fig. 51). The pitch varies, and about 100 yards north of Gigfran is vertical, so that the movement was locally horizontal (as is often the case in the Lewisian Gneiss of Scotland) and extremely violent (Fig. 61).

The Tarn Wedge (Fig. 185).—Along the foot of the great hornblende-schist escarpment runs a narrow hollow of green sward, beyond which we find a banded series dipping to the north-east and striking abruptly at the escarpment. At the junction with the Gwna Green-schist there is an equally abrupt change of strike ; so it is evident that the triangular tract about the lake must be wedged in between a diverging pair of ruptures.

Some of the smaller basic bands of this tract are green, but the great ones are beautiful glaucophane-schist, the bluest rock known in Anglesey being found above the west end of the lake. Most of it is finely foliated, but on the strong escarpment overlooking the green hollow that comes down from Ty'n-y-mynydd-west, it contains knots of green epidosite like those at the Column, and the great phacoids of imperfectly foliated material several yards long, as well as lesser ones with dioritic texture. But the glaucophane-diorites [E. 11140] described on p. 117 are best seen about 90 yards north-east of the lake, on the south side of the dyke (at the '300' on the six-inch map, and marked 'Gl-Di' on Fig. 185), some 30 yards from the alluvial tongue. None have been found quite free from foliation. The relations of the larger cores of diorite have not been seen, but smaller ones a few inches thick are completely exposed, floating in ordinary glaucophane-schist.

The banded acid rocks between these glaucophane-schists are nearly all hard compact adinoles [E. 9826] rich in albite and full of minute granules of epidote. There is, however, more white mica than is usual in this type, and it is visibly a modification of the ordinary mica-schist, strips of which remain and pass into it. It forms here a beautiful synthetic gneiss with the glaucophane-schist itself, whose margin is full of its hard sharp-edged bands up to six inches or more in thickness, both rocks folding together.

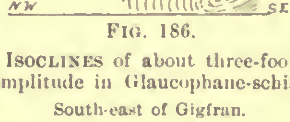


Fig. 186.

Isoclines of about three-foot amplitude in Glaucophane-schist. South-east of Gigfran.

The discordance of strike, though very pronounced in the bands considered as wholes, is not absolute, when the minuter structures are considered. For the rocks of the wedge, though dipping to the north-east, are, like those outside it, affected by an overfolding from north-west (Fig. 186) which pitches to the north-east, though the folds are usually on a small scale. South of the lake, moreover, the north-west strike begins to die away, but it is probable that the wedge is here cut off by the cross-fault that bounds the south-west end of the mountain. Northwards, however, the relations of the narrowing wedge are not easy to interpret. For, as has been shown on p. 125, there is at Hafod Leueu (Fig. 11), the cottage north-east of the 'h' of 'Llwydiarth,' a complete passage from Gwna Green-schist into the Penmynydd Zone. The eastern rupture seems, from the features, to leave the Penmynydd boundary, passing into the Gwna rocks along their strike; and it would also appear that the western one must leave the base of the great hornblende-schist to coalesce with it. The truth is that, north of the large glaucophane-schists, the north-westerly strike dies away and all the rocks begin to strike north together, with conformity of foliation, the strong feature at the base of the great hornblende-schist dying down. It is likely that both ruptures belong to the period of the metamorphism, and are themselves planes of the foliation (not brecciating faults or mylonising thrusts) formed at a time when the rocks were comparatively pliant, so that rupture could pass into folding, molar into molecular movement, easily and rapidly. Dynamical relations of that kind may often be seen on the small scale (Figs. 44, 46) in crystalline schists. Such planes would not be perceptible as ruptures in the midst of conformable foliation.

Gneiss of Holland Arms and Gaerwen.

All but a single narrow strip is basic. The best locality for study is the lofty rugged platform to the north-east of Graig-fawr. The rock varies rapidly in character, some being an almost massive, some a foliated diorite, but most of it a good hornblende-gneiss like that of the Middle Region, comprising a lighter and a darker element, combined in rude lenticular lumps a few yards long, the aspect of the whole recalling the old basic parts of the Lewisian of Scotland. Banding is rare, but well developed on the southern crags. Lenticular albite-pegmatites are frequent, bordered by thin selvages of darker gneiss than usual, and there are thin pegmatite veins, as well as one or two knots of a granite with albite-oligoclase in the middle of the platform. Epidote is common, and it is in the gneisses of this district [E. 8414, 8473—8, 11379] that the remarkable saussuritisation described on p. 130 is so highly developed. The dips tend to be high, and the strike changes continually; besides which there are innumerable mylonising crushes, seldom permitting a band to range for more than a yard unshifted. Doubtless these are the late movements of the Mona Complex, but they are developed on a much greater scale in this gneiss than in the adjacent rocks of the Penmynydd Zone. The silicification described in Chapter XIX is towards the eastern end, west of the Bwlch-gwyn track, and may possibly be Pre-Cambrian. Although the adjacent hornblende-schists contain dioritic knots and lenticular pegmatites, these gneisses are far more deep-seated and variable, and the contrast is so sharp that the boundary must be a fault of considerable magnitude, probably in part at any rate of Post-Silurian age, as a Palæozoic dyke is shifted at it. On the wooded continuation of this platform, which is such a charming feature seen from Holland Arms, the hornblende-gneiss is still more basic, but is of course less well exposed. A strong feature bounds these crags towards the south-east, and near the little farm south-west of Graig-fawr, a lower tract of saussuritised and sheared hornblende-gneiss [E. 9886] appears between them and the Penmynydd schists.

The acid gneiss mentioned is to be seen just at the edge of the high wood, south of the 're' of 'Pentre,' where a wall comes up from the little farm. It is coarse and flaky, of the 'C' type, with lenticular pegmatites, and quite granitoid in parts, an albite-biotite-muscovite-gneiss with leucoxene, and a little garnet and sillimanite [E. 9887, 11382, and analysis]. Its junction with the hornblende-gneiss of the wood, though interfered with by a local crush, conforms to the foliation-planes. Some 25 feet of it are visible, dipping vertically, at the section. Doubtless it is but a strip, cut away from extensive masses like those of the Middle Region, but in the Aethwy Region it is unique.

The tract which runs from Gaerwen towards Penmynydd is of the same general character as that of Holland Arms, and is well exposed in the places indicated by the drift-lines. Perhaps it is on the whole rather less gneissose. At Gaerwen Windmill [E. 8414] the saussuritisation is also strong. Some of the best sections are among the dykes east of Bwlch-gwyn, where there is good gneiss, with seams of pegmatite that show folding when no other planes do. Beyond this it is evidently brought against the mica-schists by a Post-Ordovician fault, north of which foliated diorite forms a considerable proportion of the mass. No junctions of these gneisses with the Penmynydd mica-schists are exposed.

Basic Gneiss of Rhos-cefn-hir.

The long band that runs past Rhos-cefn-hir, Pentraeth, is fairly exposed from that hamlet north-eastward and in Plas-gwyn woods. Its relations are not seen. The rock resembles those of Holland Arms, being partly a foliated diorite, partly gneissose, but is much crushed and injured. It has [E. 6109, 10782—3] the same types of hornblende and epidote, and the saussuritised albites.

The Llanddwyn Wedge.

This, though narrow, is of the first importance, Llanddwyn Island and the dunes of Newborough being the only places where the spilitic lavas are to be found free from deformation.

Llangaffo to Newborough.

The first tract of Gwna rocks, west of Llangaffo Church, exposed only in the lane-floor, is delimited chiefly on the evidence of strike and features. The rocky tract from near Tyddyn-fawd to Rhedyn-goch is typical Gwna Green-schist [E. 9964], and its basic rocks, now platy chlorite-schist [E. 9898] with purplish seams (doubtless reconstructed spilites), are rich in epidote and granular ternary albite.

The Dunes of Newborough.

At the Newborough—Bodorgan road these rocks become less crystalline, but can be traced at intervals among the dunes to Llanddwyn Bay. On a little boss 280 yards north-west of Tir-forgan they are cut at right angles by some four- or five-inch (Fig. 187) [E. 9967] pegmatoid pink veins, which are traversed by a marked foliation parallel to that of the schist. The vein-felspar is orthoclase with a little albite. It is surprising to find such veins in a rock so slightly reconstructed; but thin pegmatites are known in thrust masses of Torridon Sandstone that are even less altered. ['Geology North-West Highlands of Scotland' (*Mem. Geol. Surv.*), p. 576.] The western flank of the Gwna Green-schist is replaced at the Bodorgan road by a schistose mélange in which almost every member of the group is represented, and this continues as far as the old Woollen Factory. But on the knobs by the streamlet beyond that the spilites begin to escape from the shearing, and to come on in force. This, the easterly of the two great bands of spilite, is well exposed among the dunes at the 'L' of 'Llwyd,' where ellipsoids are developed, though not on the great scale of the western band. There are sills of albite-diabase [E. 11248] among the lavas.

FIG. 187. FIVE-INCH PEGMATITE-VEIN IN GWNA GREEN-SCHIST. Newborough, 280 yards north-west of Tir-forgan.

Along their west side run the rocks regarded as Tyfry Beds; fine green grits with purple and green phyllites. At the 'a' of 'Mawr' is a beautiful section in folded and evenly-banded beds that appear to have been dusts with seams of broken albites [E. 9962]. One of them is hard, and cherty in the matrix [E. 10308]. They recall the compact rocks of the Dingle at Llangefni, and of the Tyfry tract (pp. 350, 355). The limestone band that follows is a perfect type of the rose-dolomites, brecciated, with fragments of deeply hæmatised spilite. In it, on a boss 320 yards south-west of the cross-fault and dyke, is the 20-foot jasper [E. 10307, 10340, 10359, and analysis], part of which is purplish and banded, while another band weathers porously and is crowded with rhombs of a carbonate that are zoned with dusty hæmatite. Between the dykes at the cross-fault the limestone, there full of purple spilite fragments, shows most remarkable spheroidal structures (Plate VI), which can be seen to be determined by thin shells of spilite. These thicken north-westward, and the margin of the great spilite just beyond has its inter-ellipsoidal spaces filled with ashy limestone. The spheroidal limestone would seem to be a pseudomorph after a spilite-agglomerate. This is by far the finest example of the structure in the Island.

The mass that follows, 200 to 300 yards in width, is the most perfect ellipsoidal spilite in Anglesey. All the characters described on pp. 71—4, save the variolitic texture and the glass, can be studied in perfection on the great bosses of Bryn-llwyd and Cerig Mawr, for, swept by the sand-blast of this remarkable desert-like tract (see Chapter XXXII) they are not only bare of all vegetation but even of a weathered crust, and are as fresh at the surface as within. The best view of the larger ellipsoids is 260 yards north of the 'M' of 'Mawr' (Plate III) [E. 9895, Plate V, Fig. 1, and analysis], but a section just west of the 'M' is almost as good. The smaller ellipsoids are perhaps best seen just south of the 'M,' on the face of a cliff; and the summit above affords unusual advantages for a study of the inter-ellipsoidal relations of the jasper (Plate IV) [E. 9957, 10306]. Between the dykes by the cross-fault is good haematisation in an unusually porphyritic variety [E. 11252] with stout phenocrysts of albite, some of which have turbid cores. Near the 'B' of 'Bryn-llwyd' some dark skins [E. 10305] now much epidotised, with quartz-spherulites, are well developed. Outside the great spilite, bedded tuffs may be seen about a quarter of a mile north of the 'G' of 'Gwddw' [E. 9966], and still better a quarter of a mile north-north-east of that section [E. 9961]. About 150 yards north-east of the Llanddwyn Causeway a rather pale jasper [E. 9177] contains objects that may possibly be the remains of radiolaria. Before considering the structures, a spilite may be noted that abuts upon the Berw fault and forms the dark high knobs of Cerig-duon, for though considerably deformed, it contains better felspar spherulites [E. 9956, 10339] than any other. It is very fine in texture, probably in part vitreous, and has been a good deal haematised [E. 9896].

The ellipsoids of the great spilite of Cerig Mawr and Bryn-llwyd lie with their greatest axes along the strike while their shortest axes are at right angles to that and horizontal. Were the flattening of such resistant bodies due to compression after consolidation, that would undoubtedly manifest itself internally as textural deformation, from which they are completely free. It must therefore be original, acquired under gravity when the stream had ceased rolling and begun to settle. And as the two longer axes would in such case be horizontal, we thus obtain light upon the true dip, which must be vertical. As limestone appears on both sides, the spilite is doubtless in the core of a symmetrical fold, and the vertical dip, together with schistosity which develops on the flanks, indicate that this fold is ruptured. Whether the spilite be on an anticline or in a syncline depends upon whether the succession be or be not inverted in this wedge. But, in either case, the upper side of the lava-flow may be looked for along the flanks, as those face towards the Tyfry Beds.

The deformation on the eastern side is trifling, but on the western side is a zone of complicated shearing in which almost every member of the group is involved, brecciated, ripped into thin strips, dragged past and driven into one another, and rendered schistose [E. 9897]. The Gwna alternating beds appear, torn into lenticular contorted mélange and their matrix converted into green-schist [E. 9959—60], in which condition they are thrust as a long wedge into the midst of all the other rocks, whose less resistant members have broken down into a dull purplish and green schist that forms a sort of second matrix to all, even to the Tyfry Beds. As for the phyllite-and-grit mélange, no finer sections are known, even on the Bodorgan Headlands, than some sand-swept knobs to the south-west of the dark high lava-crags of Cerig-duon, where it has begun to corrugate. On the flank of the high dark crag it is seen in contact with the spilites, which are schistose at the junction. Every rock appears as definite fragments in the breccias except the Gwna Green-schist, itself therefore evidently a product of the process. Fig. 188, reproduced from the ·0004 maps, gives a little idea of a part of the zone as it is exposed upon a long low boss between Cerig-duon and Bryn-llwyd.

FIG. 188.—1/2500-PLAN OF BOSS AT CERIG-DUON, NEWBOROUGH.
Spilite-schist, limestone, quartzite, and Gwna Green-schist.

Llanddwyn Island.

This romantic isle is the type locality for the volcanic series of the Gwna Beds, and an ideal spot for the study of that varied and interesting group. The geological variety and complexity of the island are indeed remarkable, as may be seen from Folding-Plate XV[1], which is a six-inch reduction from the ·0004 maps; and this geology is laid bare on some three miles of coast and on the rocky knolls, which rise at the Lighthouse crag to a height of about 60 feet. At most states of the tide it is easy of access along the sandy isthmus, and even at high-water along the causeway, save at spring-tide flood with a heavy westerly gale.

The Halen Spilite and the Tuffs.—The great Bryn-llwyd spilite passes on to the north-eastern shoulder of Llanddwyn, where its original characters are as beautifully preserved as among the dunes of Newborough, the augite, as there, surviving in some of the cores of the ellipsoids. A few porphyritic felspars are present [E. 10085—6). The ellipsoids are of the smaller kind, often globular. Their concentric banding and dark skins with spherulites [E. 10087), broken up sometimes into fluxion-breccia, can be studied anywhere on the fine sections about Porth-yr-halen. There also the inter-ellipsoidal jaspers [E. 10093—5, 10097], often spherulitic, may be seen to great advantage. In the north-east part of the cove is the jasper with large radial spherulites that simulate organisms (pp. 85, 151), and on the top of the boss above is a mass 24 by 4 feet. In the same parts of the cove, limestone fills the

[1] The Llanddwyn place-names now used will be found on Folding-plate XV.

spaces, and here may be found the cases where it encloses a core of jasper. On the north shore some 10 yards east of the path-end, is the six-inch vein of axinite [E. 11389] (p. 74).[1] It is particularly requested that the radial spherulites, the jasper-cores in limestone, and the axinite vein, be not hammered, or if so, with great care, as they would be easily destroyed. A few zones of brecciation traverse even the Halen spilite, and when followed southwards to the Beacon Tower, it becomes schistose, as it does all along its western margin.

From the Breakwater to Ffynnon-y-sais are spilite-tuffs [E. 10091—2, 10358], the best that are known in Anglesey. Though coarse and agglomeratic, with ellipsoid 'bombs,' they are clearly bedded, with some thin purple phyllite and siliceous seams, as well as one or two flows of spilite only a foot or two in thickness. They should be studied at the cliff's foot near the north end, at low water. They are folded, with a north-north-east pitch, and in them, 20 yards west of the Breakwater, is the ashy rose-green limestone (p. 84) with blocks of spilite. It is bedded with them, and lies between them and what seems to be a six-inch lava. On the map, it is possible that some true spilite has been included with these tuffs, for along the junction the lava breaks down into a schistose breccia that simulates them.

The Tyfry Beds.—Brought against the agglomerates west of B. M. 11·2 by a vertical mylonising slide are the Tyfry Beds, which are [E. 10116—10119] hard, banded, gritty slates, with beds of massive grit up to three feet in thickness. The grits are full of broken albites (that in some cases have clear margins) and fragments of spilites and keratophyres, with some of the characteristic tourmaline-mica-schist. On the bedding-planes, about 200 yards from the Breakwater, are the bodies (p. 151) regarded as annelid castings. The bedding, which is better preserved here than anywhere else, is vertical, but the cleavage crosses it at a narrow angle, and seems to be identical with the foliation of the Gwna Beds. The Tyfry Beds appear also at Porth-y-clochydd, where, on the little point between the two coves, they are sheared in with limestone, and themselves pass into a schistose mélange indistinguishable from that of the Gwna Beds. In the east cove is jaspery phyllite interbedded with fine purple albite-grit [E. 10113—4], and similar purple phyllite [E. 10115] appears in the midst of Tyfry Beds at the Pilots' Houses.

The Western Cliffs and the Abbey.—The western coast is chiefly spilitic lava, but being on the strike of the great zone of deformation already seen in the dunes of Newborough, none of it has escaped, and large parts are now a rough chloritic schist [E. 10088—90], the origin of which, however, is never doubtful, as it contains everywhere

[1] On p. 75 it is stated (see also Sum. Progr. Geol. Surv. for 1914, *Mem. Geol. Surv.* 1915, p. 53) that axinite had not been recorded in Wales until its discovery on Llanddwyn. Since that was written it has been recorded by Mr. H. C. Sargent in the Penmaenmawr intrusion (*Geol. Mag.* 1916, p. 5). Unfortunately that issue of the *Geol. Mag.* did not reach me until after Chap. IV. of this book had been passed for Press, so the reference could not be inserted there, and has therefore been placed in this chapter.

the remains of ellipsoids and small strips of jasper. In it also, on Trwyn Ffynnon-y-sais, Porth-yr-ogof, and the Lighthouse Crag, are strips of Gwna mélange full of lenticular grits, whose matrix [E. 10120] is a true Gwna Green-schist, with secondary sericite. The long band coloured as such that runs past the little ruined Abbey from creek to creek is largely conjectural, being exposed only just below the Cross. Much of the wedge in Porth-y-clochydd is also concealed, these two being really the only obscure parts of the isle. At the neck of the Porth-yr-ogof headland thin purple phyllites appear in the spilite-schist, and increase rapidly, so that the ·0004 map is but a rude abstract. On the headland are several bands of hard flinty red beds, and similar beds, with pale green ones, folded and pitching to the north-east, are even better developed on the two islets west of the Abbey ruin. They simulate bedded jaspers, but [E. 10107—12] are far too gritty for that, and must be really purple gritty beds like the finer ones of Porth-y-Clochydd, baked by the two sills of albite-epidiorite [E. 10106], which adjoin them on the headland. The sill on the point is very massive. Transgressive junctions have survived, at which the colour of the purple sediments has been discharged by reduction of ferric to ferrous oxides, but adinoles have not been found.

The Limestones.—For a study of the peculiar Gwna limestones there is no place comparable with Llanddwyn, 34 masses being known, and the sea-washed sections at the southern end are exceptionally clear. One or two [E. 10102] are pale grey calcite rocks, but the majority are [E. 10099—101, 10103] rose-coloured rhodochrosite-dolomites, the one that was analysed [E. 10100] from the west end of the Pilot's Cove breakwater being unusually beautiful. Nearly all these rose-dolomites are rich in jasper [E. 10096]. One of them at Porth-y-clochydd, otherwise massive, shows a few feet of bedding, with bands of jasper and volcanic matter. Many of them contain fragments of hæmatised spilite, some to such an extent as to be spilitic tuffs with dolomitic cement rather than ashy limestones. The phenomenon is exceptionally well seen at the Beacon Tower, where the spilitic fragments contain steam-cavities and sub-radiate groups of thin lath-felspars [E. 10103—4] (Plate IX, Fig. 1). A sheared ashy limestone of this kind near E. 10100 contains blocks of rose-dolomite like E. 10100 itself. Allied to these rocks, but not calcareous, is a one-inch bed [E. 10105] seen on the reefs at the west end of Porth Twr-bach, of purple rolled variolite-tuff, important from containing a few fragments of albite-granites like those of the boulders of The Skerries.

Such are the leading features of the remarkable geology of Llanddwyn.

Carnarvon.

On the western side of the river's mouth at Carnarvon, just beyond the Toll Bridge, some greenish-grey schists with little corrugations and nemablastic quartz [E. 9685—7] appear along the foreshore. They have been powerfully sheared, and have developed much minute sericitic mica and iron-ores. They also show signs of thermal action, some of them being full of small spots. Apart from this, they recall the aspect of the Gwna Beds when in a low state of anamorphism, but are all fine rocks, no grits having been seen. Their relations to the adjacent shales of the zone of *Didymograptus extensus* are not visible, but those beds are totally unaffected by the powerful shearing in which these are involved, and contain large elastic micas. It is also worthy of note that some grey phyllites which resemble these are (see p. 250) not uncommon as pebbles in the Cambrian conglomerates of Llanberis. It is therefore probable that the phyllites of Carnarvon belong to the Mona Complex.

THE ORDER OF THE MINOR SUB-DIVISIONS OF THE BEDDED SUCCESSION.

In the footnote to page 169, the reader was referred to this chapter for detailed evidence in support of the relative positions assigned to the minor sub-divisions of the Complex in the Table on page 164. A brief summary will be given here, with references to the pages on which the local detail will be found. The probable order of the sub-divisions of the Gwna Group (which are not stratigraphically arranged in the Table) will then be discussed, and finally, the horizons of development of the Penmynydd metamorphism.

Sub-divisions of the South Stack Series.

It has been shown on pp. 156, 257—8 that, at the South Stack Moor, the Holyhead Quartzite is immediately underlain by the Stack Moor beds, and that these are underlain in their turn by the Llwyn beds. The same order is found (pp. 260—1) in the tract west of the North Stack fault at Rhoscolyn. On the Rhoscolyn anticline (p. 262) it is the Llwyn division that adjoins the New Harbour Beds. Between the two faults near Holyhead (pp. 264—7) the Llwyn beds follow the New Harbour Group, and are succeeded by the Stack Moor beds, upon which rests the Quartzite of Holyhead Mountain. In the Breakwater tract (pp. 270—1) there is a perfectly gradual passage between the Quartzite and the Stack Moor beds, and though the passage between these and the Llwyn beds is cut out by thrusting, the latter appear in the same order as elsewhere. In the Northern Region, the Holyhead Quartzite is not seen, but as the Coeden beds adjoin the Amlwch Beds, and are flaggy throughout, they are correlated with the Llwyn division only, and the Stack Moor division is regarded as cut out by the Carmel Head thrust-plane.

Sub-divisions of the New Harbour Group.

At the Rhoscolyn Lifeboat Station and islets (p. 261), on the Rhoscolyn anticline (p. 262), and throughout the Holyhead country between the faults (pp. 264—7) it is always the Celyn division which, with its little basic tuff, adjoins the Llwyn division of the South Stack Series. The same is the case (though the junction seems to be ruptured) at the Breakwater (pp. 268—70), where, also, the Soldier's Point beds appear on the side away from the South Stack Series. At the Tre-Arddur gap the Soldier's Point beds adjoin and graduate into the Celyn beds on the side that is remote from the South Stack Series (p. 263). In the Western Region it is the Soldier's Point member of the group that, escaping from the Bodfardden thrust-plane, adjoins and graduates into the Church Bay Tuffs at the coast (pp. 157, 278—9, 286), at Brwynog and at Llanddeusant (pp. 281, 286). The same is the case (p. 287) at the Garn Inlier. At the Corwas Inlier (p. 294), though the Church Bay Tuffs appear to be cut out, it is the Soldier's Point beds that come against the thrust, and adjoin the (locally tuff-like) Gwna Beds. Passing to the Northern Region, it is (pp. 297, 303) the Bodelwyn division of the Amlwch Beds that adjoins and graduates into the Coeden representative of the South Stack Series; but (at Llanfechell, Llanrhwydrys, and Bull Bay) (pp. 300, 315—17) it is invariably the Lynas division that adjoins and graduates into the Skerries Grits. The Soldier's Point or Lynas division is also, in both regions, the one which contains the spilitic lavas, bedded jaspers, and jaspery phyllites, for the hæmatitic schists in the Celyn beds are mere films. The lavas appear to be on an horizon or horizons not far above the Skerries Group.

Sub-divisions of the Skerries Group.

It is always the Skerries Grits that are found adjacent to the Amlwch Beds (pp. 158—9, 300, 315—17), and in Bull Bay (pp. 215, 315) they are seen to lie between the latter and the Church Bay Tuffs, graduating by alternations into both of them. The Church Bay Tuffs everywhere adjoin the Gwna Beds. The Tyfry Beds, adjoining the Gwna Beds, may be supposed to represent only the Tuffs; but it must not be forgotten that, on the Middle Mouse, a grit somewhat of Tyfry type graduates into the Lynas beds, which is the position of the not-far-distant Skerries Grits.

There is therefore conclusive evidence for placing the sub-divisions of the South Stack Series, the New Harbour Group, and the Skerries Group, in the order in which they are set in the Table on page 164.

Sub-divisions of the Gwna Group.

Lithologically well-defined though these be, the determination of their true order is a perplexing problem, owing to the excessive disruption of the group, which has produced certain discrepancies between the apparent sequences in the different regions, sometimes even within one and the same region. Little is to be gained, therefore, by setting out these local variations, but the reader can roughly verify them for himself from the one-inch map. There is little doubt that they are mainly due to the more resistant members of the group, particularly the quartzite, having been repeatedly driven *through* (as well as over) the other ones. Nevertheless, by combining the shattered sequences found in the Western Region, the Garn Inlier, the Fydlyn Inlier, the Northern Region, the western Middle Region (*i.e.* in the Penmynydd Zone), Mynydd Bodafon (much less shattered, but including little more than the quartzite), the eastern Middle Region, the Pentraeth Inliers, eastern Aethwy, and Llanddwyn; probability emerges for the following suggestion:—

Western Facies.	*Eastern Facies.*
Thin Grit and Phyllite.	Grit and Phyllite.
Thin Quartzite.	Thin Quartzite (?).
Thin Grit and Phyllite.	Grit and Phyllite.
Graphitic Beds.	——
Limestone.	Limestone.
Spilite.	Spilite (Llanddwyn).
Grit and Phyllite.	Thick Grit and Phyllite.
Quartzite.	Quartzite.
Grit and Phyllite.	Thick Grit and Phyllite.
	Spilite (Engan).
	Grit and Phyllite.

It will also be seen that, as the beds in the upper parts of these columns are much thinner than those in the lower parts, the Llanddwyn spilite and limestone must be comparatively near to the base of the Church Bay Tuffs and Tyfry Beds.

Horizons of development of the Penmynydd metamorphism.

Reasons have been given on pp. 122—8, 155, and 161 for believing the holocrystalline schists of the Penmynydd Zone to represent in the main the felsitic Fydlyn Group, with large portions also of the Gwna Group. Examination of the details given in the present chapter, however, will show that the metamorphism begins to develop on five or six different stratigraphic horizons.

These are very distinct in the Middle Region. Where the main boundary runs out on the Aberffraw coast (pp. 124, 340) the marginal Penmynydd type is a highly micaceous flaser-schist, but on the main line of railway (p. 343) it is a flaggy type, which cannot be on the same horizon. The rapidity of the passage on the coast indicates that (see p. 127) the crystallisation is developing just at the Fydlyn-Gwna junction. On the railway it is probably somewhat within the Gwna Beds. At six or seven of the inliers (p. 345) it undoubtedly develops within a few yards of the quartzite-limestone-graphitic-schist group, and is evidently keeping rather steadily to that horizon over a considerable area. Yet at Porth China, Trecastell, Bodwrog, and other places (pp. 341—4), the same stratigraphical horizon is found in the heart of the crystalline tract. On the other side of the zone, the Penmynydd metamorphism touches (p. 342), but hardly seems to invade, hornfels that is considered to represent some of the Church Bay Tuffs. At several places, indeed (pp. 127, 342), it has invaded the margin of the Coedana granite, and must therefore have eaten its way through the hornfels aureole. But at those places the granite may be in contact, not with the Skerries but with the Gwna Group.

At the western Pentraeth Inlier, the Penmynydd type seems to be well below the Llanddwyn spilites, and as the Engan spilites do not appear to be reached, the horizon of development must be above them.

In the Aethwy Region, the stratigraphic horizon of development,[1] though still variable, seems to be rather more constant, never passing much above or below that of the glaucophane-schists, which, there is some reason to think (see p. 120), represent the Engan spilites. Where the main boundary emerges from the Menai Strait at Llandysilio, the Penmynydd metamorphism sets in some way above the great glaucophane-schist, but soon descends to it, crosses it obliquely, and then passes below it for a mile and a half. In the Tarn wedge on Mynydd Llwydiarth (Fig. 185 and pp. 375—6), it is again a little above the great glaucophane-schists. At Hafod-leucu, however (Fig. 11, p. 125), bending to the west of the apex of the wedge, the margin of the Penmynydd Zone must again descend into rocks beneath all the glaucophane-schists. From the rapidity of the passage (see p. 127) it is believed to coincide with the Fydlyn-Gwna junction. At the Penmynydd inliers of Trefor, Wern, Llaniestyn, and Garth Ferry, the change is developing just at the top of the glaucophane-schists.

Thus the Penmynydd Zone, though composed for the most part of the felsitic Fydlyn Beds, is often permitted to rise into the Gwna Beds, and in one place even as far as the Church Bay Tuffs. Its effects upon the Gneisses are, unfortunately, inaccessible to us. It will be noticed that it rises to higher stratigraphic horizons in the Middle Region than in Aethwy. This is due to tectonic horizon, but has been facilitated by the great attenuation of the Gwna Beds in their western facies.

We have called it a 'Zone' of metamorphism; but perhaps a better metaphor would have been that of a 'Cloud,' that being a condition of things that may spread here to higher, there to lower, strata of an atmosphere.

[1] It will be remembered (see p. 227) that the tectonic horizon is supposed to be somewhat higher than in the Middle Region.

CHAPTER XI.

RECAPITULATION OF THE MONA COMPLEX.

THE Mona Complex falls into two divisions, a Gneissic Suite and a Bedded Succession, the latter occupying much the greater part of the surface. Not only can the order of the succession be made out,[1] but there is good evidence in favour of reading it chronologically from the Fydlyn Beds to the Holyhead Quartzite, and of placing the Gneisses below the whole.

The Gneisses are deep-seated products, in which are found the highest grades of permeation-structure. The Bedded Succession falls into six main sub-divisions, and almost every type of deposit is represented, mechanical sediment being dominant, and rapidly alternating conditions tending to recur on horizon after horizon. Interbedded with the sediments are large suites of volcanic rocks, both pyroclastic and effusive, rhyolitic and spilitic lavas being poured out on a large scale. The thickness of the whole succession is roughly estimated at about 20,000 feet. Four of the members develop different facies in different regions. There are also plutonic intrusions that range in composition from acid granites to dunite-serpentines. Albite and other sodium minerals (among which glaucophane is notable) are extremely abundant, so that the Complex as a whole may be called a sodium complex. A tendency to green colouration, which is very general, is due chiefly to chlorite of anamorphic evolution, but also to a green anamorphic biotite, and to chlorite of catamorphic dissolution.

The whole succession is (with a few local exceptions) more or less foliated: the crystallisation varying from the lowest possible, through moderate grades (which are the most widespread) in which original textures survive, to that of complete crystalloblastic reconstruction.

The Bedded Succession rests upon a still more ancient foliated complex, of which it is believed that the Gneisses are a part. There must therefore be a great unconformity between this Ancient Floor and the Bedded Succession, though known only by inference, the base being, apparently, cut out everywhere by thrusting. A break occurs also at the base of the Skerries Group, but it is both slight and local.

[1] It will, of course, be understood that this brief recapitulation is subject to the cautions and reservations with regard to the Succession and the Tectonics that are expressed in the Preface and on pp. 152, 170, as well as on pp. 169, 176, 178, 180, 182, 206, 221, 224, 227, 233, 242, 256, and at other places.

Land seems to have lain to the north-west, its direction shifting, however, about 90° in the latter part of the period. Vulcanicity slowly wanes upwards, and the highest known member of the series is completely free from it. Life must have been in existence throughout the whole period of the succession, for annelid remains are known in the Gwna Beds and Tyfry Grits as well as in the South Stack Series, and carbonaceous shales occur in the Gwna Beds, besides which there is reason to suspect an organic origin for the jaspers.

The dominating structure of the Complex is recumbent folding, combined with which is thrusting on a large scale. Three maximum recumbent folds are believed to exist, with horizontal amplitudes of many miles. These, with their thrust-planes, are thrown into major secondary folds of great vertical amplitude, upon which minor and minimum folding are in turn imposed. Thrusting develops upon those of all scales, and on the higher tectonic horizons produces a general state of autoclastic mélange. Three chief episodes of earth-movement, with three corresponding periods of dynamic metamorphism, are known ; and the distribution of the varying grades of this metamorphism, which appears at first sight entirely capricious, can be shown to be conditioned by tectonic horizon.

That the Complex is Pre-Ordovician is certain. It is equally certain that some at any rate of it is Pre-Cambrian, and there is heavy cumulative evidence that the whole is of that age.

The foregoing chapters convey, in reality, a very inadequate picture of the Mona Complex, of its well-nigh inexhaustible wealth of detail, and of its labyrinthine structures, which are far from being fully understood. There is no exaggeration in saying that every one of its districts, and every one of its horizons, will present for a long time a rich field for further research.