7. *THE TREMADOC SLATES and ASSOCIATED ROCKS of SOUTH-EAST CARNARVONSHIRE.* By WILLIAM GEORGE FEARNSIDES, M.A., F.G.S., Fellow of Sidney Sussex College, Cambridge. (Read December 1st, 1909.)

[PLATES XV-XVII—SECTIONS & MAP.]

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I. INTRODUCTION.

THE ancient parish of Ynyscynhaiarn lies along the northern shore of Cardigan Bay, at the mouth of the Afon Glaslyn, and forms the south-eastern corner of the county of Carnarvon. The area to be described in the present paper is the country represented upon the 6-inch Ordnance Survey maps of Carnarvonshire, Sheet XXXIV S.E. (Criccieth) and Sheet XXXIV S.W. (Portmadoc), with portions of Sheets XLII N.E. & N.W. and XXXIV N.E. & N.W. to the north and south of these. It includes portions of all four quarter-sheets of Sheet 75 of the 1-inch Geological Survey map.

This area is a rectangular block of some 20 square miles, and includes the townships of Portmadoc and Tremadoc (now united as the Urban District of Ynyscynhaiarn) and the flourishing health-resorts of Borth-y-gest and Criccieth. It is traversed by the Cambrian Railway, between Barmouth and Pwllheli, and is approached either by that railway or by the London and North-Western Railway (through Bangor and Afonwen), or again by the narrow-gauge railway from Ffestiniog.

For its scenery the district has long been famous, and there are few British districts which can show so great a variety of tide-flat, salt-marsh, sea-cliff, sand-dune, park, coppice, meadow, cornland, bog, moor, lake, and mountain, even over an area of many times its size. The bigger hills of the district, rising abruptly almost to

1000 feet above sea-level, occur in the north and east; and while, both geologically and topographically, Tremadoc may be said to lie among the Snowdonian foothills, Criccieth stands outside upon the foreland and belongs to the head of the Llyn peninsula.

My first introduction to the district was as a member of Prof. Hughes's field-class in the summer of 1901. The field-work upon which the present paper is based was begun in 1902,¹ and each year since that time, sometimes alone, and sometimes with a small party of Cambridge pupils, I have spent a month or more among its rocks. The interpretation of the general structure of the district, which is here put forward, was arrived at in the summer of 1906; but, as the result differs so greatly from the views arrived at by earlier writers, I have kept back publication until I could confirm its detail, and by mapping the area of the Moelwyns have proved its extension over a very much wider area.

II. PREVIOUS LITERATURE.

The district of Ynyscynhaiarn has long attracted the attention of geologists, and its literature affords an interesting insight into the mode of evolution of some of our larger geological terms.

The first recorded incursion into the district seems to be the visit of Sedgwick in 1831,² but, beyond the statement that the rocks are to be included within the newly suggested Cambrian System, little result survives. The first paper devoted to the district is one by J. E. Davis, which appeared in 1846, and is entitled 'On the Geology of the Neighbourhood of Tremadoc.'³ In this the author recognized that the hills of the district are due to differential denudation, and speaks of the Traeth as a recently-filled fjord or sea-loch. He records the unusual general strike of the rocks, and speaks of the major hill-masses as due to intrusive igneous sills. He also announces the discovery of abundant *Lingula* at various points, along what we now know to be the outcrop of the *Lingulella* Band.

In Daniel Sharpe's general memoir on the 'Geology of North Wales' we find the district mentioned, the observations due to Davis being in the main confirmed.⁴ In this memoir is found the first account of the ironstones of the Ynys about Tremadoc, and we are told that the intrusive greenstones belong to the Snowdonian (mountain) rather than to the Llyn (peninsular) type.

In 1847,⁵ in Sedgwick's revision of his Cambrian System, we

¹ See Rep. Brit. Assoc. (Belfast) 1902, p. 614.

² Introd. to M'Coy's 'Brit. Pal. Foss. Geol. Mus. Univ. Cambridge' 1855, p. xli; see also Preface to J. W. Salter's 'Catal. Cambr. Silur. Foss. Geol. Mus. Univ. Cambridge' 1871, p. xv.

³ Quart. Journ. Geol. Soc. vol. ii, p. 70.

⁴ *Ibid.* p. 283.

⁵ 'On the Classification of the Fossiliferous Slates of North Wales, &c.' *ibid.* vol. iii, p. 139.

find an accurate description of a section across the heart of the district, and meet with the term 'Tremadoc Group' applied as a name for the slates between and below the greenstone intrusions, that is, as a term embracing all rocks from the Upper Llandeilo (Zone of *Climacograptus peltifer*) downwards to the Maentwrog Beds or Lower *Lingula* Flags. We are told that such a group can be recognized by its mineral character, and great stress is laid upon the diagnostic value of the occurrence of pisolitic iron. We are informed that the slaty members of this Tremadoc Group have yielded two graptolites, an *Asaphus* and a *Lingula*. We gather further from that paper that the bed containing the *Lingula* (*Lingulella* Band) has been traced a great way around the Harlech dome, and that it affords an excellent datum-line for the determination of the geological horizon of other beds, both above and below.¹ A little farther on in the paper the beds below and about the *Lingula* datum-line in the Tremadoc district are compared with similar rocks to the south of Ffestiniog, and the term 'Ffestiniog Group' is hinted at as a name for these.² In the final summary, however, the terms Tremadoc and Ffestiniog are used synonymously, and in the figure of the general vertical section the Tremadoc Group is shown resting upon 'Crystalline Slates' (*op. cit.* p. 156).

By 1851 it would seem that the progress of the official geological survey of Wales under Ramsay and Selwyn, and in this district by Salter especially, had shown the necessity for an amplification of the 1847 scheme: hence, in the introduction to M'Coy's 'Systematic Description of the British Palæozoic Fossils in the Geological Museum of the University of Cambridge' 1855, p. xx, we find the nomenclature entirely recast, and the older Ffestiniog or Tremadoc Group subdivided by Sedgwick thus:—

CAMBRIAN.	Upper.	Bala Group.	{ Upper Bala. Lower Bala.
	Middle.	Ffestiniog Group.	{ Arenig Slates and Porphyries. Tremadoc Slates. <i>Lingula</i> Flags.
	Lower.	Bangor Group.	{ Harlech Grits. Llanberis Slates.

In this scheme the term Ffestiniog is retained as a collective name for the three middle subdivisions, while Tremadoc is completely specialized and applied to a definite slate series forming the middle member of the Ffestiniog Group.

In Sedgwick's classic paper on the 'Classification & Nomenclature of the Lower Palæozoic Rocks of England & Wales'³ the

¹ Quart. Journ. Geol. Soc. vol. iii (1847) p. 143.

² *Ibid.* p. 144.

³ *Ibid.* vol. viii (1852) p. 136.

various subdivisions of this scheme are further defined, and we are again told that the Tremadoc Slates are to be recognized by their peculiar mineral structure¹; but, as great stress is laid upon the occurrence of mineral veins, and of beds and concretions of magnetic and pisolitic iron, it would seem that the graptolitic shales of the Upper Llandeilo were still included. The definition of the *Lingula* Flags, as extending downwards from the base of the Tremadoc Slates to the sea at Treflys, would seem to be entirely satisfactory.

The paper by Ramsay on the 'Physical Structure & Succession of some of the Lower Palæozoic Rocks of North Wales, &c.,'² which followed in 1853, has only a passing reference to the Tremadoc country, but bears intrinsic evidence that the term *Lingula* Flags was then held by the Geological Survey to include Sedgwick's Tremadoc Slates, although, as shown by Salter's paper 'On the Tracks of a Crustacean in the *Lingula* Flags',³ the district had been worked over in the summer of 1852. From that time until the appearance of Ramsay's great memoir on the 'Geology of North Wales' in 1866, the Tremadoc area seems to have been recognized as Salter's particular preserve; and, except for the excellent collecting work of Homfray and Ash, all the later work seems to be due to him.⁴ From the Introduction to M'Coy's 'Brit. Pal. Foss.' already quoted, we learn that Salter was taken over the ground by Sedgwick in 1847 and 1848; but, according to Salter,⁵ it was Barrande who, in maintaining that the *Lingula* Flags belong to his Primordial Zone (Stage C) of Bohemia, caused him to return again. By Salter also we are told that already in 1853⁶ he had obtained palæontological evidence of a threefold division of the *Lingula* Flags; and from Ramsay⁷ we learn that [after 1857] Salter was able to demonstrate the value of the Tremadoc Slates as a formation containing a distinctive fauna.

Salter claims to have followed and mapped the Tremadoc rocks and the three divisions of the *Lingula* Flags from Portmadoc all around the anticline to Criccieth in 1860 (Mem. Geol. Surv. vol. iii, 1866, p. 246). After 1860 he turned his attention to the subdivision of the Tremadoc Slates; but, although the determination of an Upper and a Lower division and the section across the Deudraeth peninsula are in the main satisfactory, his application of the results to the actual Ynyscynhaiarn area is not so easy to follow.

From 1866, the date of publication of Ramsay's 'Geology of North Wales,' although we find frequent mention of the district in

¹ Quart. Journ. Geol. Soc. vol. viii (1852) p. 148.

² *Ibid.* vol. ix (1853) p. 161.

³ *Ibid.* vol. x (1854) p. 208, & Rep. Brit. Assoc. (Belfast) 1852, Trans. of Sections, p. 58.

⁴ Mem. Geol. Surv. vol. iii (1866) pp. 67 & 242.

⁵ *Ibid.* Appendix, p. 245.

⁶ *Ibid.* p. 246.

⁷ Quart. Journ. Geol. Soc. vol. xix (1863) p. xxxviii, & Mem. Geol. Surv. vol. iii (1866) p. 7.

the various papers on Cambrian rocks in general, there is little evidence of actual progress of field-work within its boundaries. Very important in their general bearing are papers by Salter and by Salter & Hicks,¹ on the separation of the Menevian from the base of the *Lingula* Flags, and especially the great classic of Belt,² in which the remaining upper part of the *Lingula* Flag Series is broken into the three groups, Maentwrog, Ffestiniog, and Dolgelly, which are defined with all the exactitude of modern palæontological methods.

Turning now to the subdivisions of the Ordovician System, we are told³ that in the very year (1843 or 1844) in which Sedgwick had discovered the *Asaphus* and graptolites at Tremadoc, he and Salter had also obtained *Calymene parvifrons* and *Ogygia selwynii* from beds which they called 'Tremadoc,' on the western flanks of Arenig. These (Arenig) beds, however, were never correlated with any member of Murchison's Shropshire series; and, although Salter had described the fossils in 1847, it was not until 1853 that he determined them as of age intermediate between the fauna of the Tremadoc Slates and the better-known fauna of the Bala or Caradoc beds.

In 1854 Salter went with Murchison to Shropshire, and on p. 52 of the second edition of 'Siluria,' which appeared about the end of the year 1859, he figures fossils exactly similar to those that he knew from Arenig, along with others from the lower lead-bearing series of Shelve. The rocks containing them are spoken of indifferently as Highest *Lingula* Flags or Lower Llandeilo.

Throughout his later work in Wales,⁴ and especially in his Presidential Address of 1863,⁵ Ramsay always insisted upon the importance of the break and unconformity at the top of the Tremadoc Slate of the Deudraeth, and hence must have given up any idea of the synonymy between Tremadoc and Lower Llandeilo at a very early date. In so doing, he must of necessity have opened the way for Hicks,⁶ who was working in South Wales, to supplant the Murchisonian term 'Lower Llandeilo' by the scientifically defined revival of the Sedgwickian Arenig. Salter, too, in 1866, seems to have been very ready for the new arrangement, and his lists of Llandeilo fossils in the Geological Survey memoir (vol. iii, pp. 255-59) are obviously arranged upon the Hicksian plan. The lists, however, are unfortunate, in that certain beds which at Ty Obry and at Tyddyn-diewm, within the area here described, contain Upper Llandeilo (Hicks) graptolites, are identified as Lower Llandeilo, and in the second edition (1881, p. 371) have their fossils included

¹ Quart. Journ. Geol. Soc. vol. xxiv (1868) p. 510.

² Geol. Mag. 1867, pp. 493, 536.

³ Mem. Geol. Surv. vol. iii (1866) p. 257.

⁴ *Ibid.* pp. 63, 71.

⁵ Quart. Journ. Geol. Soc. vol. xix, p. xxxviii.

⁶ *Ibid.* vol. xxxi (1875) p. 167.

among the lists of Arenig species. This mistake was recognized by Mr. Hopkinson & Prof. Lapworth in 1874,¹ and is pointedly referred to by the latter in his 'Distribution of the Rhabdophora,'² but was allowed to pass uncorrected into the second (1881) edition of Ramsay's great work.

The papers by Hicks fully establishing the faunistic classification-scheme were published in 1873 and 1875³; and, in addition to their incidental application of the new terms to the naming of the rock-series within our district, they contain the suggestion that the Upper Tremadoc Slates (as the term was employed by Salter) are the equivalents of, and are to be included within, his (Hicks's) Lower Arenig. Such a suggestion, involving, as it does, the placing of the Tremadoc as the lowest member of the Ordovician System, is still a matter of interest; but, as it may involve the complete absorption of the ancient term 'Tremadoc Slates,' it cannot, I think, be proceeded with on the evidence before us.

The scheme of classification of the rocks that I have found most useful in working out the rocks of the district is an amplification of the one which I adopted in describing the corresponding rock series at Arenig,⁴ and, like the older schemes of Sedgwick and Salter, is based upon a combination of the palæontological and lithological evidence locally obtained. It is as follows:—

	<i>Western or Crickieth District.</i>	<i>Eastern or Tremadoc District.</i>
CARADOC SERIES.	Rhyolitic ashes and agglomerates. Variable dark-grey and black shivery slates, banded, but with no distinguishable horizons.	Grey slate series, often strongly banded, with a few shelly fossils (<i>Trimucleus</i> and <i>Orthis</i>) in the upper part. Andesitic ashes and ashy shales. Vesicular andesites.
LLANDEILO SERIES.	Dark banded slates with intense cleavage; no fossils found.	Blue-black slates containing graptolites. Zone of <i>Nemagraptus gracilis</i> .
	Earthy slates, with occasional 'tuning-fork' graptolites.	
ARENIG SERIES.	Shivery slates passing down into Flaggy grits yielding <i>Calymene parvifrons</i> . Basal conglomeratic grit.	Conglomeratic grit of Ynys Towyn.

Unconformity.

¹ Quart. Journ. Geol. Soc. vol. xxxi (1875) pp. 631 *et seqq.*

² Ann. & Mag. Nat. Hist. ser. 5, vol. iv (1879) p. 340.

³ Quart. Journ. Geol. Soc. vol. xxix, p. 39, & vol. xxxi, p. 167.

⁴ *Ibid.* vol. lxi (1905) pp. 612 *et seqq.*

TREMADOC SERIES.	{	Garth Hill Beds: (Incomplete in the Ynyscynhaiarn area.) Grey-blue slates with <i>Angelina</i> .
		Penmorfa Beds: Flaggy mudstones and thinly-bedded slates with <i>Shumardia</i> and the Shineton fauna.
		Portmadoc Beds: Thickly-bedded felspathic slates, with occa- sional <i>Asaphellus</i> .
		Moelygest Beds: Banded grey slates and mudstones; few fossils, <i>Acrotreta</i> and <i>Bellerophon</i> .
		The <i>Dictyonema</i> Band: A constant and characteristic band of bright-rusting blue-grey mudstones, with abundant <i>Dictyonema sociale</i> .
		Tynllan Beds: Thinly-bedded rusty shales, with some hard grey mudstone-bands, containing <i>Niobe</i> and <i>Psilcephalus</i> (<i>Symphysurus</i>).
<hr/>		
DOLGELLY SERIES.	{	Sooty-black mudstones, with <i>Pelturascara</i> <i>bæoides</i> . Blue-black mudstone, with <i>Agnostus trisectus</i> . Black slates, with calcareous bands often crowded with <i>Orthis lenticularis</i> . Dark flaggy slates, with <i>Parabolina spinulosa</i> .
		Grey-blue slates and flags, crowded with <i>Lingu- lella davisii</i> . Grey flags and grauwacke, with some coarser bands (1800 feet thick).
FFESTINIOG SERIES.	{	Rusty grey and blue slates, with thin bands of felspathic grauwacke.
MAENTWROG SERIES.	{	

I shall now briefly describe the rock series in the order of their formation.

III. THE MAENTWROG OR RUSTY FLAG SERIES.

The oldest beds in the Ynyscynhaiarn district are exposed in the cliff-sections between Mount Pleasant and Cefn, and form the low promontory to the south and west of Treflys Church, as far as Careg-yr-Bryr and the Black Rock. They are a series of ill-cleaved, banded, dark grey, black, or green slates, silky in fracture. Their exposed surfaces are soon filmed over with rust, and in weathering they break up into bladed fragments about the size and shape of a man's hand. Interbedded with the slates, in all except the lowest bands, are numerous coarser felspathic or gritty 'ringers,' which are massive in their bedding and well defined from their surroundings. These ringers range from something less than an inch up to a foot in thickness, and, though irregular in their distribution, seem to become more abundant as we pass up the series.

The measured succession below the columnar greenstone of the shore east of Craig-ddû (Black Rock) is:—

	<i>Thickness in feet.</i>
Thin and thick, alternating grey and blue, flaggy shales, much cleaved and puckered, with ringers 4 to 6 feet apart. Notable ringers at 20 and 60 feet below the sill, and a 3 to 6-inch grit-band at 40 feet	80
Sill along which the main cave has been eroded	3 to 6
Flaggy slates with ringers: 4-inch ringers at the base	10
Splintery shales with thin ringers: 4-inch ringers at the base ..	20
Flaggy beds with strong double ringer: 9 inches to 1 foot thick at the base	30
Rusty slaty flags, with strong ringers, composite: 1-foot ringer at the base	50
Intrusive sill.	
Rusty slates, with about three ill-defined ringers to each yard.	50
Massive, fine-grained, flaggy band	1
Thinly-bedded silky flags or slates, without ringers.....	50
	<hr/> say 300 <hr/>

Ill-preserved specimens of *Olenus cataractes* from 1 to 2 inches long are found in the splintery slates, some 25 feet below the sill of the main cave; small *Agnosti* and an indeterminate *Conocoryphe* are not infrequent in the silky flags and rusty slates at the base of the series.

This section is much complicated by small anticlinal folds and by faulting, the effect of which is not easy to make out. It is, however, washed clean by the tide and fretted or polished by the wind-driven sand, and so affords a most instructive exposure. Joints and decayed sills and dykes of an ancient dolerite have given scope for differential erosion by the waves, and the beautiful caves so produced have long been famous. In these caves the colour-banding of the slates and flags which form their walls adds largely to the fascination. Greens, greys, and purples are the colours which appear; and one can often count some two or three large, and perhaps twenty to thirty small, colour-changes on each inch of rock.

The cliffs below Cefn on the east of the bay were probably at one time equally well exposed, but now the sand-hills partly covering and partly protecting the cliffs from the direct action of the sea have spoiled the section, and one can do little more than note the rarity of ringers among the slaty flags exposed. The contorted *Olenus*-bearing flags of Ffynnon-Ochr-cefn appear to be identical with the fossiliferous splintery slates which form the low detached stack on the other side.

Rocks referable to the top of the Maentwrog Series appear again along the old sea-cliffs to the east of Morfa Bychan, from Garegwen to Fechan Point, and in the outstanding rocks of Careg-enwe and Gareg-gôch. In all these places they are thinly bedded and well striped, but not very rusty. They contain trilobite fragments and small *Lingula*, and are associated with greenstone intrusions.

The land topography of the Maentwrog Series is uniform and uninteresting. The ringer-beds of the coast-section seem to conceal themselves, while the igneous sills which weather into sea-caves stand up in slight relief. The soil is everywhere scanty, but is generally fertile enough to be worthy of cultivation.

IV. THE Ffestiniog or Grey Flag and Grauwacke Series.

The Ffestiniog Series of the district is a thick and massive shallow-water deposit, which, by reason of its monotony and the paucity of its fossils, I have not been able to subdivide. The outcrop varies from about half a mile to one and a half in width, and is continuous. The lowest beds are not well marked off from the highest Maentwrog Beds, but the line of dolerite sills which comes in from the sea at Craig-ddû and goes out at Gareg-gôch, near Borth, serves as a convenient line for mapping. This line of intrusion can be followed from Craig-ddû along Careg-yr-Eryr; it appears in the marsh of Llyn Ystumllyn, a quarter of a mile south-east of St. Cynhaiarn's church and along the side of the field south of the barn of Coed-y-llyn, again in the crags of Capel Siloam, at Ynys Cyngar, Careg-cnwc, and finally at Gareg-gôch, near the bathing-place of Borth.

Like the Maentwrog Series, the Ffestiniog Beds show innumerable alternations in the coarseness and fineness of the material. Usually of a flaggy nature, they include at many horizons bands of massive and very compact grauwacke grits, rich in feldspars more or less decayed, and set with quartz-grains, in a tough chloritic, or micaceous, muddy base. These, although sometimes massive through a thickness of 3 feet or more, are never coarse enough for real grits, and a new term to describe them is badly needed.

Their lithology and association with more slaty beds is strongly reminiscent of the ringers in the Maentwrog Beds below, but the marking-off of the beds is rarely so well defined. A notable feature of the coarser of the grauwackes is the occurrence of false bedding, and with it a more complicated arrangement of bedding-planes which I would term 'curled.' The minute unconformities and overlaps which constitute false bedding are well known, and are common to all sediments deposited by drift-bedding in shallow water. They are associated with true ripple-drifting and with worm-tracking, *Scolithes*, *Cruziana*, etc., occurring upon the upper surface of the coarser beds. The 'curled' bedding and general contortions of the planes of deposition within massive strata is less easy either to describe or to explain.

Curled bedding is generally seen only in section. As so observed, it bears a strong resemblance to the figures and description of the contortions of the Langdale slates given by Sorby.¹ It is always associated with considerable variations in the thickness of the bed which it affects, and often where the curvature is strongest cracks have formed transverse to the bedding and are now filled with quartz.

When seen in plan or upon an exposed dip-surface the curled-bedded grauwackes are seen to be broken into nodular pavements. These, in extreme cases, become discontinuous; and in their general behaviour the curled-bedded masses even strongly resemble the nodular cement-stones of the Middle and Lower Lias. The curling

¹ Quart. Journ. Geol. Soc. vol. lxiv (1908) pl. xiv.

of the bedding within the nodules involves curvature in three dimensions; but, although the actual nodules in the pavements seem to have a directional elongation due to the later cleavage-stress, I am unable to discover any polarity in the actual arrangement of the curled bedding-planes. A certain amount of discontinuity and some evidence of sliding is usual between a curled-bedded grauwacke and the super- or subjacent flag or slate.

Under the microscope the curled-bedded grauwackes have little to distinguish them. They contain much fresh felspar, and possibly the recrystallization of the quartz-grains and quartz-cement is more advanced than in the evenly-bedded flags, but I have not examined enough specimens of either sort to be sure. It is the quartz-cement and its recrystallization in crystalline continuity with the quartz-grains which makes the rocks so tough.

I have measured several sections across the moorland exposures of the Ffestiniog Beds, but cannot discover either fossil bands or well-characterized lithological groups within them, and have therefore had to rest content with making a strike-map of their exposures (see map, Pl. XVII). The most open section is through the farm of Ty'n-y-mynydd on the south side of Moel-y-gest, where the total thickness exposed is about 1700 feet. In this section the rocks appear to fall into five groups, each marked by a convexity on the hillside, and having a flat or hollow separating it from its neighbour.

The lowest group (about some 400 feet thick) consists of rather dark-grey flags with thin and thick beds alternating. These, from a distance, show some eight or nine subsidiary features, with the hard bands (Nos. 5 & 6) most prominent.

The second group is more massive, and has but few and very thin bands well bedded enough to be called 'flags.' It also is nearly 400 feet thick, and might be further subdivided according to some four or five grit maxima.

The third group, about 300 feet thick, is less massive in its bedding, and consists of thickly-bedded flags with not infrequent *Lingulella*. It would subdivide into either three or five, by the grouping of its resistant bands. The house Ty'n-y-mynydd stands on the ledge at the top of this third group.

The fourth group begins with a set of very strong, thickly-bedded, grey-weathering, massive grey grits, with grey flag-partings. These gradually diminish in weather-resisting power upwards, and pass into grey flags. They are about 250 feet thick, and might subdivide into five.

They pass gradually upwards into the fifth group, which consists of flags of a much darker and more rusty colour. These subdivide readily into some seven grit maxima, and are about 350 feet thick. The highest big grauwacke is about 100 feet from the top of the series and 50 feet below the base of the well-marked *Lingulella* Band, which in this, as in the Arenig district, is very distinctive.

The *Lingulella* Band.

The topmost layers of the Ffestiniog Beds are characterized by the presence of very numerous specimens of *Lingulella davisii* in a bright-rusting flaggy grey slate. The fossiliferous flags are about 50 feet thick, and can be mapped continuously. They come in from the sea at the cliffs south of Rhiw-for-fawr, near Ogof-ddû (Criccieth), and pass northwards by Ystumllyn House to the quarry by the turnpike at Pencraig. Thence by Gareg-felen to Glanbwl they are drift-covered, but at the farmyard of Gwern-ddwyryd they reappear, striking east and west. From the little reservoir on the stream east of Bryn Cilynen, south-eastwards along the hillside behind Wern, they form a dip-slope and make a great exposure. South of the railway they occupy the slopes of Coed-y-chwarel, and through the Coed-y-capel plantation can be followed to the meadows south of Bron-y-foel. Thence over the col by Beudy Pencerbi they pass to the farm of Llanerch, where a fault intervenes displacing them some half a mile to the south.

On the southern shores of Llyn Gareg-wen they reappear, and so by the cowhouses on the hill can be traced through the quarry near the schoolhouse and on through the village to form the southern shore and promontory of the harbour at Borth.

The topography of the Ffestiniog Series is in this district very characteristic. The rock weathers very slowly, and bracken, gorse, bell-heather, bramble, and a thin wire-grass form the usual vegetation. Even these flourish only upon the flaggy outcrops and along the shatterings due to joints, and the grauwacke grits stand up as lichen-covered cliffs and rock-knobs, which even close to sea-level give the impression of a rough mountain-country and are exceedingly picturesque.

Though thus giving rise to a diversified moorland topography, the Ffestiniog Series does not, as a whole, behave as a resistant formation; and it is noticeable that in this district it forms the low ground of Llyn Ystumllyn at the centre of the anticline, and does not at any point attain an elevation greater than 400 feet.

V. THE DOLGELLY OR BLACK BAND SERIES.

The Dolgelly Series follows directly upon the *Lingulella* Band. Whether we consider the series in its original signification as including only the dark slates of the Black Band, or whether we allow it to include all the beds up to the horizon of the *Dictyonema* (as suggested in my Arenig paper),¹ it is in this district perfectly well defined, and lends itself beyond all other series to the plotting upon a large-scale map.

The lithologically defined Black Band is especially convenient from this point of view, and, following round the Ynyscynhaiarn anticline outside the line of the *Lingulella* Band, above described,

¹ Quart. Journ. Geol. Soc. vol. lxi (1905) pp. 614-15.

can be traced with great accuracy. Across the northern end of the district about Gwern-ddwryrd and on to Coed-yr-Eglwys above Penmorfa Church, the outcrop is cut out by a fault; but from St. Beuno's Church it is readily followed through Wern and Bron-y-foel round the southern slopes of Moel-y-gest to Llanerch, and again from the head of Llyn Gareg-wen to the bay of Borth-y-gest.

The best exposures are the cliff-section by the railway at Ogof-ddû, the road-and-stream section below Penmorfa Church, the old Bron-y-foel slate-quarry, and the field banks between Gareg-wen and Borth. The section at Ogof-ddû is as follows:—

	Thickness in feet.
Blocky tough blue slate, weathering dark, which elinks when struck. Used for buildings. It makes black walls, but rusts to a foxy-brown colour on inside joints. It contains small pyrito-calcareous nodules, which weather to white elongate spots upon the surface.....	12
Ill-exposed splintery blue rock, weathering dark and with yellow rust on the inside joints. White pyrito-calcareous spots in the lowest 4 feet	20
Hard banded blue grit, with pin-head particles bedded in ribs, each about 4 inches thick	6
Rusty grey-blue slates with paler bands in the upper part, becoming darker below	15
Finely-banded (30 bands to an inch) blue-black slate, breaking into long splinters and weathering to a dark colour, very rusty	6
Dead-black rock, with blue-grey streaks, homogeneous, and breaking into splinters. Contains some spangles of mica.....	10
Finely banded, splintery, blue-black slates. Very rusty. Minutely jointed and with rust working in from the joints. The rock-cores bleach to a bluish grey. <i>Agnostus</i> Band with <i>Peltura</i> , <i>Dikellocephalus</i> , and numerous other fossils 7 feet from the top and generally throughout; small specimens of <i>Orthis lenticularis</i> abundant in the lower part. These slates generally break into bands about 2 to 6 inches thick	18
Granular felspathic ash-band	2 inches to 1 ft.
Hard, dark blue-grey or black, gritty slate with three rows of large concretions of iron carbonate. The dominant line of concretions seems to have grown round discontinuous masses of a 2-inch bed of coarse gritty material, which contains angular pebbles up to $\frac{1}{4}$ inch in diameter. The largest concretion is an ellipsoid measuring 3 by 4 by 2 feet, which has obviously grown <i>in situ</i> , distorting the slates in contact with it, and making the bands within it swell out to about 10 times their original thickness. The non-concretionary slate is banded with about 20 beds to the inch, and contains abundant <i>Sphaerophthalmus</i>	12
Finely banded (40 to inch) black rock, with a dark streak, becoming fine-grained below, containing small pyrite crystals throughout. When the rock has become rusty and has lost its pyrite in the weathering, the banding is very prominent	12
Not exposed.....	6
Rather hard, splintery black slate, with a dark-blue streak. Banded, and with thin ashy bands up to a quarter of an inch thick at intervals of about 3 inches. Mica everywhere abundant. Small <i>Obolus</i> and still smaller <i>Orthis</i> not rare. A concretion measuring 6 by 4 by 3 feet lies in the midst.....	12

Thickness in feet.

	130
Black rock with blue streak. Outside surfaces covered with thick rust.....	6
Intensely black rock with black streak. Very finely laminated. Shining mica-flakes along the bedding. Bedded in 4- to 5-inch bands. Very rusty.....	6
Blocky black rock, showing black outside, finely laminated within, and having visible colour-bands, up to a quarter of an inch thick, at intervals of about 3 to 4 inches. Some of the beds are nodular.....	12
Hard black calcareous nodules alternating with splintery black shales. The topmost band appears almost pisolitic, the lowest is like an ashy grit, but weathers to a rottenstone. Mica-flakes abundant, lamination well marked.....	6
Black non-laminated slates, with band of cone-in-cone ironstone concretions weathering out into holes, measuring 3 by 2 by 1 foot at the base.....	6
Banded blue-black and dark-grey slates, soft, and rusting deeply with a thick crust. Cleavage rather good; bad fossils occasionally, <i>Parabolina spinulosa</i>	8
Rock not exposed. Once eaten out into a cave.....	6
Dark-grey, finely-banded splintery flags, smooth, and grey-weathering on the outside. <i>Parabolina spinulosa</i> not rare ...	10
Dark-weathering splintery flags, breaking into fragments which measure often about 12 inches by $\frac{3}{4}$ by $\frac{1}{2}$ inch. These during weathering become covered with a hard dark crust, and where broken in the cliff have often had their cores removed, leaving holes like finger-stalls.....	6
Grey dark-weathering flags, with ill-defined knobby ringers ...	10
Bright-weathering grey flags, banded in the upper part, and with a prominent 1-foot ringer at the base. Crowded with <i>Lingulella davisi</i>	20
Total.....	<u>226</u>

The road and stream-section south of St. Beuno's Church at Penmorfa does not lend itself to absolute measurement, but the total thickness exposed is much the same as at Ogof-ddû, and the variations of lithology follow the same order. The *Parabolina* Beds at the base have their trilobites unspoiled by cleavage, and the overlying impure limestone-bands, seen under the southern wall of the road where it rises from the corner towards Coed Bryntwr, are rich in *Orthis lenticularis*, the remains of which probably supply the calcareous material. The very black beds above these contain *Agnostus pisiformis* sparsely throughout, and also yield occasionally the compact tails of a *Niobe*-like trilobite. The *Sphærophthalmus* Beds crop out in the ditches on either side of the road from Tyn-lilan Farm down to Wern, and the *Peltura* Beds lower down the same road and south of the burn.

The Wern gate-cutting exposure, the field-side cuttings, and the blocks of slate ploughed up in the arable ground above Llanerch, and between Llyn Gareg-wen and Borth, have long been known as hunting-grounds for those who would collect trilobites from the Black Band. At each and all of these localities the detailed succession confirms the section measured at Ogof-ddû, and goes to

show that even the minutest variations of lithology, in Dolgelly rocks, are constant over several miles of country.

The Bron-y-foel slate-quarry was worked in the lower part of the Black Band, and afforded a black, closely-laminated slate, which is too soft and full of pyrite to enter into serious competition with the slates of Ffestiniog.

The Black Band, as the least resistant rock of the district, is usually weathered into a hollow, and deeply covered with soil. Its outcrop is therefore marked by a succession of arable fields and smooth meadows, with copses and plantations along the stream-courses. Its outcrop can also usually be recognized by the flaky black slates and the ochreous springs which come out at intervals along its course.

VI. THE TREMADOC SERIES.

(1) The Tynllan or *Niobe* Beds.

Resting upon the Black Band, and lying between it and the horizon of abundant *Dictyonema*, come the *Niobe* Beds. These are a series of fine-grained, silky grey slates, and with the Black Band preserve their characteristics unchanged round the Ynyscynhaiarn anticline, from Ogof-ddû to Borth.

The section at Ogof-ddû is a striking one. The highest beds adjoin the *Dictyonema* Band, while the lowest beds are continuous with the Black-Band section just described. The section is as follows :—

	<i>Thickness in feet.</i>
Rough, dark leaden-grey slates with some whitish partings and white-weathering pyritous spots. Ill-cleaved, and breaking into long tile-like fragments, with splintery ends, weathering grey or rusting to a rather bright tan colour	50
Hard, blocky, blue to grey-blue beds with pyritous spottings, in bands about 4 inches apart, uncleaved. This series is bedded in 1- to 3-foot bands, most massive in the higher part, and often showing conchoidal fracture. <i>Obolus</i> is found on certain bedding-planes of these blocky rocks, which weather blue or drab, and do not rust. The middle beds are often sufficiently rough-grained to be worthy of the name of grit, but generally the beds are hard mudstones	40
Splintery or shivery black-weathering shales with an earthy fracture. The topmost 12 feet are passage-beds to the more massive grey-weathering bed above. The lower beds are very thinly bedded, and when far weathered turn brown and flake into short flat splinters	40
Splintery, smoothly-breaking blue beds without pyritous nodules. They either bleach or rust to a foxy-brown colour during weathering	20
Hard, clinking blue rock, very massive, and showing cleavage-joints only. It breaks conchoidally, but has some slight banding. It contains <i>Acrotreta</i> , and rusts thickly. This rock forms the outstanding crag through which the railway-cutting at Ogof-ddû has been made	40
Total	<u>190</u>

The cave of Ogof-ddû was worn out by the sea along a 3-foot band of well-banded blue and grey rock, which forms the base of this mass.

The corresponding sea-cliff section on the east of the anticline is at Trwyn-cae-iago, east of Borth Harbour. The lowest beds seen are the clinking blue rocks of Craig-y-don. Splintery rocks (first without spots, and then well spotted) follow, and have yielded a good many specimens of *Niobe* and *Psilocephalus*. The blocky spotted grey rocks of the *Obolus* Band follow, and determine the edge and highest part of the cliff-bound promontory, being themselves overlain by the banded, well-jointed, ill-cleaved beds, which at the entrance to Maenofferen Wharf underlie the *Dictyonema* Band. Here, too, the total thickness is about 200 feet.

The Tyn-llan exposures behind Penmorfa Church were known to Homfray and Salter as a locality for *Niobe* and *Psilocephalus* as long ago as 1860. Again, it is the spotted splintery beds some 60 feet from the base which contain the most abundant trilobites. The best exposure is a small crag in the field immediately to the east of Coed-yr-Eglwys, and between that wood and the road by Wern Lodge to Carnarvon. The stream-section along the wood side is also productive, but is difficult to work.

The fossils usually found are *Niobe homfrayi*, *Psilocephalus innotatus*, and *Hymenocaris vermicauda*. With these I have obtained some small sheared specimens of a *Shumardia*, an *Agnostus*, and a *Theca*. *Acrotreta*, *Lingulella lepis*, and a big *Lingulella* very like *L. davisii*, but pointed in front and rectangular behind, occur just below the trilobite-bed, and are abundant in the massive beds a little lower down the field.

The *Obolus* Beds make a small feature, which crosses the Wern-Carnarvon road just below the old tramroad bridge, and continues down the east side of that road to the corner of Coed-ty-n-llan. This set of beds is very hard and cherty: by its spotting and white weathering it is easy to follow and map in detail, and so affords a fine datum-line from which to measure up 50 feet, and thus arrive at the exposures of the fossil band with *Dictyonema*. By this indicator stratum, *Niobe* Beds have been mapped continuously from the Portmadoc-Criccieth road, south of Wern by Cefn-cyfanedd, round the southern slopes of Moel-y-gest, to the north-and-south fault through Llanerch, and again by way of Moelfra, through the woods of Parc-y-Borth, to the Trwyn-cae-iago section described above. The same bed is also useful as a datum-line across the moorland and between Ystumllyn and Ogof-ddû.

The outcrop of the *Niobe* Beds is generally rough and rocky.

(2) The *Dictyonema* Band.

Characteristic beyond all other beds known in the Ynyscynhaiarn district is the belt of strata, 15 to 20 feet thick, which contains *Dictyonema sociale*. This band wherever exposed is abundantly fossiliferous, and certain of its bedding-planes are completely covered

with the nets of this graptolite. Somewhat less resistant in its weathering than the beds above and below, the *Dictyonema* Band generally crops out along a slight hollow, and the fossils must be sought along the under side of the outstanding rock-rib which comes next above the prominent *Obolus* Bed described above. The *Dictyonema* rock itself is quite distinctive. It is a fine-grained rock of a darkish blue-grey, and with faint pale bandings, which come to maxima three or four times in each inch. It breaks not along its bedding, but along joints, into pieces shaped like irregular paper-knives, with very sharp edges, each three or four times as long as broad. As it weathers the surfaces first turn green, and then to an iridescent gold which is characteristic; later, they are covered with a foxy-brown rust-film, which they retain until the whole rock is bleached to a pale but bright creamy paste.

Dictyonema sociale was discovered and first described by Salter¹ from this district, but his specimens were not of the best, and the species and its variations require, and are worthy of, a modern revision. As generally collected, the specimens are in the form of casts, filled with iron oxide; but, although such specimens show the form of the net and the association of individuals, they do not retain the details of original cell-structure, and from a zoological point of view are uninteresting. Fragments of more satisfactory specimens are occasionally to be obtained from fresh and unweathered rock, but the slate will break along the bedding only by accident, and the pieces of the graptolite seen are small. In such rock the *Dictyonema* is found replaced by the unstable form of pyrite (marcasite) and is preserved in full relief.

The outcrop of the *Dictyonema* Band is indicated with sufficient care upon the map (Pl. XVII), and I need only add some notes upon localities at which one can be sure of finding the rock in a condition suitable for the collecting of fossils.

At the eastern outcrop, by the sea, below Bron-y-garth, the richest fossil bed is mostly covered by scree. At Lletty and along the little cliff which bounds the paddock between Bryn-parc and the wood of Parc-y-Borth, there is a fine exposure, which is maintained through the northern corner of the wood and through the plantation beyond the Morfa Bychan road along the cart-road to Llanerch Farm. The fault there carries the outcrop to the 400-foot contour south of the eastern summit of Moel-y-gest, and there fine exposures occur. Hence rising, it attains 600 feet at the wall south of the western summit, whence descending it skirts Coed-y-cefn, and crosses the road from Wern to Bron-y-foel, just below the 300-foot contour, with open moorland exposures all the way. Lower down, at the 200-foot contour on the same road, is the original locality of Salter's *Dictyonema* (called from the keeper's house Cefn-cyfanedd), and there, at the turn of the road, is a wall every

¹ Mem. Geol. Surv. vol. iii (1866) Pal. Appendix, p. 331.

piece of which when broken open is fit for preservation in a museum. North of Wern the exposures are more difficult, and I shall only mention the old tramway-cutting at the 200-foot contour east of the bridge over the Tyn-llan road; the field opposite Wern Lodge; and the quarry for road-metal at the 300-foot contour close to the second milestone out of Tremadoc, on the southern branch of the Carnarvon road.

Exposures on the Criccieth side of the anticline are difficult to work, for their cleavage is overwhelming, the dip steep, and the bed determines only a hollow in the moorland. Loose slabs with some *Dictyonema* are nevertheless not infrequent among the heather.

Along with the *Dictyonema* occur usually a few elongate *Lingula*, cap-like *Acrotreta*, and especially spicules of a sponge which may be *Protospongia*. I have also found occasional tails of *Psilocephalus*, loose thoracic segments of some broad and large trilobites, and the head of some *Peltura*-like Olenid and of another trilobite not unlike *Hysterolenus törnquisti*. The *Protospongia* is especially characteristic of the harder slates which overlie the *Dictyonema* Band.

(3) The Moelygest Beds.

Above the *Dictyonema* Band come a series of rusty-grey slaty mudstones which appear to be almost devoid of fossils. For this subdivision of the Tremadoc Series, from the circumstance that it forms the underscarp and dip-slope of Moel-y-gest, I have taken the name Moelygest Beds.

The best continuous exposure is along the road-cutting behind the wharves at Portmadoc, south of, and beneath, the rock which has been so extensively quarried. The bulk of the rock is an ill-cleaved dark-grey mudstone, sometimes splintery, but usually more noticeable by the obliqueness and rippled surfaces of its joints.

The following subdivisions may be distinguished:—

	Thickness in feet.
Dark-weathering bladed rustyslate, fine-grained and dark within, joints very much rippled where they cross coarser and finer beds	100
Paler-weathering blue slate, with very occasional white-weathering pyritous spots. Some gritty partings, also a well-marked band of cone-in-cone ironstone nodules, which sometimes run together as a continuous bed	50
Strongly banded, tough, rusty-weathering, dark-grey slate with rippled joints	40
Very uniform, blue-grey slate, with some white-weathering pyritous spots forming a passage-zone to the <i>Dictyonema</i> Band and like it containing <i>Protospongia</i>	50
Total	240

Along the dismantled tram-road above Penmorfa the banded beds are beautifully seen in the cutting east of the Carnarvon-road

bridge. There the joints are clean cut, and the rocks shiver rather than break under the hammer. They are overlain by the more thinly-bedded grey slate, which not infrequently contains *Acrotreta*. The great laccolite of Moel-y-gest follows approximately the bedding of the paler slates above the line of ironstone concretions, and about 150 feet above the *Dictyonema* Band; and the small sill quarried in the old railway above Penmorfa is at a similar horizon. Everywhere in the vicinity of these intrusions the rocks have lost their cleavage, and, being hardened almost to recrystallization, have had their bedding and flaggy character rendered very prominent.

Among the upper portion of the Moelygest Beds I have found no trace of fossils, and this despite a long-continued search over the open dip-slopes on the north of Moel-y-gest.

The Geological Survey Memoir (vol. iii, 1866, pp. 251, etc.) records fossils from the northern slopes of Moel-y-gest, but their exact localities are now lost. In the Memoir it is also stated (pp. 69 & 256) that all the localities for Lower Tremadoc fossils (*Niobe* and *Psilocephalus*) occur along a line about 100 feet above the *Dictyonema* Band; but with Homfray I agree in regarding this statement as due to a mistaken conception of the position of *Dictyonema*.

On the hill-side between Tyddyn-diewm-uchaf and the Carnarvon turnpike there are many exposures of the Moelygest Beds, but, owing to strike-faulting, I have not made out the tangle of their succession. At Ty'n-y-coed, and along the bank above Llwyn-derw, I have collected specimens of an *Orthis*, very like the *Orthis christianæ* figured by Moberg,¹ and these I think must belong to the banded lower portion of the Moelygest Beds.

The exposures in the rough pastures of Caer-dyni near Criccieth show slates of similar type, too crushed and slickensided for successful fossil-hunting. The pale bands which here occur about the middle of the series are associated with gritty or felspathic bandings and partings.

(4) The Portmadoc Flags.

The flaggy beds which overlie the rusty bladed slates of the highest Moelygest Beds are quarried along the wharf-side at Portmadoc, and as they have provided the stone of which the town is built, I suggest for them the name 'Portmadoc Flags.'

The change from slates to the more massive and coarser beds, which have been termed 'flags,' takes place rapidly, and is associated with the appearance of a more massive and regular arrangement of the jointing, which makes the quarrying of building-blocks possible. The rock quarried is a minutely-banded blue-grey stone, with ten or twelve flag-like laminæ to each inch, and with prominent pale, and somewhat coarser, felspathic bands every few inches. By reason of a rude cleavage, the rock does not split along all these

¹ 'Ceratopyge Regionen' Med. från Lunds Geol. Faltklub, ser. B, No. 2, 1906, pl. ii.

bands, but bedding-planes with actual discontinuity come in at intervals of from 2 to 6 feet, and the quarry is mostly worked by 4-foot shot-holes along the direction of cleavage and at right angles to these.

Cone-in-cone ironstone nodules, sometimes spreading into beds, occur at irregular intervals through the quarry, and sporadic pyrite-crystals or white-weathering nodules are not uncommon. In weathering the sulphides leach out to the surface, which becomes first black, and then bleaches without much rusting. The heading joints are very clean cut, but only occur at long intervals, and when the weathering eventually breaks up the rock into small pieces it splits into long, rod-like, prismatic masses which have their greatest elongation along the direction of the cleavage.

The best stone is provided by the more felspathic beds, which occur at the southern end of the quarry, and belong to the basal beds; but stone has been got all along the wharf-side, and a thickness of some 180 or 200 feet of strata has been worked over. Upwards above this the texture becomes finer and the rock more pyritous, and though some of its beds are still massive and flaggy, the bulk of it passes into a splintery rusty-weathering needle-slate.

A similar succession can be confirmed along the road by Garth Terrace to Bron-y-garth, and also along the main road to Borth-y-gest. In the quarry opposite the end of Ffordd Morfa-bychan, the lower gritty beds are worked for slabs and building-stone. At Pen-y-clogwyn, and at the cliff above the gate to Morfa Lodge, from this same road, the gritty beds make a fine exposure, and from it can be traced continuously to their abutment upon the Llanerch Fault, at the eastern end of Moel-y-gest. West of this fault the Portmadoc Beds are much broken by strike-faulting, and, although I have mapped the gritty beds, I have not been able always to distinguish the needle-slate above from the Moelygest Beds below them, and the grit outcrop accordingly appears as a set of discontinuous augen in a slaty matrix.

The grit of the augen which includes the two farms of Tyddyn-dicwm (isaf and uchaf) has long been known. One of its grits is massive and almost a quartzite, and has been taken by some to represent the basal Arenig grit. It is, however, only 4 feet thick, and the flags above it contain Tremadoc trilobites in fair abundance.

The gritty augen on the Criccieth side of the outcrop contain coarser and even stronger grits. The slates among them are much crushed and very ill exposed, but the quartz-cemented felspathic grits generally protrude through the scanty soil and can be readily discovered. One of these cropping out along the 300-foot contour, a quarter of a mile south of the farm of Mynydd-ddû, is 16 feet thick and almost massive throughout. Below the 100-foot contour, 100 yards north of Caer-dyni, a whole bundle of similar grits is exposed.

The fossils of the Portmadoc Flags are few and ill preserved. Occasional tails and broken fragments of *Asaphellus* can be got by breaking the cone-in-cone ironstone nodules along their centres,

but this requires much knowledge and skill. The higher flags, with 'needle-rock' between, contain *Bellerophon* and *Asaphellus* in some abundance.

(5) The Penmorfa Beds.

Closely related to the beds quarried along the wharf at Portmadoc are the coarse-textured banded needle-slates which overlie them. These contain a distinctive fauna, and are so generally fossiliferous that I have thought it well, although I cannot separate them with great precision on the map, to give them a distinctive name. This name I have chosen from the village in the street of which I find the best exposure and the richest assemblage of trilobites.

Unfortunately, about Penmorfa there is no open section where the 100 feet of rock which separate the gritty beds from the fossil band can be examined. Such rocks as can be seen in the fields and roads west of Penmorfa are generally thin-bedded, shivery, and presenting occasional coarse bands, which are notably micaceous. They are everywhere pyritous; in wet places they rust with an inky aspect, and where reasonably dry become brightly ochreous. South of the village the fossil band can be dug out of the cattle-track which leads down to the Morfa. Below the fossil band the section is obscure for about 15 feet, and the next exposure is of a flaggy rock. This flaggy rock, which is seen to a thickness of about 30 feet, has alternating bands of harder and softer material. It passes down into dark blue-black slates, which weather into long blade-like splinters and contain *Asaphellus*.

The fossil band of Penmorfa occurs in the village-street at the fork of the New and Old Carnarvon roads between Capel Garisim and the Post Office. Fossils are also found in the raw rock shown behind the cottages, south of the three roads and west of Bwlchedwin. The fossiliferous rock appears again in the corner of the playground of the village school, and ranges continuously up the hill almost to the new reservoir, from which the village now takes its water-supply. Near the Capel (chapel) blue and brown micaceous flaggy beds contain large trilobites, such as *Dicelloccephalus* and the broad form of *Asaphellus*. It is the beds above these, rather fine smoothly-bedded but earthy slates, which yield the richest fauna: *Shumardia*, *Holometopus*, *Agnostus*, *Macrocystella*, *Symphysurus*, along with the larger *Asaphellus*, *Cheirurus*, and *Angelina* being characteristic. So far as I can discover, the fossil bed with *Shumardia* is only 8 feet thick, but the bigger trilobites are found through a much wider range of strata. Below the *Shumardia* Band at Penmorfa *Angelina* is very rare, while above that band one can be sure of finding fragments of *Angelina* in almost every bed.

At Portmadoc the outcrop of the Penmorfa Beds is built over by the houses of the suburb of Garth. There they are seen as rusty grey-blue or leaden-grey needle-slates, with some coarser mica-bearing bands, and have yielded many fragments of big trilobites. At Pen-y-clogwyn and at the entrance to Morfa Lodge they are better exposed, and in the old days provided Homfra and Ash

with many trilobites. Their coarse-textured needle-slates form the country-rock into which the Tu-hwn't-i'r-bwlch sill of porphyritic dolerite is intruded, and over much of their outcrop to the east of Moel-y-gest they are altered by that intrusion.

The old quarry at Tyddyn-llwyn is opened in the beds immediately overlying the Portmadoc Flags, and is just within the metamorphic aureole. Here the slates exhibit no needle-cleavage, but break rather along the bedding, showing a fracture with a silky sheen. At the top of the quarry (nearest the intrusion) some of the beds become pale and spotted almost to a desmoisite, and the coarser bands come away in massive flagstones of first-class quality. The pyrite which at Garth gives rise to very rusty weathering is here concentrated into sporadic bands of small, well-formed, cubic crystals.

The Tu-hwn't-i'r-bwlch quarry on the north side of the sill, and close to the Criccieth-Portmadoc road, is also partly within the zone of alteration. There, too, the rock has little cleavage, but the shape of the fossils gives ample proof of great distortion. The rock quarried is of a blue colour, and comes away in massive slabs along certain more gritty bedding-planes. The bedding-planes are generally silky, and in the deepest part of the quarry some of the beds show the beginnings of a 'desmoisitc' spotting. Fossils, abundant when the quarry was less advanced, are now difficult to obtain at Tu-hwn't-i'r-bwlch. The finding of a *Holometopus* and a *Macrocystella* at the entrance to the quarry persuades me that the fossil band of Penmorfa is not far above.

On the hill-side overlooking Ystumllyn (near Criccieth) finely-bedded blue-grey slates overlies the grit-belt. From these I have obtained a few specimens of *Asaphellus* and a *Cheirurus*, but the shivering and cleavage are so intense that fossil-collecting is a slow process. From the banded slates in the field north of the Criccieth road, next but one east of Tan-y-rhiwiau, I have recently obtained the tail of a *Dicellocephalus*, and by it am further confirmed in my identification of the Penmorfa Beds in this district.

(6) The Garth Hill Beds.

Overlying the Penmorfa fossil-band are the thinly-bedded, rusty, flaggy slates containing *Angelina*, which from the time of Salter's survey of 'the region extending from Tremadoc to Ffestiniog' in 1853¹ have been known as uppermost Tremadoc Slates. These have their most open exposure along the slopes of Garth Hill near Minffordd on the south side of the Afon Glaslyn, and outside our district; but, as they form a dip-slope, and are richly fossiliferous along Garth Terrace above Portmadoc, the name taken from the famous collecting-ground across the river will also serve here.

Perhaps the most accessible exposure is the cliff at the edge of the alluvium or morfa south of Penmorfa village. The section

¹ Mem. Geol. Surv. vol. iii (1866) p. 308.

begins at the cart-track 150 yards S. 40° W. from the first milestone on the Tremadoc-Carnarvon road.

Thickness in feet.

Thinly bedded dark-blue slate, bladed irregularly along the bedding, weathering to iridescent tints and a rich red-brown. Contains abundant tails of <i>Ogygia</i> and numerous pitted heads of <i>Angelina</i>	20
Very thinly-bedded shivering slate-rock, with thin white-weathering bands. Some of its beds are calcareous, and almost consist of broken fragments of <i>Angelina</i>	20
Flaggy slate, prominently ribbed in 3-inch bands, paler and not so rusty as the higher beds, and forming an outstanding rock-rib. Large nodules of cone-in-cone ironstone not infrequent. A flaggy bed in the midst has yielded several specimens of <i>Dicelloccephalus furca</i>	30

Above these rocks, between the *Ogygia* Band and the great Penmorfa Fault, comes some 50 feet of thinly-bedded *Angelina*-bearing slate, but this is too much crushed by the fault to yield good specimens.

At Garth Terrace the rock is similarly thin-bedded and silky; but the needle-cleavage is strong, and it is difficult to break open any bedding-plane over the area of a whole trilobite. At the lodge-gate to Tu-hwn't-i'r-bwlch, and along the Criccieth road as far as the Tu-hwn't-i'r-bwlch quarry, similar banded needle-rock is exposed, and fragmentary fossils can generally be had for the seeking. As we go westwards along the road the needle-jointing gives place to blading, and fossils become easier to get. Farther west, at Penrhyn-llwyd and north of the railway at Penamser, quite good trilobites have been collected, and at the last-named locality the same succession as at Penmorfa has been made out.

On the Criccieth side of the anticline three specimens of *Angelina* were taken from a block of hard blue slate on the road-bank, 250 yards south of Braich-y-saint.

Another famous locality for *Angelina* is Ynys-towyn, on the east side of Portmadoc Harbour. Most of the Tremadoc rock there was quarried away in the making of the road-and-railway embankment, but the remaining hill-mass shows a fine exposure of Garth Hill Beds and of the overlying Ordovician grit. Along the Oakeley slate-wharf the rocks are needle-slates like those of the Garth Hill dip-slope; but north of the roadway the higher beds, less intensely cleaved, are pyritous leaden-grey mudstones with coarser flaggy partings. These weather with an inky or ochreous-brown rusty crust, which is very characteristic, and contain rows of spreading sheet-like concretions of cone-in-cone ironstone at many horizons. Some of the mudstone beds are quite massive, to a thickness of more than a foot. The Tremadoc rocks exposed at Ynys-towyn are about 90 feet thick.

The Ynys, upon which Pen-syflog House is built, shows rock like that of Ynys-towyn. The small rock in the field south-west of the farm yields abundantly *Ogygia* and *Angelina*.

VII. THE ARENIG AND LLANDEILO SERIES.

(1) The Basal Grit.

Upon the Garth Hill Beds at Ynys-towyn rests a strong, massive, quartzose pea-grit which is supposed to overlie the Tremadoc beds unconformably.

The base of the grit rests upon a rough surface, which shows erosion-pockets some few inches deep and a foot or two wide, but I am unable to prove any continuous discordance in the dip. The lowest grit is clean, compact, and well-cemented. It builds a bank almost 20 feet thick, which is massive or irregularly jointed throughout. In the midst of this bank a pebble-bed with quartz-pebbles up to an inch in diameter occurs, and along with the quartz-pebbles occasional flakes of shale, which also may have been pebbles, are observed, but do not break the massive character of the grit.

Above the basal grit-bank small shale-pebbles abound, and flaggy partings break the second 20 feet into irregular 1 to 3-foot banks not quite so coarse-grained as the basal mass. The upper 30 feet are again massive, but, except in the topmost bed, the dip-slopes of which are washed by the waters of the harbour, there are no evident pebbles.

The cementing material of the grit is almost wholly quartz in crystalline continuity with the quartz-grains, but in some places adjoining the more vertical joints interstitial iron pyrites serves the same purpose. Some of the quartz-grains are quite hyaline and blue, and small quantities of various fresh feldspars, including microcline, are not infrequent.

As to the exact age of this grit, we know little. The grit itself seems to contain no fossils; but, by analogy with the grit of Garth Hill, Minffordd,¹ and elsewhere, it is generally considered to be the original local base of the Ordovician.

On the Criccieth side of the district here described, from Tan-y-rhiwiau by the eastern ridge of Moel-bach and Pen-ystumlyn Farm to Pen-mynydd-dû and Bryn Braich-y-saint, a more or less massive felspathic grit much crushed by faulting may be traced continuously, and seems to separate Tremadoc from Ordovician slates all the way. As at Ynys-towyn, it is rich in hyaline quartz, and is often very pyritous. Generally the crushing is extreme, and, although slaty beds are usually interstratified with the grit at many localities, they may be crushed in, and no information as to the succession can be obtained.

Below the first gate across the cart-track, 75 yards north-east from Tan-y-rhiwiau, an exposure of rusty, fine-grained, gritty rocks forms a passage series between the normal grits and slates, and overlies the basal grit. This rock closely resembles some beds of the *Calymene*² Ashes of Arenig or the flag series³ of Manod-bach, and like them contains occasional examples of *Obolella plumbea* and *Ogygia selwynii*. From a loose block adjoining this exposure I

¹ Presid. Address, Quart. Journ. Geol. Soc. vol. xix (1863) p. xxxviii.

² Quart. Journ. Geol. Soc. vol. lxi (1905) p. 619.

³ Mem. Geol. Surv. vol. iii (1866) p. 60.

have also obtained a single specimen of *Calymene parvifrons*. These are the only definite Arenig fossils yet discovered in the Ynysynhaiarn district.

(2) The Western Slate Rocks.

The basal grit just considered is overlain in the Criccieth district by a thick series of slates, which, although they occupy a great area, offer little opportunity for the making out of their succession. Near Portmadoc the possible slate-outcrop is deeply buried beneath the alluvium of the Afon Glaslyn.

Along the foot of the Tremadoc scars the slates are so mixed up in the great thrust-faults which I shall describe later (p. 167) that I am unable to disentangle their succession, and in the Criccieth country (Moel-bach and Braich-y-saint), where the outcrop is widest, the only exposures are the low hummocks of rock which protrude through the scanty soil of well-cultivated land.

In this western district I have at three places measured an apparent thickness of more than 1000 feet of rock; but, knowing the complexity of the strike-faulting in the grit-beds below, I suspect isoclinal folding from the west, and am little disposed to attach importance to the measurement.

The lowest slates, which adjoin the grit, are generally dark, and contain bands of coarse rock with kaolinized feldspars (probably of volcanic origin). From 50 to 200 yards west of the grit-outcrop, the slates are very dark in colouring, but soft and earthy in texture. These generally refuse to break along their bedding-planes, and crush when struck with a hammer. In the Ceunant-du (a strange glacial overflow-channel on the south-western slopes of Moel-bach) the black rocks are seen to pass up into silky, blue-grey, spotted slates, which are well exposed, and have yielded a few tuning-fork graptolites that seem to belong to an early form of *Didymograptus murchisoni*.

At the foot of the Ceunant and along the hill-slopes to the old Gloddfa slate-quarry, which is now used as a reservoir for the Criccieth water-supply, the slates become paler and rather prominently banded. Some of the bands there are ashy and almost flaggy in texture, and, unlike the slates between them and the basal grit, take on a bright rusty tone as they weather.

The slates quarried were soft and almost too well cleaved; they are dark blue-grey in colour, showing rusty bands as they weather, and break with a lustrous silky sheen. They are exceedingly like the Llanvirn Slates of Llanfihangel-y-pennant and the northern Snowdon slate-belt.¹

The exposures of beds higher than these are all unsatisfactory, but it would seem that there is a further series of dark-blue mud-stones, and of very shivery blue shales, before we come to the sooty, mica-spangled, black beds which underlie the felsites of Moel Ednyfed and Ystum-cegid. I have been unable to find any fossils in these higher slates.

¹ Rep. Brit. Assoc. 1903 (Southport) p. 665.

(3) The Criccieth Felsites.

Overlying the black slates of Moel Ednyfed and of the valley east of Ystum-cegid, as far south as the village of Dolbenmaen, is a great mass of fine-grained, cream-coloured or pink, felsitic rock with small porphyritic crystals of felspar, and generally without visible quartz. This rock is either a set of lava-flows or of sills, and, from the character of the platy and columnar jointing and the general absence of associated ashy beds, I incline to the latter view. There is, however, practically no evidence of metamorphism along the junction; and hence, while suggesting that the rock is one of the Llyn rhyolites, which were intruded at the time of the Snowdonian volcanic activity, I would leave the matter open. The fine columnar rhyolite of Dinas and the sea-cliffs of Criccieth Castle form the seaward continuation of the same rock-mass. It is noticed by Mr. Harker¹ as one of those rocks which is probably intrusive; but, so far as I can find its exposures, they show no stratigraphical relations except with the Drift. At Ystum-cegid-bellaf the rhyolite mass is seen to be overlain by andesitic-rhyolite ashes and agglomerate, which it seems to cut transgressively.

VIII. THE TREMADOC COUNTRY.

In the consideration of the Cambrian and Tremadoc rocks it was found possible to make out a stratigraphical succession from the evidences of the accidental dip-sections which circumstances have provided, and to carry on that succession unchanged around the whole Ynyscynhaiarn ring. The Ordovician rocks are not so simple, and the Ordovician succession about Tremadoc appears very unlike the slate-rock series near Criccieth, which I have just described. This difference was long ago recognized by Sharpe, who, in 1846,² remarked that the Tremadoc district with its greenstones belongs to Snowdonia; but, except in so far as Ramsay³ and after him Harker⁴ have noted that Tremadoc lies within the westerly extension of the Lower Ordovician volcanic products, while Criccieth is outside, the matter has received little comment.

When one begins to measure a horizontal section along the dip, say from Tyddyn-diewm to the base of the Snowdonian rhyolites of Ynys-wen or Moel-ddû across this Tremadoc country, one is impressed by the apparent tremendous thickness of the rocks traversed. Such a section measured directly seems to show about 4000 feet of slate-rock between Tremadoc and the base of the Snowdonian rhyolites. In the old days, when the Tyddyn-diewm rocks with their iron-ores were thought to be 'Tremadoc Slate,' a thickness of 4000 feet to represent the Tremadoc, Arenig, and Llandeilo series might be received with little comment; but, when Salter in 1857 had shown that the rocks at Tyddyn-diewm contained graptolites,

¹ 'Bala Volcanic Series of Caernarvonshire' (Sedgwick Prize Essay) 1889, p. 12.

² *Quart. Journ. Geol. Soc.* vol. ii, p. 303.

³ *Mem. Geol. Surv.* vol. iii (1866) chapt. xi.

⁴ 'Bala Volcanic Series of Caernarvonshire' 1889, § vi.

which he identified as of Arenig age, the 4000 feet for the Upper Arenig and Llandeilo rocks seemed a good deal; and when Hopkinson & Lapworth,¹ and Lapworth,² had further shown that these graptolites belong to a horizon which is higher than the Llandeilo limestone of South Wales, the acceptance of 4000 feet for the thickness of Upper Llandeilo rocks became impossible. There must be repetition, and, as there is no evidence of isoclinal folding, that repetition must be accomplished by faulting.

The Penmorfa Fault.

Like most great faults, the Penmorfa Fault is a series of parallel shatterings, which have a common direction. It separates formations as far apart as Tremadoc and Upper Llandeilo; but, since it brings slate against slate along the strike, its exact position is, in the absence of fossils, very difficult to localize.

The eastern course of the fault as it enters the district here described is concealed by the Glaslyn alluvium. It must pass between Yns-towyn and Ynys-galch, probably by way of the Cambrian Railway-station. It ranges through the Ynys on which Pen-syflog House is built, and brings the Garth Hill Beds with *Angelina* there, within 50 yards' of Llandeilo slates containing *Climacograptus schärenbergi*.

Across the Morfa to Glan-morfa it lies beneath recent sand and silt; but, along the south-western edge of the mound Hen-fynwent (the site of the Roman villa), a little cliff on the field side shows a fine section of an overdrag affecting Ordovician slates. In Penmorfa village the road-cutting at the corner between Capel Seion and Plas-isaf shows Garth Hill Beds and splintered Ordovician rock side by side. The new well-house is on the Ordovician side of the fault, but Tremadoc fossils can be found 50 yards to the west of it. Above Tyddyn-dicwm the fault continues obliquely up the hill, and passes the 600-foot contour before it comes down, and is buried beneath the Cwm Ystradllyn Drift. Some 2 miles farther along, a fault of similar hade and direction can be proved along the crags of Tyddyn, south of the river, at Dolbenmaen.

Along this line the fault maintains an even course, the geometry and general outcrop of which indicate a strike of about N. 50° W. to N. 60° W. and a general gentle dip to the north of north-east. In order the better to study the fault-plane, I arranged with Mr. Greaves (Wern), the owner, and Mr. Jones, the farmer, to have trenches cut across the fault, at the locality, above Tyddyn-dicwm, where its course is most open, and where the Tremadoc and Llandeilo fossils had been proved in closest apposition. The spots chosen are in the big field containing the westernmost of the Tyddyn-dicwm iron-ore trial-holes, and are both above the 600-foot contour, on the southern slopes of Craig-y-gesail. The sections are dip-sections and are best described by true-scale diagrams (see figs. 1 & 2, pp. 168-69).

¹ Quart. Journ. Geol. Soc. vol. xxxi (1875) p. 636.

² Ann. & Mag. Nat. Hist. ser. 5, vol. iv (1879) p. 340.

Fig. 1.—Section of the hillside above Tyddyn-dicwm, showing the relationship of the Tremadoc and Llandovery rocks across the Penmorfa Fault.

Fig. 2.—Sections of the eastern and western trenches, Tyddyn-dicwm, on the scale of 15 feet to the inch.

Tremadoc trilobites were found in the rocks at the foot of the eastern trench, and graptolites frequent in some of the rocks of the eastern were abundant at the top of the western trench. In the making of these trenches it was found that the Tremadoc rocks of the sole of the thrust are little affected by induced minor cracking, but the Ordovician slates are cut again and again by small overthrust-faults, each a little steeper than the great plane of discontinuity at their base.

In the eastern trench the Ordovician rocks are often gnarled and shivered beyond description. They break into sheared and slicken-sided, augen or spearhead-shaped masses, which are set with their long axes a little more nearly north and south than the dip of the thrust, which is here striking N. 60° W. and dipping at 25° to N. 30° E.

In the western trench the Llandeilo rocks are partly pyritized and somewhat mineralized, and so, although broken by the minor thrust-planes, form larger augen within which the slates retain their bedding. From these augen the graptolite fauna recorded in the Rep. Brit. Assoc. (Belfast) 1902, p. 599, was obtained.¹ In making the trench it was noticed that there are three kinds of graptolite-bearing rock characterized respectively by:—

- (1) Swarms of *Climacograptus schärenbergi*,
- (2) *Nemagraptus gracilis*,
- (3) *Climacograptus peltifer*,

each distinct one from the other. The occurrence of these in the trench is plotted in the diagram, which surely gives abundant proof of reduplication by faulting. Though the graptolitic assemblages in the three bands are quite distinct, the evidence before us is not sufficient to make it clear that the bands belong to distinct graptolite zones.

The Pisolitic Iron-Ores and Tyddyn-dicwm Shales.

The rocks next above the Penmorfa thrust-plane are gnarled, shivered, and kneaded into a regular augen-schist through a thickness (measured at right angles to dip and strike) which varies from

¹ The following list, kindly prepared for me by Miss G. L. Elles, D.Sc., includes all the specimens of graptolites from Tyddyn-dicwm which are preserved in the Sedgwick Museum to January 1st, 1910:—

Didymograptus superstes, Lapw.
Dicellograptus sextans, Hall.
Dicellograptus intortus, Lapw.
Dicellograptus divaricatus, Hall.
Dicellograptus moffatensis, Carr.
Dicranograptus ramosus, Hall.
Dicranograptus rectus, Hopk.
Dicranograptus ziezac, Lapw.
Dicranograptus furcatus, var. *minimus*,
Lapw.
Dicranograptus nicholsoni, Hopk.
Nemagraptus gracilis, Hall.
Climacograptus schärenbergi, Lapw.

Climacograptus bicornis, Hall.
Climacograptus bicornis, var. *peltifer*,
Lapw.
Climacograptus antiquus, Lapw.
Climacograptus antiquus, var. *bursifer*
(Elles & Wood).
Amplexograptus perexcavatus, Lapw.
Glyptograptus teretiusculus, His.
Orthograptus priscus, E. & W.
Orthograptus whitfieldi, Hall.
Glossograptus hincksii, var. *fimbriatus*,
Nich.
Cryptograptus tricornis, Carr.

about 100 feet at Tyddyn-diewm to perhaps 300 feet in the Ynys near Tremadoc. Within this crush-belt the slates are so flaked and shattered by the jointing, that both cleavage and bedding are difficult to observe. Soft, silky, or earthy in their texture, they are dark enough in colour to have persuaded some prospectors to dig for coal among them, and it was in the search for coal that the pisolitic iron-ore was discovered.

The pisolitic iron-ore masses, like all other rock-units within the crush, occur in the form of augen or lenticular lumps which vary from the size of a bean to that of a 100-ton schooner, and have a distribution which seems to be sporadic all through the dark shale of the crush-band. Until 1860 the ore was worked with great zeal; but, as in the deeper workings the proportion of sulphur increased, it

Fig. 3.—*Sketch-plan of the surface from which the iron-ore has been stripped.*

became unprofitable. The plotting of the contour strike-lines of the surface from which ore has been stripped in the Tremadoc mine between Tremadoc and Glanmorfa gives the accompanying diagram (fig. 3), which shows well the augen character of the large ore-units. The puckering of the dip-surfaces between which the augen lie, illustrated in the second diagram (fig. 4, p. 172), is also characteristic.

Though, from their mode of occurrence, the ore-masses must be related to the crushing movements, the individual ore-masses, whether large or small, show no signs of crushing, and the pisolitic grains within them maintain their sphericity, right up to the surface. The slates around may be rolled out to a regular sericitic mylonite, and pieces of shale within the ore be of similar character, but the ore itself is never in the very least affected. This, and the circumstance

Fig. 4.—Section showing the mode of occurrence of the pisolitic iron-ore among the slate-rocks, in the iron-mine north of the Penmorfa road, Tremadoc.

that the largest ore-bodies occur near the top of the crush-zone, where it abuts upon the metamorphic aureoles¹ of the late intrusive dolerites, has led me to urge that the ore is of secondary or metasomatic origin, and owes its distribution to the position of the fault.

The country-rock about the mines consists always of blue-black or dark leaden-grey slates, which rust to a uniform dead brown colour. Most of the slates seem devoid of fossils, but at Ynys-galch, Pen-syflog, and the old tramway-cutting 50 yards north-west of the Tremadoc mine, *Climacograptus schärenbergi* and *Dicellograptus sextans* occur in some abundance. It was from the debris turned out of the iron trial-holes at Tyddyn-diewm that Salter and later observers have obtained the graptolites which they record. The country-rock of the pisolitic iron-ore is therefore of Llandeilo age, and, like the graptolite-bearing rock in the trench at Tyddyn-diewm, was originally of that open-water

¹ Geol. Mag. 1907, p. 422.

facies which we call Glenkiln.¹ It is noteworthy that from the time of Sedgwick to that of Cole² and Jennings & Williams,³ slates with pisolitic iron-ore have been regarded as the most characteristic of the 'Tremadoc' Slates, and rocks at Llanelhaiarn, Abersoch, Cader Idris, etc., are identified as of Tremadoc age, because they are rather similar to these Llandeilo rocks.

Above the belt of pisolitic iron-bearing rocks the slates lose their dark colour, and pass into blue or greenish-grey banded slates, with coarser flaggy or ashy beds above them. Fossils in the higher rocks are difficult to find, and I have been compelled to map the area on lithological evidence alone. Upon the map I distinguish the following four very distinct lithological types:—

- (1) The well-known gabbroid dolerites,⁴ which form the crags of Y Gesail Y Castell above Tremadoc, and Pant-ifan behind Tan-yr-allt.
- (2) Banded blue-grey slates, into which the dolerites are intruded, and which they, when in contact with them, have altered into 'spilositic' flags and hornstones.⁵
- (3) Ash-bands, usually of andesitic composition, and varying in their texture from fine tufts to agglomerates.
- (4) A non-porphyrific vesicular rock, probably once an andesitic lava, which underlies, and is closely associated with, the most prominent ash-bands and agglomerate.

Regarding the slate-rock (2) as a matrix in which the others are set, it is apparent that on the map the dolerites (1), the ashes (3), and the vesicular andesites (4) alike appear as strings of elongate lenticles. Since the time of J. E. Davis⁶ these dolerites have been recognized as intrusive, but, unless we postulate a separate volcanic vent for each lenticle of ash or agglomerate, the stringing-out of the andesite exposures (4) can only be explained by faulting; and since we have proved such faulting along the line of the pisolitic-iron belt, it is not unreasonable to explain the further repetitions and general 'shuffled' arrangement of the whole country to the north-east of it upon a similar plan.

The Andesitic Volcanic Rocks.

The main outcrops of the andesitic rocks (3) and (4) form subsidiary cliffs on the scarp-faces of the hill-masses which are determined by the dolerites. They occur in four main series of exposures. The westernmost exposure of these is on the south-western face or edge of Craig-y-gesail (fig. 1, p. 168). This exposure shows only a few feet of cherty ash, which is too much baked by the

¹ C. Lapworth, *Quart. Journ. Geol. Soc.* vol. xxiv (1878) p. 253.

² G. A. J. Cole & V. Jennings, *ibid.* vol. xlv (1889) p. 436.

³ V. Jennings & G. J. Williams, *ibid.* vol. xlvii (1891) p. 372.

⁴ A. Harker, 'Bala Volcanic Series of Caernarvonshire' (Sedgwick Prize Essay) 1889, § vi.

⁵ J. J. H. Teall, 'British Petrography' 1888, p. 219.

⁶ *Quart. Journ. Geol. Soc.* vol. ii (1846) p. 70.

dolerite to yield further information. The second series of outcrops is seen on the path up from Penmorfa to Beudy'r-garth, and can be traced continuously for some half a mile along that path, as far as the old Penmorfa flag-quarry on the slopes of Allt Wen. In the quarry it consists of several distinct beds, altogether about 8 feet thick. In this exposure the crumpling of the bedding of the ash-bands under the stresses which produced a slaty cleavage in the beds above and below is beautifully shown, and is most characteristic (see fig. 5, below).

Fig. 5.—*Exposure in the Penmorfa flag-quarry.*

[The above view shows the andesitic ashes of the 'second series' of exposures interstratified with slaty rocks now metamorphosed to desmoisitc flags. The slates, by compression under cleavage-stress, have suffered uniform distortion; while the andesitic ashes (now almost adinoles) have become crumpled.]

Due north of the Tremadoc iron-mine the ash-band appears again, and is underlain by 25 feet of the vesicular rock (4), which itself overlies a dark slate with ill-preserved *Diplograptus*, and these three beds follow on together until they are covered by the screens of

Y Castell. Farther south-east, beyond Tremadoc Church, shivering shales with graptolites are seen in Ynys-fadog, and are overlain by the vesicular rock and a couple of ash-bands. At Bodawen gate a flaggy ash-band underlies the *Diplograptus*-bearing slate, which is overlain first by the 30-foot mass of vesicular andesite of Ynys-hir, and then by the massive ashes and agglomerates of Y Nursery, which are at least 50 feet thick. The rocks above these are dark needle-slates, very like the crush-rock at Ynys-galch. At Ynys Cerrig-duon, east of Portmadoc, another mass of ash is underlain by an andesite the larger vesicles of which, not having come within range of the dolerite metamorphism, still contain some zeolitic minerals.

The third range of andesitic rocks is much more massive, and forms the hill-ridges of Y Fedw and Y Glog, as well as the outstanding promontory on which the Roman Altar was built. Though massive to a thickness of at least 100 feet, just south of Llyn Cwm-bach, the outcrop thins to vanishing point at the western end of that lake. It is also completely pinched out for a considerable distance in the woods of Tan-yr-allt, between Y Glog and the foot of the hill. West of Y Fedw, above Cwm-mawr House, the slates for 150 feet or more below the agglomerate are very flaggy, and enclose strings of thin ash-lenticles. These continue past the Cwm-bach farmhouse, and approaching the Y Glog ash-mass are separated from it only by a vesicular andesite. The section through Y Glog is, therefore, identical with that at Bodawen and Ynys-hir mentioned above, and it is satisfactory to find that the slates among the flaggy ashes at both places yield specimens of *Diplograptus*. The small outcrop of ash in the wood, 150 yards north of Tan-yr-allt House, is also underlain by vesicular rock.

A fourth range of andesitic ashes and agglomerates forms the culminating ridge of Pen-yr-allt. There are, however, no vesicular rocks; and, as the rocks below the ash-bands show a complete and gradual passage down into slate, I wait for palæontological evidence before venturing to suggest that these rocks also belong to the same horizon with the three outcrops below the dolerites just discussed.

A diagrammatic section from Tyddyn-diewm to the corner of the map passing through Y Glog and Pen-yr-allt is appended (Pl. XV, section B). On this section it will be noted that the reduplicating thrust-planes are occupied by the dolerite sills; but, with this interpretation, though I am unable to find any other explanation of the phenomena, I am not altogether satisfied.

The Banded Slates.

Having now seen something of the structure of the country, we are in a position to discuss the age of the grey and banded slates. Since the latter overlie the graptolite-bearing *Climacograptus-peltifer* beds of Tyddyn-diewm, there is no reason to believe that they are older than these; but, pending the discovery of more fossils, we must

leave open the question of an upper limit. In this connexion it is interesting to find that Sedgwick¹ records a *Homalonotus bisulcatus* above the dolerite of Pant-Ifan. In similar rock from the waste heaps of Portreuddyn, Mr. J. G. Black in 1909 turned out a *Trinucleus*, and I an *Ogygia*; and in the cliffs of Prenteg, which, as I believe, are a continuation of the rocks of Pen-yr-allt, various ill-preserved specimens of *Orthis* (*O. elegantula*, *O. actonii*, *O. calligramma*) are not rare.

Such indications as we have, suggest therefore, that the grey and banded upper slates and their associated andesites belong to a high Llandeilian or a low Caradocian (Snowdonian) horizon, and this the further tracing of the andesites to a source upon the Moelwyn seems to confirm.

The sediments of the Ynyscynhaiarn country having now been described, there remain the rocks which are intrusive into these, and the structures which have been impressed upon the country by post-Ordovician earth-movements. These I shall consider in what was probably the chronological order of their development, and shall give the evidence for this chronology as I describe the phenomena.

IX. THE FOLDING.

The most outstanding characteristic of the geological map of Ynyscynhaiarn is the ring-like arrangement of the *Lingula* Flags and Tremadoc rocks about a centre which lies among the sand-hills half a mile east of Craig-ddû and midway between Borth and Criccieth (see Pl. XVI, sections C & D). From this centre, an anticline, with its axis pitching at about 1 in 6, ranges N. 5° E. through the marshes of Llyn Ystumllyn, and onwards until it is lost beneath the Drift at Gwern-ddwryd, half a mile beyond the village of Pentrefelin. From this axis the rocks dip away eastwards at about 10° or 20°. To the westward the dip is steeper; but this, in part, is due to the later (parasitic) sharp folding which has developed irregularly along this western side.

Half a mile east of the main anticline the arrangement of the strike-lines between Treflys Church and Coed-y-cefn, south of Wern, shows a syncline which ranges along a curving line considerably east of north, and dies away north-eastwards. The anticline which corresponds to this follows the hollow from Bron-y-foel to Morfabychan, and runs more nearly north and south.

From some points of view, the southward thrown fault-mass upon which Borth stands may be regarded as the syncline that corresponds to the Ynyscynhaiarn anticline; but the evidence before us is not sufficient to decide whether the Llanerch displacement, which bounds it on the west, is earlier or later than the cleavage. The manner in which the dolerite mass of Capel Siloam crosses the Llanerch Fault at Ynys Gyngar Farm seems to show that that dolerite is more recent than the fault.

¹ Quart. Journ. Geol. Soc. vol. iii (1847) p. 141.

X. THE OLDER DOLERITES.

Probably the oldest of the intrusive rocks of the district are the sills of 'white trap' the outcrop of which I have taken to mark the line of separation between the Maentwrog and the Ffestiniog Beds. These were once dolerites of an andesitic type, but are now become aggregates of calcite, chlorite, leucoxene, zoisite, and other secondary minerals only. They and their feeder dykes, which trend N. 40° E., form the crags of Craig-ddû and Careg-yr-Eryr, the low *roche moutonnée* in the midst of the Ystumllyn marsh, and again appear in the crags which overlook the Portmadoc golf-links, at Morfabychan, and Ynys Gyngar.

Wherever found, the form and the distribution of the sills are partly determined by the folding of the strata among which they lie; and as they are also universally affected by foliation and distortion due to cleavage, we must conclude that they are of an age intermediate between the folding of the Ynyscynhaiarn anticline and the oncoming of the cleavage.

XI. THE CLEAVAGE.

The modification of the sedimentary rocks of the Ynyscynhaiarn district, by stresses at some period subsequent to their accumulation, is a circumstance which forces itself upon the attention of the most casual observer. All the rocks, except the gabbroid dolerites, show evidence of intense compression, and even the most rigid of the grits have lost their porosity. Speaking generally, all the finer-grained rocks have become slates, and by the uniform rearrangement of their particles have suffered distortion, but have maintained the continuity of their bedding.

Rigid and coarser-grained rocks have behaved differently. Sometimes their individual beds have crumpled up separately, as at the Penmorfa flag-quarry (see fig. 5, p. 174). Sometimes, shearing across, the rigid beds have piled themselves up into 'knoll-reef' lenticles—such as the augen of grit in the Portmadoc Flags near Criccieth, or those of andesitic ash above Tan-yr-allt. Sometimes, again, as among the Ffestiniog grauwackes of Moel-y-Gadair and St. Cynhaiarn's Church, where the compression has been very intense, they have buckled or broken into sharply-pitching isoclinal folds.

Within our district, the most patent effect of the compression has been a complementary elongation of the mineral particles in a direction at right angles to the stress. All rocks alike and every fossil found show such distortion, and have been drawn out along an axis which varies from N. 5° E. in the west and south to N. 35° E. in the extreme north-east. A normal steeply-dipping slaty cleavage, also ranging N. 5° E., has been developed in the Arenig and Llandeilo slates of the west; but over the eastern half of the district the slaty rocks show only a less intense cleavage which at Bron-y-foel dips at 35° to E. 10° S.

In working over this district, I have been unable to obtain specimens that can be made to show the characteristic arrangement of mineral particles constituting the needle-cleavage, which so frequently affects the Tremadoc and later beds: so, for the present, I will postpone further consideration of the subject. I cannot, however, agree that a needle-cleavage is the result¹ of the superposition of two cleavages.

XII. THE FAULTING.

After the cleavage came the faulting, which, as I believe, must belong to a continuation or later phase of the same set of earth-movements as those that produced the cleavage. Elongation of deep-seated rocks can never continue indefinitely; and, as the prolongation of the postulated N. 5° E. and N. 35° E. cleavage-axis would lead us among the rigid igneous rock-masses of Snowdonia, it is obvious that expansion could not take place far in that direction. Conversely, the rocks between the district here described and Snowdonia which were also compressed would have to expand south-westwards; and, according to my view, it was their riding to the surface which compelled the formation of the Penmorfa Fault and of the pisolitic-iron crush-belt. The strike-faulting in the country to the north-east of the Penmorfa Fault has been already described (pp. 167-75), and I know of no other faulting in that region.

The belt of country south-west of the Penmorfa Fault is affected by several parallel faults, induced by the shearing movement of the over-riding mass. One of these which, from Glan-byl (see Pl. XV, section B) to the top of the woods behind Penmorfa Church, cuts out the whole of the Dolgelly Beds, must be a thrust of some magnitude, but there are hosts of others too small to map. The rocks on the northern slope of Moel-y-gest also are similarly placed in respect of the continuation of the Penmorfa crush beneath the Morfa, and they, too, are cut into detached lenticles along the strike. It was between two of these lenticles that the pisolitic iron-ore was found and worked south of Penamser.² The most evident of the strike-faults of Moel-y-gest is one along which the main road passes north of Penamser (see Pl. XV, section A); it continues through the Cemetery, and forms the hollow in which Penrhyn-llwyd stands. This fault gives rise to a repetition of the Portmadoc Flags; but it is more particularly interesting from the circumstance that it cuts off the north-and-south fault which so markedly displaces the *Lingula* Flags and Tremadoc Beds in the neighbourhood of Llanerch. This Llanerch Fault (see Pl. XVI, section D) is a displacement with a steep hade to the west, and about Llanerch has a downthrow to the east which brings the *Dietyonema* Band against the *Lingulella* Band of the Ffestiniog Beds. It is associated with a local flattening of the dip, and may represent

¹ A. C. Ramsay, *Mem. Geol. Surv.* vol. iii (1866) p. 235.

² *Ibid.* p. 252.

a small syncline on the eastern flank of the Ynyscynhaiarn dome. The course of the fault is sufficiently indicated by the map (Pl. XVII), and as a line of topographic features between Moel-y-gest and Ynys-gyngar Farm is very evident. It is traversed by, and is, therefore, probably earlier than, the doleritic intrusion of Moel-y-gest.

A parallel fault through the hollow along which the road from Portmadoc to Borth Harbour passes is of less importance. It also has a downthrow to the east.

The faulting which displaces the Dolgelly Beds south of Wern is also interesting; but, although the fault-face is evident in the road-cutting west of Wern gate, I cannot determine its importance.

XIII. THE LATER DOLERITES.

Most prominent of all the topographical features of Ynyscynhaiarn are the great dolerite cliffs of Moel-y-gest, Y Gesail, Tremadoc, and Tan-yr-allt. These are the most recent rocks (other than Pleistocene accumulations) that occur in the district. They and their attendant metamorphic effects have been described by Dr. Teall¹ and again by Mr. Harker,² and I shall not at present add to these descriptions. Mr. Harker, however, says that 'one effect of the alteration has been to prevent the impression of the cleavage-structure on the argillaceous strata'; and, as he goes on to distinguish this from the examples where cleavage has been obliterated by metamorphism, and so infers that the dolerites are older than the cleavage, I must put forward some additional evidence as to their age. First of all, however, it will be convenient to say something of the jointing of the region.

XIV. THE JOINTING.

The joints in this district are complex, even for a region of older Palaeozoic rocks, but in the plotting of the map their detailed variations have proved of great value in distinguishing between the different rock-series.

As might be expected from cracks which have opened along the directions of least breaking strain, during the folding or weathering of the rocks, many of the joints follow the structures of the rocks with great closeness. The direction of greatest elongation of the rock-particles by the cleavage is the direction of the most regular of the joints, which in most rock-exposures serve as 'leaders.' In rock in which a slaty cleavage has fully developed these leaders dip with that cleavage, but in the harder rocks where fracture still in the main follows the bedding-planes, they break at right

¹ 'British Petrography' 1888, p. 216.

² 'Bala Volcanic Series of Caernarvonshire' (Sedgwick Prize Essay) 1889, p. 79.

angles to the bedding. 'Heading' joints, approximately at right angles to the cleavage-direction, are also common. These generally make an angle of 10° to 20° with the vertical, and dip with the cleavage. They cut across the bedding, and open with a 'rippled' surface, which is very characteristic. The individual ripples on these joints mark the alternations of harder and softer beds.

Strike-joints, also nearly vertical, are frequent, but are rarely traceable over any considerable distance. They, too, sometimes show rippled surfaces, but they may be clean cut.

Dip-joints are never common, and when found are usually 'bevels,' the association of which with the direction of dip is mostly accidental.

Bedding-planes, cleavage-joints, and either strike-joints or headings are the planes of discontinuity, which detach the distorted parallelepipeds of rock that litter the quarries and exposures of sedimentary rocks.

Of minor jointing the most noteworthy is that which follows the needle-cleavage, and splits up the rocks into the rods, needles, or blades, already described. Where needle-cleavage occurs, the weathered rock breaks into fragments, the long axes of which agree with the main cleavage-direction of the country, irrespective of the strike of the rock. Where undisturbed, the rock-pieces lie inclined along the cleavage at an angle which is some few degrees steeper than the bedding, and maintain their inclination over considerable distances irrespective of the dip of the bed. In most rock-beds the transverse section of the individual needles is characteristic. Sometimes almost square, with one face steeply inclined and the other nearly flat (rodded structure), they are at other times flattened down to a knife-blade, with the roughest of conchoidal fracture along their faces (bladed structure); and all the stages between these extremes can be found, if sought for. Usually, the cross-section is more or less of a parallelogram, which has its longest side dipping eastwards.

Besides these jointings, which belong to the minute structures and arrangements of the particular rock-beds, there are also certain joints or structure-lines, which cross the *Lingula*-Flag and Tremadoc-Slate country irrespective of everything. These, in the district here described, range between 50° and 60° W. of N., and have like normal faults. Their directions agree fairly well with that of the Penmorfa thrust-plane; but, as their inclination is almost vertical, I do not think that the directional relationship can be more than accidental. They are especially evident in the bare Ffestiniog-Group country, south and west of Moel-y-gest and north of Pentrefelin. There, crossing the alternating flag and grauwacke outcrops, they determine the faces of the scarps which are formed by the harder beds; and hence, though each individual crag marks the outcrop of a hard bed, the alignment of the crags on the hillside or on the map is plagioclinal.¹

¹ C. Callaway, Geol. Mag. 1879, p. 216.

Coming now to the jointing of the igneous rock-masses, we find that those (the andesites) which are contemporaneous behave as do the grits and grauwackes, and have joints in similar directions. The early dolerites of Craig-ddû, etc. do likewise, but show some evidence that when they were foliated by the cleavage-stress, they were also sheared along certain pre-existing columnar joints. This shearing is particularly evident at Gareg-gôch, Careg-cnwc, and at several points along the edge of the golf-links of Morfabychan.

The later gabbroid dolerites of Moel-y-gest, Craig-y-gesail, Y Castell, and Pant Ifan, etc. behave very differently. Where not too massive, as at Morfa Lodge, Portmadoc, they exhibit only the rude columnar jointing which is characteristic of basic sills. Where coarse-grained and very thick, they show similar columnar structures in the fine-grained rock at their edges, but within the main mass they break up more regularly along master-joints. The most prominent of the master-joints are those which determine the slab-like character of the cliff-faces, and these not following any other rock-structure in the district range east and west and have a steep hade to the south. On the bare hill-exposures, the east-and-west joints frequently determine subsidiary crags, and with dip-joints, occasional strike-joints normal to the sill surface, and a platy structure which follows the elongation of felspar-crystals, break up the gabbroid rock into blocks which are rudely cuboidal.

The hornstones immediately in contact with the gabbroid dolerites have a system of jointing which is very complete, and partakes of the arrangement of the columnar joints within the margin of the dolerite. Completely recrystallized, they have lost all original structures, except the chemical banding of their bedding which has often become emphasized.¹

The slabby rocks, 'desmoisites and spilositcs,'² of the outer zone of metamorphism have also a few east-and-west master-joints in common with the altering rock; but, although they have now no tendency to break along a cleavage, their most dominant jointing always follows the cleavage-direction of the country. This circumstance is suggestive, in that it helps to confirm the post-cleavage age of the dolerites, and it is interesting to note that the worm-tracks, nodular concretions, etc., which are sometimes preserved upon the bedding-surfaces show evidence of having been pulled out in a similar direction. The puckerings of interstratified coarser bands and a certain 'flakiness' of the surface of the finer-grained slabs also show an elongation in this same cleavage-direction.

¹ A. Harker, 'Bala Volcanic Series of Caernarvonshire' (Sedgwick Prize Essay) 1889, § vi.

² J. J. H. Teall, 'British Petrography' 1888, p. 219.

XV. THE AGE OF THE GABBROID DOLERITES.

I may now summarize the evidence as to the age of the gabbroid dolerites of Tremadoc, Y Gesail, Pant Ifan, and Moel-y-gest.

(1) The gabbroid dolerites have everywhere altered the rocks in contact with them, both above and below. They are, therefore, intrusive, and later than the Ordovician sediments of the country.

(2) The laccolites of dolerite follow the general strike of the sediments of the country, but do not follow the course of any individual bedding-plane for more than a few yards together. The outcrops do not, however, partake of the discontinuities that affect the rigid members of the sedimentary series with which they are associated. The dolerites have, in fact, metamorphosed sedimentary rocks which had already attained their present discontinuous arrangement, and are therefore later than the tearing of the Ordovician volcanic rocks into lenticles.

(3) The dolerites are completely unaffected by any shearing or foliation which has an orientation related to the cleavage of the country, but, as shown by the distortion and jointing of the rocks which they alter, are later than the cleavage.

(4) The Moel-y-gest dolerite cuts, and is later than, the Llanerch Fault.

(5) At Tyddyn-diewm the metamorphic aureole of the Craig-y-gesail dolerite extends into the crush-belt of the Penmorfa Fault. Within this crush-belt there is no interfaulting of altered and unaltered rock, but the margin of the metamorphic aureole, as in other places, is regular. The Craig-y-gesail dolerite is consequently later than the Penmorfa Fault.

Probably, therefore, the gabbroid dolerites of Tremadoc are of late Devonian or Carboniferous age.

XVI. THE PLEISTOCENE ACCUMULATIONS.

A discussion of the sequence of events which took place in Ynyscynhaiarn between the time of the later dolerites and the Pleistocene would require consideration of an area much larger than the district studied, and will not here be attempted.

The Pleistocene accumulations also, though interesting, do not locally afford sufficient evidence of their origin, and these, after brief mention of their lithological character and distribution, I shall leave over for another occasion.

The oldest Pleistocene deposit that I have discovered in the district is the shore-talus or 'head' occurring close under the cliff, and is overstepped by the Boulder-Clay which is banked against the Criccieth Castle rock. This ancient cliff-deposit is seen on both sides of the Castle, and consists of angular unworn rock with scree-like stratification. It rests quite undisturbed upon a wave-cut platform within a foot or two of the present limit of the highest tides.

The Glacial accumulations of Ynyseynhaiarn are practically all boulder-clays. These occupy a very considerable area in the northern part of the district, and north of a line running north-eastwards from Criccieth by Eisteddfa and Gesail Gyfarch to Foel-yr-erw, cover and completely conceal the outcrop of the solid rock. The hills of Pen Mynydd-ddû, Bryn Braich-y-saint, Moel Ednyfed, Ymwlich, and Ystum-cegid are exceptions. To the south-east of this line also the constant occurrence of striated pavements, roches moutonnées, travelled rocks perched upon eminences, and drift-pockets under the lee of upstanding crags, makes it certain that the whole country has been intensely glaciated.

Two types of Boulder Clay may be distinguished. The most dominant is the Northern Drift, characterized by boulders from Cwm Ystradllyn, Moel Hebog, and the Pennant Valley. This covers the whole of the Drift area above the 300-foot contour, and as far south as Moel Ednyfed. The other type is the Western Drift, containing travelled boulders from the Lleyn (West Carnarvonshire) and Anglesey, which locally seems to have come in-shore from Cardigan Bay. This Western Drift is well seen in the shore-cliffs both west and east of Criccieth Castle, and its eastward extension forms the ground-rock of the Criccieth 'New' Esplanade and the stony promontory of Merllyn, half a mile to the east of the town. Travelled rocks of the type seen *in situ* on the Rivals are found in the grounds of Bron Eifion, and as far up the hill as the reservoir which supplies Bron Eifion with water; but the limit between Northern and Western Drift is not an easy one to define.

The boulders found scattered over the south-eastern driftless area all belong to rock-types found in the Glaslyn Valley, and as the striations noted also point to a glaciation from north-east to south-west, we may take it that there the glacial sculpture was accomplished by the Glaslyn glacier. Such a glacier with an ice-supply from high up among the mountains of Snowdonia would be more powerful than its neighbour from Cwm Ystradllyn; and it is possible that while the former was able to carry its débris right out to sea, the latter, checked at Criccieth by the bar of western ice, was compelled to stagnate behind that bar, and so deposited its burden of boulder-clay on the land. The Glaslyn ice must have advanced directly across the 'grain' of the Tremadoc country, and in its passage has sculptured each outstanding scarp from Pen-yr-allt to Moel-y-gest into a roche moutonnée. The glacial plucking and removal of all scree and loose rock on the steep south-westward facing scarps seems also to have been accomplished very completely.

Of post-Glacial phenomena one of the most striking is the very complete removal of all fine-textured débris from the south-eastern tract of the area here described. Except locally, where covered by scree from a steep upstanding crag, hardly a trace of Drift remains; and, in many places, the rocks are still so bare that the soil can hardly support the most meagre vegetation. Such scouring

is possibly of late Glacial date, and may be due to floods coursing along the edges of the waning valley-glaciers at a stage when they were becoming rather short of, or perhaps free from, lateral moraine. It is a phenomenon which is common to the southward-facing slopes of the lower courses of many of the valleys of Carnarvonshire and Merionethshire.

Of post-Glacial accumulations Ynyscynhaiarn has its full share. A raised beach I have not certainly identified, but the promontory of Craig-ddû seems to show a wave-cut platform about 10 feet above most tides, and at Ynys Gyngar, Careg-cnw, Gareg-gôch, Trwyn-y-borth, and Trwyn-cae-iago (Craig-y-don) about Borth, I think that I can recognize a similar but less deeply cut wave-notch. The various Ynys about Tremadoc also show wide rock-platforms a little above the level of the morfa; but it would require careful measurement to determine their relationship to the tide-level outside the embankments.

The alluvial deposits of the Afon Glaslyn and the manner in which tidal silt is building up the Traeth Mawr into land is well known. The cliffs beyond Tan-y-graig below Craig Pant-ifan have no scree at their base, and are pierced by caves as fresh now as in the days when they were washed by the tide. The Roman inhabitant of Hen Fynwent was a fisherman, and the find of kitchen-middens of cockle-shells (*Cardium edule*) at Wern shows that the silting up of the whole morfa of Penmorfa is not much more ancient. There was a sea-bathing place at Tremadoc at the beginning of last century.

The morfa of Morfa-bychan is of similar date, but owes its formation to the sand blown in from the tidal sands and to the growth of salt-marsh plants in the bogs behind the sand-hills.

The pebble-bank between Criccieth and Craig-ddû is also worthy of notice. It is formed by tidal drift from the west, and consists of well-sorted rounded pebbles from the Western Drift-mass of Criccieth; and, as in their eastward migration the pebbles are unable to pass Craig-ddû, it is still growing. Pushed out as a spit from the cliff of Ogof-ddû, the beach has barred the outflow of the waters which come from the hills into Llyn Ystumllyn, and holding up the lake has compelled its waters to find exit between the pebbles or through the well-jointed rocks of Craig-ddû, which they do most effectually, appearing at low tide as springs on the foreshore.

XVII. GENERAL SUMMARY AND CONCLUSIONS.

The district of Ynyscynhaiarn consists of Cambrian and Ordovician rocks arranged about a northward-pitching north-and-south anticline, which has its axis through Llyn Ystumllyn close by St. Cynhaiarn's Church. The rocks have been cleaved along lines which range a little east of north and south, dip eastwards, and are broken by a series of thrust-planes, which are inclined to the north-east. Into the sedimentary rocks, possibly along the lines of

the thrust-planes, large laccolites of gabbroid dolerites have been intruded at a date subsequent to both cleavage and faulting, and a metasomatic development of pisolitic iron-ore has taken place along the line of the most notable (Penmorfa) thrust. Glacial accumulations mask the geology of the north-western district, but the adaptation of surface-features to underground geology is very perfect, and the exposures of the outcrops in the driftless area of the south-east are very complete. There is a considerable development of post-Glacial accumulations at or near sea-level.

The stratigraphical succession begins with the Maentwrog Beds and ends somewhere in the Upper Llandeilo or Caradoc. As far as the unconformity which transgresses the Tremadoc Slates the succession is simple and complete; but the Arenig rocks are not well exposed, and the Llandeilo and later rocks have been involved in much earth-movement.

The Maentwrog Beds are dark rusty-grey slates with ringers of felspathic material, and are like the Lower rather than the Upper Maentwrog Beds described by Belt at Llanelltyd.

The Ffestiniog Beds are a thick series of grey flags and compact grauwackes, with the *Lingulella* Band at their top.

The Dolgelly Beds are black slates, as at Arenig, but at the base of the *Peltura* horizon contain thin felspathic bands as at Dolgelly.

The Tremadoc Beds I have described in detail. Tremadoc in Ynyscynhaiarn is the name-locality at which Sedgwick first distinguished Tremadoc Slates; and, although the slates of the village of Tremadoc with their pisolitic iron-ore are of Llandeilo age, this need not affect the nomenclature.

The Tynllan Beds or 'Lower Tremadoc' of Salter are thinly-bedded rusty-grey slates with a harder cherty band near the top, and have characteristic white-weathering spots due to small pyritous concretions. They are the *Niobe* horizon of Arenig, and have not been recognized elsewhere.

The *Dictyonema* Band, 15 feet thick, is a notable horizon. I have discussed its importance and distribution in another place.¹

The Moelygest Beds are a barren series of banded grey slates or mudstones, containing enough pyrite to cover their weathered surfaces with rust. They correspond exactly with the *Bellerophon* Beds of Arenig.

The Portmadoc Flags are the coarsest of the Tremadoc Slates. They contain the debris of much felspathic material, and in the west include considerable masses of ashy grit. They are the *Asaphellus* Beds of Arenig.

The Penmorfa Beds are micaceous and slightly calcareous. They occur at Penmorfa as flaggy blue mudstones without much cleavage, and elsewhere as thinly-bedded banded needle-slate. They contain *Shumardia* and the Shineton fauna,² and with it occasional

¹ Geol. Mag. 1907, pp. 260 *et seqq.*

² C. Callaway, Quart. Journ. Geol. Soc. vol. xxxiii (1877) p. 652.

specimens of a variety of *Angelina*. They are the 'Middle Tremadoc' of Salter and the *Shumardia* Shales of Arenig.

The Garth Hill Beds are finely-bedded grey-blue slates with some flaggy bands, and are always very rusty. They are the 'Upper Tremadoc' of Salter, and are characterized by the abundance of *Angelina*.¹ There is no evidence upon which to correlate them with any particular formation in South Wales, and they are certainly cut out by the Ordovician unconformity at Arenig.

The Arenig Grit of Ynys-towyn is 70 feet thick. It is placed in the Arenig by analogy only; but near Criccieth a few Arenig fossils have been found in ashy beds which overlie a similar deposit. The strata above the ashy beds with Arenig fossils at Criccieth are slates, so cleaved and crushed that the collecting of fossils is impossible, and the local distinction between Arenig and Llandeilo slates remains unknown. In the eastern district the Penmorfa Fault has cut out the Arenig beds.

The Llandeilo Beds of the east are dark slates, much crushed and broken into slickensided augen by the faulting. From certain of their augen in which cleavage has been destroyed and bedding partly revived by the metamorphism due to a later dolerite, the graptolites of Tyddyn-dicwm, Ynys-galech, and Pen-syflog have been collected. These all belong to the zone of *Nemagraptus gracilis* or to the overlying subzone of *Climacograptus peltifer*, and are of the horizon of the Glenkiln Beds of Moffat,² or of the shales immediately above the Mydrim Limestone in South Wales (Llandeilo).³

The higher grey slates are everywhere crushed, cleaved, or baked by the dolerites, and have yielded no fossils which determine their horizon. The andesites of the Tremadoc Ynys and the related andesitic ashes and agglomerates of the Penmorfa flag-quarry, Y Glog, and several localities, are interstratified among these grey slates. They thin out south-westwards and thicken eastwards, and may be attributed to some volcanic source upon the Moelwyn. The felsites of the Criccieth district are intrusive, but belong to the Snowdonian stage of volcanic activity. The intrusion of the gabbroid dolerites⁴ of Moel-y-gest, Y Gesail, Tremadoc, and Pant Ifan is of some date more recent than the impression of the cleavage of the country.

EXPLANATION OF PLATES XV-XVII.

PLATE XV.

Sections showing the relations of Cambrian and Ordovician rocks across the Penmorfa Fault, on the scale of 6 inches to the mile:—A, from Morfabychan to Fach Gêch; B, from Glan-byl to Pen-yr-allt.

¹ H. Hicks, Quart. Journ. Geol. Soc. vol. xxix (1873) p. 43 & vol. xxxi (1875) p. 175.

² C. Lapworth, *ibid.* vol. xxxiv (1878) p. 253.

³ Summary of Progress of Geol. Surv. 1906, p. 44. See also 'Geology of the Country around Caernarthen' Mem. Geol. Surv. 1909, p. 49.

⁴ A. Harker, 'Bala' Volcanic Series of Caernarvonshire' (Sedgwick Prize Essay) 1889, pp. 76-79.

PLATE XVI.

Sections across the Ynyscynhaiarn anticline, on the scale of 6 inches to the mile:—C, from Gell to Black Rock Beach; D, from Careg-yr-Eryr to Ynys-towyn.

PLATE XVII.

Geological map of the Ynyscynhaiarn District (South-East Carnarvonshire), on the scale of 3 inches to the mile.

DISCUSSION.

THE PRESIDENT (Prof. W. J. SOLLAS) congratulated the Author on his admirable account of a classic locality; it was complete in every respect—in mapping, in palæontology, and in tectonics. The problem of deceptive conformities was one of great importance, and awaited investigation. The presence of a visible unconformity at Tremadoc which could not be detected in South Wales was a case in point; another would seem to be that which in many localities occurred at the base of the Upper Silurian, and in others was apparently absent over wide areas. The intrusion of basic rocks along the thrust-planes afforded an additional instance to those already made known by Suess. The most magnificent example was afforded by the 'exotic blocks' of the Himalaya.

Dr. MARR said that he would have wished to refer to many things, such as the position of the *Dictyonema* Band, and the correct designation of the fossil referred to that genus; but at that late hour he would only congratulate the Author on his paper, wherein he had practically completed one piece of work, and given a great impetus to another. He had in this and in a previous paper shown definitely what were the Arenig Beds of Arenig and the Tremadoc Beds of Tremadoc, for which all students of the Lower Palæozoic rocks, at home and abroad, must thank him. He had, by his careful study of the tectonics of the district, added largely to that most interesting subject, the building up of North Wales, and pointed the way to much future work therein.

Prof. WATTS remarked that the Author's work was bringing the Tremadoc Beds of Tremadoc into line with those of Shropshire.

Mr. J. F. N. GREEN observed that, near St. David's, where folding and thrusting similar in many respects to the phenomena described by the Author occurred in rocks of the same age, quartziferous and hypersthene-bearing dolerites had been described in detail by Mr. J. V. Elsdon. That author and the speaker came independently to the conclusion that these dolerites were later than the main faulting.

THE AUTHOR, in reply, thanked the President and Fellows for their very generous appreciation of his paper.

In answer to Mr. Green, he said that, although in the district under consideration he had found no fault such as could be mapped later than the dolerite-intrusions, there was at Garth Hill Quarry, Minffordd, a very prominent fault of such a character which had

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converted a thick belt of rock on either side into the condition of a quartz-chlorite-schist. That fault was a normal fault of slight throw.

Further, he could offer no opinion as to the exact relative ages of the *Angelina* Beds and the beds with *Peltura punctata* in South Wales. He had collected several examples of a *Peltura* not unlike *Peltura punctata* from the Penmorfa Beds, and could see no inherent reason for excluding the *Peltura-punctata* Beds from the Tremadoc Series.

He believed that the unconformity between the Garth Hill Beds and the basal Ordovician grit was due to the same north-and-south folding as that which had corrugated the Cambrian rocks of the Harlech country; and as, at Llanystumdwy (1 mile west of Criccieth), there was complete passage from the uppermost Ordovician into the Skelgill facies of the Lower Llandovery, he could not agree that the stratigraphical break between the Cambrian and the Ordovician Systems in this area was of less importance than the unconformity between the Ordovician and the Silurian.