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On the Supposed Pre-Cambrian Rocks *of* St. David's.

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Introduction.

Some explanation is required of the grounds on which another contribution is added to the already voluminous literature connected with the rocks of St. David's. The circumstances under which I have reluctantly found myself compelled to make this contribution are briefly these.

A new edition of the Rock Catalogue of the Museum of Practical Geology, Jermyn Street, being required, it became necessary to ascertain how far the stratigraphical order followed in previous editions required to be modified by the results of more recent research. In particular, the question of the existence of Pre-Cambrian rocks in Wales, which has emerged since the last issue of the Catalogue, appeared to demand full recognition in any republication of the work. I felt it to be due to those authors who have written so largely on this subject that ample acknowledgment of the results of their labours should be given. On the other hand, I was equally desirous that in admitting corrections of the views expressed upon the maps and sections of the Geological Survey I should do so from an actual inspection of the ground, which would enable me to judge how far and in what manner the required alterations should be made.

It was obvious that in maps of districts surveyed forty years ago some important structures might have escaped notice, positive errors might have been committed, and petrographical details could not be expected to have been treated in a more satisfactory manner than in other English geological works of the same date.

The existence of Pre-Cambrian rocks in South Wales had been

proclaimed so loudly and persistently that, in spite of the protests of my predecessor, Sir Andrew C. Ramsay, who will not admit the presence of such rocks in any part of the Principality, I had gradually been led to believe that they really must exist, though probably not to the extent that had been claimed for them. In visiting Wales, therefore, I went with no prejudice in favour of the views expressed by the Geological Survey. On the contrary, I had a conviction that these views must be, in some measure, at least, erroneous, and that this admission ought to be frankly made.

I chose the St. David's district as being that about which most had been written, and which had, in a measure, been taken as a typical area for the "Pre-Cambrian" rocks of Wales. It is desirable at the outset that it should be clearly understood that the conclusions to which I have come refer solely to that district, and that, in the meantime, I offer no opinion regarding other so-called Pre-Cambrian areas in the Principality.

That my examination of the ground might be made in greater detail, I requested my colleague Mr. B. N. Peach, of the Geological Survey of Scotland, to accompany me. His long experience among crystalline rocks of many kinds has given him great practical insight into the structure of these formations in the field. Like myself, he went prepossessed in favour of "Pre-Cambrian" ideas.

We visited all the sections together, and came to complete agreement in our interpretation of them. The following pages give an account of our joint research in the field, and of my own subsequent petrographical investigation of the rocks collected by us *.

The earliest published account of the rocks of St. David's appears to have been that given by Dr. Kidd, in vol. ii. of the First Series of the Society's 'Transactions.' This author speaks of the rocks as being in some instances "stratified," in others "unstratified;" the hills, or rocky summits, consisting of materials that "bear no marks of regular stratification," but "appear as so many nuclei, about which is arranged a very curiously diversified series of highly-inclined strata of a kind of slate"†.

The next notice is that of Sir Henry De la Beche, in a paper read to this Society in 1823. He separates the "trap" and "greywacke" rocks of St. David's, and is inclined to regard the trap as "having been forcibly intruded amongst the other rocks at a period subsequent to their consolidation"‡. The areas respectively

* Since this was written I have made a second visit to St. David's, accompanied by my colleague Mr. W. Topley, of the Geological Survey of England and Wales, with the object of collecting additional material for the second part of the present paper. I have thus been able fully to confirm the conclusions arrived at on the first occasion, and to obtain some additional evidence in the same direction. But nearly the whole of the data bearing upon the question of the existence of Pre-Cambrian rocks were collected in company with Mr. Peach; and the first part of the paper had been prepared before my second excursion.

† Trans. Geol. Soc. ser. 1, vol. ii. p. 79 (1814).

‡ Trans. Geol. Soc. ser. 2, vol. ii. p. 2 (note).

occupied by the two kinds of rock are depicted on the geological map of South Pembrokeshire accompanying this memoir.

In the 'Silurian System' (1839) Sir Roderick Murchison inserted a brief description of the trap-rocks of Pembrokeshire, in which he spoke of them as consisting of two classes, "viz., stratified masses alternating with sedimentary deposits, and amorphous masses which have burst through the strata." Among the older trap-rocks he distinguished "thick-bedded coarse felspathic conglomerates, containing fragments of schist and slate, which range from north-east to south-west in allinement with the other ridges of amorphous trap." These words would seem to imply that he had recognized the presence of true tuffs or fragmental igneous rocks in that region. He also noticed proofs of the intrusive character of some of the amorphous masses; for in the district of Roche Castle, Trefgarn, and Ambleston he found that "the intrusion of this [igneous] rock has produced a powerful effect upon the adjacent strata, particularly on those masses inclosed between the forks of trap in the gorge of the river at Trefgarn, where the red and green sandstones are converted into a brittle, siliceous substance resembling the ribbon jasper of mineralogists" (pp. 401, 402)*.

In the first volume of the 'Memoirs of the Geological Survey of Great Britain,' De la Beche makes further reference to the geology of Pembrokeshire, and in particular to some of the rocks which have been the subject of more recent discussion. He refers to the rock of Roche and adjoining districts as illustrating the remarkable varieties of texture assumed by the same mass of igneous rock; and the cites the granite between St. Lawrence and Brawdy, a few miles to the east of St. David's, as presenting along its margin a fine-grained variety, like a Cornish elvan, owing to more rapid cooling, and as "certainly seeming to have altered the stratified rocks in contact with it in many places"†.

The Geological Survey of the St. David's district was begun as far back as the year 1842, by Sir A. C. Ramsay, soon after he joined the service. The Map was published in 1845, and was followed by a sheet of Horizontal Sections across the district‡. In these publications all the igneous rocks are included in one colour (green). But in the Horizontal Section the belt of country so coloured, extending (on the map) from the sea at Porth-lisky to beyond Llanhowell, is stated to be composed of "trap, in its strike of various structure,—syenitic greenstone and felspathic volcanic ash"§.

* The intrusive nature of the Trefgarn rocks was shown by Murchison in 1836 (Proc. Geol. Soc. vol. ii. p. 229). These rocks are included by Dr. Hicks in his "Arvonian" group.

† Mem. Geol. Survey, vol. i. p. 230 (1846). The belt of rocks here referred to has been mapped by Dr. Hicks as belonging mainly to his "Dimetian," but partly to his "Arvonian" group. Quart. Journ. Geol. Soc. vol. xxxv. p. 287 (1879).

‡ Sheet 40 of the Geological Survey Map of England and Wales and Sheet 1 of the Horizontal Sections.

§ Sir A. C. Ramsay's field-maps, preserved among the official records of the Survey, show that he not only recognized marked differences among the igneous rocks, but that he mapped out the more important varieties. A MS. report

A second (revised) edition of the Map was published in 1857, and was soon followed by a second edition of the Sections. The primary object in the revision of the work was the tracing of a line for the base of the Lingula-flags; but the opportunity was also used for separating some of the more important varieties among the igneous rocks. These were now classed as "syenite" and "greenstone," all mention of the "volcanic ash" of the previous edition being omitted from the St. David's area. A considerable tract to the west of St. David's, which had been mapped by Ramsay as igneous rock, and which was regarded by him as composed mainly of volcanic ash, was now coloured as "altered Cambrian"*.

As thus revised, the Map showed a long strip of syenite and felstone, stretching from the sea through St. David's in a north-easterly direction for about seven miles, flanked on the south-east by Cambrian strata, and on the north-west by "altered Cambrian" rocks through which long parallel sheets of greenstone had been erupted. The existence of abundant contemporaneous igneous rocks further north and east is clearly shown on the map; but in the immediate

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drawn up by him at the time, but never published, has fortunately been also preserved. From this interesting document a few extracts may here be appropriate:—"The igneous rocks of North Pembrokeshire are both intrusive and contemporaneous; the latter, however, occupy by far the greater area. The greatest intrusive mass is that which from Ramsay Sound stretches in a north-easterly direction nearly eleven miles. The best evidence of this trap being intrusive may be seen on the coast near St. David's, at Ogof-llesugn, where it cuts through the strata ..at right angles to the line of strike.

"The apparent composition of this large mass is very various, resulting, no doubt, in many instances from the different circumstances under which it cooled and consolidated. Thus, on the east side of Porth Lisky, and on both sides of the Allan at St. David's, it is a large-grained, coarsely crystallized syenite, hornblende being comparatively sparingly diffused throughout. At Porth Lisky granular crystals of quartz are largely developed. In other places the same development may be seen.

"The coast of Porth Lisky is almost entirely composed of volcanic ash, which, being of a softer texture than the traps on the E. and W. sides of the bay, has yielded to the action of the waves, and thus formed a little harbour. ... From hence, in the direction of Ramsay Sound, the rocks are composed of hard siliceous trap [and] various greenstones. ... These frequently alternate with partial layers of volcanic ash. These varieties constitute the rest of the mass to the eastward, without any very apparent order in the manner of their distribution. ... Near Trelethin (St. David's) and elsewhere there is a little volcanic conglomerate. With the exception already mentioned, the strike of the strata generally more or less conforms to the general run of the intrusive mass.

"A glance at the contemporaneous traps shows that volcanic agencies had been in operation for long successive periods. ... From the intermixture of volcanic ash and greenstone at Porth Lisky, it would appear that the formation of this mass was in some measure the work of successive eruptions."

* Professor Ramsay, as Local Director of the Survey, agreed to this change, which was made on the ground by Mr. Aveline. In many respects the map was a marked improvement upon the first edition; but the suppression of the reference to fragmental volcanic rocks and the introduction of the term "altered Cambrian" were unfortunate changes, one effect of which has been to obscure the fact that to Ramsay belongs the merit of having first clearly recognized the presence of truly contemporaneous fragmental volcanic rocks in a formation of such high antiquity.

vicinity of St. David's all the rocks of igneous origin are represented as intrusive.

Until the year 1864 this interpretation of the structure of the district appears to have remained unchallenged. At the meeting of the British Association in that year, however, a suggestion was thrown out by the late J. W. Salter that the syenitic belt of the Survey was a portion of Pre-Cambrian land *. The only grounds given for this suggestion were that the rock is syenitic, and that it does not penetrate the overlying Cambrian strata. Next year Mr. Salter, acknowledging himself to have been mistaken, stated that Dr. Hicks had found portions of schist entangled in the syenite, as well as altered strata on the south side of the latter rock †.

In the year 1871 appeared a joint paper by the late Professor Harkness and Dr. Hicks on the "Ancient Rocks of St. David's Promontory" ‡. A foot-note in this paper contains an announcement by Dr. Hicks that he had subsequently found on the ridge of St. David's evidence of bedding in its component rocks, and that, as the strike is discordant to that of the Cambrian strata, there must be here a more ancient group of rocks than the Cambrian, occupying a position equivalent to that of the Laurentian group of Canada.

In 1875 Dr. Hicks asserts more confidently the Pre-Cambrian age of the rocks of this ridge, denies that these rocks are syenite as coloured by the Geological Survey, but maintains that they are bedded rocks—quartz-conglomerates and dark-green shales, partly metamorphosed,—and affirms that they are covered unconformably by the Cambrian series §.

Returning to the subject two years later, Dr. Hicks showed a still wider divergence from his original opinion. He now states that he can recognize two distinct series of Pre-Cambrian rocks at St. David's, giving the name "Dimetian" to what he supposes to be the older, and "Pebidian" to the younger series. Discarding the identification of any part of these rocks with syenite, he describes the "Dimetian" as composed chiefly of compact quartz-schists, chloritic schists, and indurated shales, and the "Pebidian" as consisting mainly of indurated shales, often porcellanitic in character. He regards the "Pebidian" as resting unconformably upon and partly derived from the waste of the "Dimetian" rocks. The Cambrian beds are stated to lie unconformably on both these series and to contain abundant fragments of them ‖. A little later Dr.

* Rep. Brit. Assoc. for 1864, Sections, p. 64; Geol. Mag. vol. i. p. 289. The Rev. W. S. Symonds, however, claims to have first suggested to Salter a Pre-Cambrian origin for the St. David's rock. See his 'Records of the Rocks,' p. 31, 1872.

† Geol. Mag. vol. ii. p. 430.

‡ Quart. Journ. Geol. Soc. vol. xxvii. p. 384. For the introduction of bedding into the crystalline rocks of the ridge, as expressed in this paper, Professor Harkness does not appear to have been directly responsible. See foot-note on p. 387 above referred to.

§ Quart. Journ. Geol. Soc. vol. xxxi. p. 167.

‖ Quart. Journ. Geol. Soc. vol. xxxiii. p. 229 (1877).

Hicks recognizes that his "Pebidian" series is in great part made up of volcanic tuffs and agglomerates *.

In 1878 the late Mr. E. B. Tawney, who, in company with Professor Hughes and Mr. Hudleston, went over the St. David's district under Dr. Hicks's personal guidance, gave an interesting and valuable description of the rocks, to which I shall have occasion to make repeated reference in the sequel. In this paper he accepts generally Dr. Hicks's conclusions, but, though classing the crystalline rock of the axis as metamorphic, confesses that "over a portion of the area, at any rate, it did not show evident bedding enough to prevent our classing it as a massive crystalline rock" †.

In the same year, Dr. Hicks announces the discovery of what he terms a new group of Pre-Cambrian rocks, named by him "Arvonian" ‡, consisting of "breccias, hälleflintas, and quartz-felsites," previously included by him in his "Dimetian and Pebidian," but now regarded as intermediate between them, and unconformable with both. In later papers he summarizes the results of his researches §.

During the progress of Dr. Hicks's researches, the rocks of St. David's have been referred to by other writers, sometimes on his authority, sometimes from personal observation under his guidance. It is not necessary to augment this bibliographical outline by citing all such references. Some of them are quoted in subsequent pages, where also several of Dr. Hicks's own papers are dealt with more in detail.

The object of the present communication is twofold,—first to discuss the evidence for the assertion that Pre-Cambrian rocks exist at St. David's, and secondly to lay before the Society an outline of what appears to me to be the true structure and geological history of that district.

Part I.

The first part of the paper is unavoidably controversial. I propose to examine the evidence for the alleged presence of Pre-Cambrian rocks at St. David's, and to state the facts which, when brought to the notice of geologists, will, I think, be admitted completely to disprove the existence of any such rocks at that locality. Disliking controversy so much as I do, it is with extreme reluctance that I now enter upon it. But I am sure that, in the interest of truth, Dr. Hicks himself, whose published views I must oppose, will be glad that these views should be subjected to the most searching criticism. It is due to him, no less than to my colleagues on the Geological Survey, whose opinions he has controverted, that I should enter

* *Op. cit.* vol. xxxiv. p. 153 (1878). [Their volcanic origin appears to have been first pointed out to him by Mr. Hudleston.]

† Proc. Bristol Nat. Soc. new ser. vol. ii. part ii, p. 121.

‡ Rep. Brit. Assoc. for 1878, p. 536; Quart. Journ. Geol. Soc. vol. xxxv. p. 285 (1879).

§ Popular Science Review, N. S. vol. v. p. 289 (1881); Proc. Geol. Assoc. vol. vii. pt. i. p. 59 (1881).

into the fullest details. In the discussion of the subject I am mainly desirous to get at the truth; and I feel confident that my natural and, I hope, laudable pride in the work done by my predecessors and colleagues on the Geological Survey will not lead me for a moment to forget the signal services rendered to the history of the Cambrian rocks by Dr. Hicks, which no one can more cordially recognize than I do.

At the outset I may allude to a characteristic feature in the literature of the subject. From the brief summary above given of the various papers which have appeared, it will be clear that the views at present entertained regarding the Pre-Cambrian age and metamorphic character of the rocks of St. David's are the result of a process of development during a course of years. Dr. Hicks at first put forward the idea of Pre-Cambrianism somewhat vaguely and timidly; but each successive communication from him has shown increasing boldness in the enunciation and extension of his doctrine. Though interesting in itself, this evolution of opinion has been attended with the disadvantage that so many of the statements and views expressed in the earlier papers have since been tacitly modified or abandoned in the later ones, that it is difficult to know how far these earlier publications are available for citation as expressing Dr. Hicks's ultimate opinions. Indeed they appear to possess little more than an historical value, as records of the successive stages through which their author's present convictions have been reached. I shall only cite them where their observations are not positively contradicted in his later memoirs.

It will be most convenient to discuss *seriatim* each of the three alleged Pre-Cambrian groups at St. David's, beginning with the oldest. This, moreover, is nearly the order in which my investigations in the field were conducted.

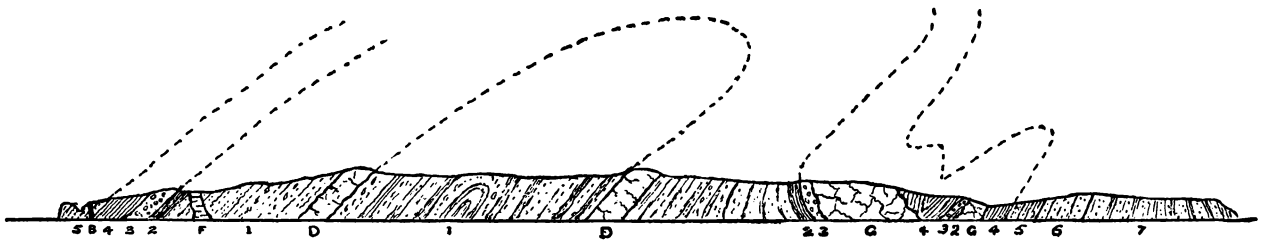
1. "Dimetian."

Immediately to the south of St. David's a gentle ridge, roughened here and there with rocky prominences, stretches in a south-westerly direction for rather less than two miles. Its component rock is seen in scattered knobs, but in no continuous section, until, at its seaward termination, from the bay of Porth-lisky eastwards for about half a mile, it forms a rocky shore. This coast-section is the only continuous exposure of the rock in the district. But laying that rock bare as it does, both in horizontal ledges and vertical cliffs, and revealing its contact with the adjacent strata, this coast-section affords the geologist every facility for determining the structure and stratigraphical relations of the rock that forms the ridge.

In the original work of De la Beche, and in the subsequent investigations of the Geological Survey, the rock in question was regarded as eruptive, and as later in date than the Cambrian strata, through which it was believed to have been intruded. At the time when these observations were made, the study of petrography was in a sadly neglected state in this country. We must not, therefore,

Diagrammatic Sections illustrating the Geology of St. Davids.

W.N.W. Fig. 1.—*Section from near Castell to Porth-clais.* E.S.E.



N.W. Fig. 2.—*Section from Porth-seli to Cliffs near Nun's Chapel.* S.E.

For explanation of numbers and letters see Map, Plate VIII.

expect precision or accuracy in the determination of rocks then made, either in the Survey or out of it. The rock of St. David's was marked down as "Syenite" on the Survey Map and Section; and so it remains up to this hour. But in the present discussion the main fact to be noticed in regard to the Survey mapping is that the rock in question was declared to be an eruptive rock, intrusive in, and therefore later than, Cambrian strata.

In his latest papers Dr. Hicks thus describes the rock in question. "The rocks included under this name [Dimetian] . . . . everywhere show more or less distinct lines of bedding, striking from about N.W. to S.E. They vary also, to some extent, in their mineralogical characters, if examined at different points, and have apparently an order of succession in which these changes occur at recognizable horizons. The prevailing rocks in this group are of a granitoid character, usually of rather a massive, but sometimes of a schistose nature.

"Sometimes almost pure quartzites are found; but by far the largest proportion contain an admixture of felspar of a white or pinkish colour. Specks of viridite usually occur more or less throughout, and sometimes give quite a tinge to the rock. Mica occurs sparingly, for the most part; but there are occasionally micaceous, chloritic, impure limestone and serpentinous bands. At some places also, thin, compact, white bands of a more highly felspathic character occur. Some of the beds assume a brecciated appearance, the masses being generally angular or subangular, and in composition much like the associated rocks.

"Speaking generally, the majority of the rocks comprising this group are highly quartzose, of a granitoid or rather massively gneissic nature, and usually easily recognizable by these characters; their strike is about from N.W. to S.E."*.

"This formation [Dimetian] consists chiefly of highly crystalline gneissic rocks, the prevailing types, however, being the so-called granitoid rocks, made up largely of quartz with some pinkish or white felspar. Hornblende is much less abundant than in the Lewisian rocks; but mica is more frequently met with. It may be said to consist chiefly of acid types of rocks, whilst the former is made up mainly of basic types. Bands of limestone, hornblende, chlorite and micaceous schists occur occasionally in this formation"†.

These rocks are regarded by Dr. Hicks as a great, bedded, metamorphic Pre-Cambrian series, later in age than the ancient gneiss of the Hebrides. They are subdivided by him into two groups—a lower, consisting of "the massive granitoid and gneissose rocks of Bryn-y-Garn, St. Davids," and an upper, composed of "the so-called quartz-schists of Porth-lisky"‡.

* Proc. Geol. Assoc. vol. vii. no. i. p. 61 (1881). On the next page the "Dimetian" rocks are asserted to be "chiefly of clastic origin."

† Popular Science Review, N. S. vol. v. p. 291 (1881). It is to be noted that this paragraph relates to "Dimetian" rocks generally, and is not intended to apply specially to those of St. David's.

‡ Popular Science Review, *loc. cit.*

In reading Dr. Hicks's papers I have been unable to find descriptions of, or references to, the numerous natural sections where the relations of the crystalline rock of the ridge to the surrounding mineral masses are displayed. He states, indeed, that the rock is unconformably overlain by later formations, but he does not mention any localities where he has observed this unconformability. In one passage he speaks of the Cambrian conglomerates resting immediately on the "Dimetian" rocks, at the bend in the Porth-clais valley, and of higher Cambrian beds in a similar position in the harbour *. It would be more correct to say that the "Dimetian" rock rests there on the conglomerate, as I shall afterwards point out. In another paper he states that "the junction of the Arvonian with the Dimetian may be seen at St. David's, about a quarter of a mile to the south of the Cathedral, and near Rock House" †. But he immediately adds that a slight depression probably marks a fault at that locality. Mr. Peach and I found on examination no evidence of any fault, nor of any line of demarcation between two formations. I shall have occasion to refer to this locality in a later part of the present paper.

Dr. Hicks, in his various memoirs, introduces many lines of fault, of which, after diligent search, we could discover no trace on the ground, and which, for a clear understanding of the structure of the district, are not required ‡.

An unconformability is so important a fact in the geological history of a region, that the most convincing proof of it ought to be demanded. We are entitled to expect that, unless where it is too clear to be mistaken, every available fragment of evidence regarding it should be produced. Still more must this expectation be fulfilled where the rocks in question have been greatly disturbed. No one who has not practically tried it can realize the difficulty of the problem to determine whether or not an unconformability exists between two groups of rocks both of which have been intensely plicated or fractured. But to this difficulty no allusion is to be found in Dr. Hicks's papers.

Mr. Peach and I began our work by an examination of the ridge of which Bryn-y-Garn is the crest. We were unable to detect anywhere a trace of a structure which had the remotest resemblance to the foliation of gneiss or schist. Nor could we discover in the mass any alternations of other rocks. On the contrary, it everywhere retained the same general aspect, and presented all the familiar external characters of a massive eruptive rock. The presence of gneissic structure and intercalations of schistose bands, however, had

* Quart. Journ. Geol. Soc. vol. xxxiii. p. 231 (1877).

† Quart. Journ. Geol. Soc. vol. xxxv. p. 289 (1879).

‡ In his map published in 1877 (Quart. Journ. Geol. Soc. vol. xxxiii. pl. x.) Dr. Hicks represents a fault at every locality where the junction of the "Dimetian" with the other rocks is actually visible. These supposed faults have been introduced owing to a mistaken notion of the structure of the ground, and are not required even on the theory to support which they have been invoked.

been so confidently and constantly affirmed that, for a time, we were inclined to believe we had missed the proper exposures. It was not until we had diligently hammered every knob and boss of rock in the whole district, without discovering any other structure than that of an eruptive mass, that we were driven to abandon as entirely imaginary the idea of a bedded structure and metamorphic origin for the central rock of the ridge. The comparatively limited and disconnected sections of the interior amply suffice to make this quite clear. But the admirable continuous sections of the coast-line reveal the structure of the rock so completely that one could not but ask oneself the question many times a day, how such a rock could ever, by any possible stretch of the imagination, be credited with a bedded structure and a metamorphic origin. Cut at all angles by the sinuosities of the coast-line, it can be studied foot by foot across its entire breadth. Did it, therefore, possess foliation of any kind, or were it made up of parallel bands of different lithological characters, such a structure could not possibly escape notice. After the most careful search, however, neither my companion nor myself could discover any thing of the sort. But for the published statements regarding the rock, we should never have thought of making any such search; for the first few exposures would have sufficed to mark it out as unquestionably an eruptive mass.

The petrographical characters of this rock will be given in Part II. of this paper (p. 313). To the naked eye it appears everywhere to be thoroughly crystalline and granitic in structure, like a granite of medium grain, perfectly amorphous, without any trace of groundmass or any approach to foliation. It can readily be seen to be composed mainly of a granular crystalline aggregate of quartz and felspar with abundant minute black or dark-green specks, which, by their decomposition, give rise to a diffused greenish discoloration. These dark specks were regarded by the Geological Survey as hornblende; and hence, according to the old nomenclature, the rock was termed a syenite. On the other hand, were these dark green specks shown to be a mica, there could be no hesitation in classing the rock as a variety of granite. Whether examined in mass, in hand-specimens, or under the microscope, it presents the ordinary structure of a granite. I shall therefore speak of it simply as a granite, and leave its peculiarities of composition to be discussed in the sequel. I may here mention, in passing, that I have examined microscopically a large series of slices of the rocks of St. David's, and that the result of this examination will be given in Part II. (as previously stated).

The numerous rocky bosses upon the ridge south-west from St. David's, and still more the long coast-section from Porth-lisky eastward, everywhere present a massive rock entirely destitute of definite structure, but traversed by irregular joints, which divide it into blocks, as in any ordinary granite. Here and there by a dominant set of joints it is separated into rudely parallel beds, or even thin slabs, as at Porth-lisky and eastward, where one series of joints, running from N.N.E. to S.S.W. with a high inclination,

gives, at a distance, a deceptive resemblance to bedding. This resemblance, however, disappears on examination.

Numerous other systems of similar joints cut through the mass, precisely as they do through any eruptive crystalline rock. But nowhere have they the character of the divisional planes of a foliated rock, nor do they correspond with any internal arrangement of the component materials in parallel folia*.

Dr. Hicks lays stress on the fact that, owing to its tendency to split, the rock cannot be dressed for building- or paving-purposes. He proceeds to generalize this fact into a kind of test "in distinguishing many of the metamorphic rocks from those of igneous origin" †. But surely there is no more familiar structure among the eruptive rocks than their tendency towards multiplied jointing in certain directions. Even in a massive homogeneous granite, where a practised geologist could not detect the least trace of any divisional planes, the quarrymen will at once show him what they call the "reed" of the rock, along which it will break easily, but across which its fracture is less reliable and definite. From this condition every gradation may be traced, especially among the weathered parts, until the rock splits into slabs and might at first be mistaken for a bedded mass.

A tendency to split in a given direction is therefore no necessary indication of bedding, and need have no connexion with foliation. Had the rock of St. David's been one which might be classed with the gneisses and schists, it would certainly have revealed abundant proofs of foliation—that is, of a crystalline arrangement of its component minerals parallel with the general divisional planes of the rock. Dr. Hicks asserts that "traces of foliation are abundant" ‡. I can only meet this assertion by the statement that my companion and I searched most carefully every exposure of the rock we could find on the ground, and that I have since examined microscopically a series of specimens taken from all parts of the ridge, without detecting either on the large or the small scale any, even the most distant, approach to a foliated structure. Many eruptive granites exhibit perfect foliation along certain pegmatite veins; but even this structure we failed to detect §.

Between the walls of the joints various decomposition-products

* It may not be out of place to quote here, in confirmation of our observations, those of Mr. Tawney. He recognized the tendency of the rock at Porthlisky to split into flaggy and rhomboidal pieces, owing to concealed laminæ coated with a thin chloritic lining, and was disposed to look on this structure as bedding; but he states that "elsewhere it is difficult to say which divisional planes are dominant or less irregular than the others." (Proc. Bristol. Nat. Soc. N. S. vol. ii. pt. ii. p. 117).

† Geol. Mag. dec. 2, vol. viii. p. 143 (1881).

‡ Geol. Mag. dec. 2, vol. viii. p. 142.

§ Dr. Callaway also could find no trace of foliated structure in the crystalline rock of St. David's, though he searched for it in the principal localities named in Dr. Hicks's papers (Geol. Mag. dec. 2, vol. viii. pp. 94, 237, 1881), and, as he adds, it is not mentioned as existing in any of the microscopic descriptions that have been published of the rock.

have been introduced. Most of these are greenish in colour and more or less earthy in texture. Where the opposite walls have been displaced, slickensided surfaces may be seen upon them and upon the substances interposed between them. But these appearances present no features differing from what are universally found among massive jointed rocks. They cannot be confounded with any original structure of the mass.

Occasionally veins of a paler colour and finer texture ramify through the rock. They vary in width from an inch or less up to more than a foot. Every one familiar with a large mass of granite will recognize such veins at once as characteristic features of it. These also are referred to more in detail in Part II.

The only distinct species of rock which we could discover in the mass is a dull-greenish, more or less decomposing, diabase or wacke, occurring in the form of abundant dykes and veins. These vary from a few inches to several feet in breadth, and traverse the granite irregularly in all directions. Where several run parallel at a short distance from each other, and have a slight hade in the same direction, they produce a deceptive resemblance to an alternation of beds.

That these dark-green rocks, however, are all eruptive, intrusive, and of later date than the granite, may be confidently inferred on the following grounds:—1st. They have precisely the ordinary external forms of eruptive dykes and veins, ramifying in different directions, coalescing and reuniting. 2nd. They present the usual microscopic characters of dykes of diabase or ancient basalt-rocks, with which they agree in crystalline structure, in the presence and linear arrangement of amygdules, in the existence of a rude prismatic structure transverse to the walls, and in their tendency to spheroidal weathering. 3rd. In microscopic structure they unmistakably belong to the basalt family. 4th. They not only traverse the granite (being most abundant in it) but are found cutting through the Cambrian beds on many different horizons. The true character of these eruptive rocks appears to have been first detected by Prof. Judd *,—a conclusion confirmed by Mr. Tawney †. Dr. Hicks draws a distinction between some of them which he admits to be intrusive and others which he seems disposed to regard as bedded in the "Dimetian" mass ‡. But for this distinction I was unable to discover any ground whatever. There can be no question as to their universally intrusive character and late Cambrian or Post-Cambrian date.

In some of his earlier papers Dr. Hicks refers to the occurrence of abundant shales among the more crystalline rocks of the ridge. In his more recent summaries no reference is made to such inter-

* Quart. Journ. Geol. Soc. vol. xxxiii. p. 235 (1877), and xxxiv. p. 156 (1878).

† Proc. Brist. Nat. Soc. new ser. vol. ii. pt. 2, pp. 113 *et seq.*

‡ Quart. Journ. Geol. Soc. vol. xxxiv. p. 156. In his more recent papers he omits mention of these rocks as integral parts of his "Dimetian" series, unless they are included in the "hornblende and chloritic schist," which he states to be also a portion of the same series.

calations, though the occasional occurrence of micaceous and chloritic schists is referred to. I have been unable to determine what portions of the mass of rock at St. David's could have been regarded by him as stratified or foliated intercalations of any kind. I believe him to have been deceived sometimes by the greenish decayed material filling up the partially opened joints, sometimes by the diabase dykes and veins. He appears also to have included in his "Dimetian" group portions of the undoubtedly bedded rocks (quartz-schists, quartzites, shales, &c.) which flank the massive rock of the ridge, as will be shown in the subsequent description of the coast-section at Porth-lisky. I repeat in the most emphatic manner that, after an exhaustive search over the whole ridge in question, neither Mr. Peach nor I could find the slightest trace of any shale, schist, quartzite, gneiss, or other stratified rock, bedded with that composing the ridge between Bryn-y-garn and the headlands south of Porth-lisky—nor of bedding or definite structure of any kind, save the joints universally present in similar massive rocks. We cannot even conjecture on what grounds the assertion has been so often made that the central part of the ridge is bedded, and that its bedding has an invariable strike from N.W. to S.E. We could see absolutely nothing in the rock to afford any basis for such a statement *.

Did no other than petrographical characters exist to guide us, these are so clear in their concurrent testimony that there could be no doubt as to the propriety of placing the rock in question among the granites. It has the usual typical features of a granite, and none of those of a schistose rock.

But further evidence is abundantly available. That this rock is not only a granite but one which has been erupted through the Cambrian strata, and must therefore be younger than they, is admirably demonstrated by the way in which it behaves to the rocks that surround it. A field-geologist naturally turns at once to the line of junction between two rock-masses to ascertain their mutual relations. Unfortunately, in most cases such a line is so much obscured by superficial deposits that the actual contact of the rocks can, at the best, be seen only to a limited extent and in few places. At St. David's, however, the coast-section and the transverse valley cut by the river Allan permit the actual junction of the granite with the surrounding rocks to be seen at several localities and on both sides. I have searched in vain among the published papers for any account of these localities. It is difficult to believe that they can have been actually seen by any one who could afterwards maintain the rock to be Pre-Cambrian in age and metamorphic in origin †. They show the granite to be unmistakably

* On the occasion of my second visit to St. David's I again sought, with Mr. Topley, for any trace of foliation or bedding in the crystalline rock of the ridge, but equally without success.

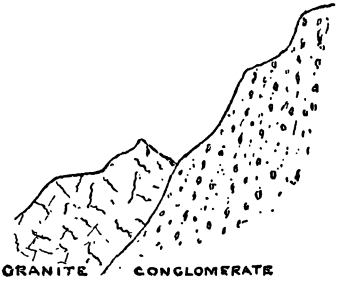
† It appears that Dr. Hicks started with the idea expressed on the Geological Survey map that the crystalline rock of the St. David's ridge is intrusive. He afterwards wrote that "on further examination it seemed clear that the syenite

eruptive; for the strata adjacent to it present examples of the induration and silicification so commonly, though not universally, observable along the borders of a granite boss.

In describing the sections that exhibit the actual contact of the eruptive and sedimentary rocks, I would first allude to a fact of some importance which hitherto appears to have escaped notice. In the course of my examination my colleague and I observed that as it crosses the valley of the Allan above Porth-lisky, the granite sends out a tongue-like projection across the river at the ford, and that this projection is separated, by an intervening mass of Cambrian shales and sandstones, from another projecting tongue of granite lying further north. This northern portion may cross the river as a narrow belt and thereby connect the main mass of Bryn-y-garn with the lesser area that extends to Porth-lisky. As it contracts, however, to a breadth of not more than eighty yards on the west side of the Allan, there seems to be hardly any room for it to pass across the valley. Though, no doubt, continuous underneath, the granite mass is probably divided at the present surface into two separate areas by intervening Cambrian strata. (See Map, Plate VIII. p. 268.)

The Bryg-y-garn granite mass projects for a few yards into the Cambrian grits and shales on the right bank of the Allan. I had several yards of the actual contact of the rocks laid bare at the foot of the hill, and found that the granite distinctly overlies the grit (fig. 3),

Fig. 3.—*Section of Junction of Granite with Cambrian Strata. Right bank of Allan River, Porth-clais.*



the line of junction being a wavy surface inclined at an angle of about 55°*. The grits are much indurated; and their bedding is

did not penetrate any of these beds" (Quart. Journ. Geol. Soc. vol. xxxiii. p. 229, 1877). I cannot conceive in what direction this further examination was carried, nor how the very clear proofs of intrusion could have been missed or misunderstood.

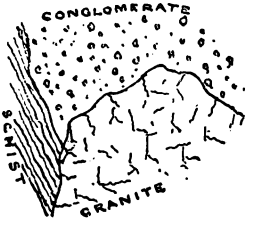
* This junction was bared, with Mr. Topley's assistance, on the occasion of my second visit. Some portions of this grit are so coarse as to pass into a quartzose conglomerate, which may be the conglomerate band above the volcanic group. This is about the place where that band should come in, next the green and red beds seen at Porth-clais. Its position is suggested in Section fig. 1, p. 268.

obliterated, though lines of pebbles can be traced which appear to indicate that the strata are nearly vertical.

On the opposite side of the river another junction of the granite with the Cambrian beds can be seen. The latter consist of greenish shales and sandstones dipping N. 20 W. at 55°., and are here again distinctly overlain by the granite, which cuts across the edges of the strata that dip beneath it. At this point the line of junction has served as a channel for percolating water; and the rocks on either side are so decomposed that no satisfactory observations of the internal characters can be made.

It is deserving of remark that, in its course across the valley, the projecting tongue of granite now described traverses obliquely a considerable thickness of strata. In particular, it can be seen to have cut out nearly the whole of the thick bed of grit above referred to, no portion of which appears on the opposite side (figs. 4 and 5).

Fig. 4.—*Plan of Junction of Granite with Cambrian Strata, Porth-clais.*

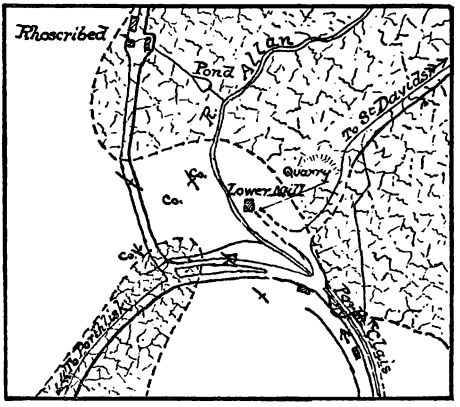


The eastward prolongation of the Porth-lisky granite mass likewise protrudes as a tongue into the Allan valley. This tongue has a breadth of about eighty yards; but it seems to be narrowing eastwards, so that, as already stated, it probably does not cross the valley. On both its northern and southern borders its junction with the Cambrian rocks can be seen. On the south side greenish sandstones, shales, and silky hydro-mica schists, like some of those to be afterwards referred to as occurring at Porth-lisky, abut against the granite; but the rocks along the line of contact have been decomposed into clay by the rise of water. On the north side the junction is more satisfactorily shown in a quarry on the left side of the road from Porth-clais to Rhoscribed. Here the conglomerate, in highly inclined beds, is overlain by the granite, which leans against it. The conglomerate is indurated; but at the actual contact both rocks have been much decomposed by percolating water. Some of the details of these junctions of the granite with the stratified rocks are reserved for the second part of this paper (p. 317).

Before leaving the relations of the granite to the Cambrian strata in the Allan valley, I must allude to the fact that this is the locality cited by Dr. Hicks as showing the Cambrian conglomerates and

higher beds resting on his "Dimetian" ridge*. At every section, instead of lying upon the granite unconformably, they plunge beneath it. The general disposition of the rocks in this part of the valley is expressed in the accompanying diagram (fig. 5). It will

Fig. 5.—*Sketch Plan of the Disposition of the Rocks in the Allan Valley at Porth-clais.*



be evident from this map and from the foregoing description that the relative positions of the two rocks cannot be accounted for by faulting†. At Porth-clais the actual terminal curve of the granite projection can be traced across the bed of grit through which it has risen (fig. 4). These junctions are characteristically those of an eruptive mass.

But the most important junction of the granite and Cambrian beds is that which has been cut by the sea in the range of cliffs between Porth-lisky and Porth-clais at the little inlet of Ogof-llesugn (fig. 6). The granite, which extends continuously eastward from Porth-lisky, abruptly ends off, and is succeeded at once by vertical sandstones and shales, which are truncated by it nearly at a right angle‡. On the seaward face of the cliff the granite has

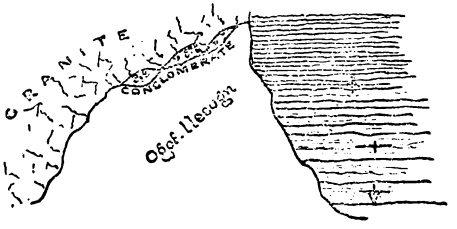
* Quart. Journ. Geol. Soc. vol. xxxiii. p. 231 (1877).

† That there may have been some local slipping along the boundary-line between the granite and the rocks it has invaded is not unlikely. In the Allan valley the faults would need to be reversed ones, and to wind about so as precisely to counterfeit the boundary-line on an eruptive rock. This subject is further referred to in Part II. (p. 310).

‡ This locality is referred to by Dr. Hicks as a line of fault; indeed, in his map (Quart. Journ. Geol. Soc. vol. xxxi. pl. viii.), as already stated, he makes the boundary-line between the two rocks everywhere a fault. I have admitted that, along the flanks of the granite, occasional local slips may have taken place; but the visible sections prove that no continuous or important faults occur there. Possibly some slight displacement may have taken place at Ogof-llesugn; but the mass of conglomerate is imbedded in the granite. It should be noted here that the section described in the text is the same as that already referred to in the citation from Sir A. C. Ramsay's early MS. report as affording the best evidence of the intrusive nature of the igneous rock.

torn off a mass of conglomerate and associated tuffs. These rocks have been so intensely indurated and silicified that the quartz pebbles are hardly traceable on a fresh fracture, though they project more evidently from a weathered surface. It is even difficult in places to say precisely where the line between granite and conglomerate should be drawn, so intimately are they welded together. The former rock, still presenting its normal petrographical characters, may be seen both underlying and overlying the involved portions of conglomerate, red shale, and fine tuff, the latter being altered into a kind of hornfels or porcellanite. Veins of granite penetrate these altered rocks. Great numbers of diabase dykes traverse the granite; and some of them cut the Cambrian strata also.

Fig. 6.—*Plan of Junction of Granite with Cambrian Strata, Ogof-llesugn, St. David's.*



The importance of this section in any discussion as to the nature of the crystalline rock of the ridge south of St. David's cannot be exaggerated. It is rather difficult of access, which may possibly account for the absence of any description of it in the papers hitherto published; but it completes the demonstration that the rock, which can be traced from St. David's to the coast south of Porth-lisky, is an eruptive mass that has been intruded into the Cambrian strata. The quartz conglomerate, here altered by the granite, is unquestionably the same band which can be traced along the coast for fully two miles eastward, and the greenish and reddish tuffaceous shales are recognizably those that everywhere accompany the conglomerate.

On the opposite side of this portion of the granite ridge the eruptive mass comes into contact with the stratified rocks in the Bay of Porth-lisky. Unfortunately, however, the actual junction is obscured, on the cliffs by the decomposition of the schists that abut on the granite *, and on the beach by the quantity of fallen blocks.

The condition of the beach doubtless varies from time to time; but neither on the occasion of my first visit last September, nor on the second examination five months later, could I trace the actual contact of the two kinds of rock, though I followed them to within a few feet of each other. The schists are, in some bands, much indurated, passing into a kind of quartzite or quartz schist. The crystalline rock of the ridge, as exposed along the cliff, presents

* There may have been a shift at the line of junction here.

features not unfrequently observable along the edge of the granite, being fine-grained and of a diffused greenish tint. On the beach it becomes in places very quartzose and much impregnated with calcite, some portions weathering with a nodular surface not unlike that of a conglomerate. Possibly there may be some dislocation along the line of junction, and the calcareous portions may be due to infiltration along the lines of fracture*. Though I searched the locality very carefully with Mr. Peach, and subsequently with Mr. Topley, I could not trace bedding in the granite such as has been described by Dr. Hicks. As already mentioned, the granite is much jointed here, and the joints are in some places close and rudely parallel; but they are mere joints, readily distinguishable from any original structure of the rock.

It is worthy of remark that the schists which abut on the granite, and extend across the Bay of Porth-lisky, dip at high angles towards N.N.W. They strike at the granite, so that, apparently, lower beds come out as they are followed seawards. I shall afterwards show that all these strata are inverted, and that, consequently, the most easterly beds at Porth-lisky are stratigraphically higher than those immediately to the west of them. Mr. Peach and I observed these peculiar schists at Ramsey Sound lying below the conglomerate; indeed, if the rocks of Porth-lisky could be traced for a quarter of a mile further out to sea, the conglomerate would doubtless make its appearance †.

If now we turn to the Map (Pl. VIII., p. 268), it will be seen that the granite, in its course from St. David's to the sea, cuts across successive horizons of Cambrian beds, penetrating deepest into them on the north and east, and reaching its highest platform on the south. The way in which it has broken through and pushed aside the conglomerate is peculiarly striking. That band of rock has been assumed by Dr. Hicks to be the base of his Cambrian system; we find, however, that the granite not only invades it, but ascends across the overlying shales and sandstones.

One further statement calls for notice here. Dr. Hicks, having satisfied himself that the granite of St. David's is a bedded metamorphic rock, has ventured upon estimates of its thickness; in his paper of May 1878, he remarks that the thickness previously claimed by him for his "Dimetian" group, *viz.* 15,000 feet, is not an overestimate ‡. But, as will be afterwards pointed out, the only bedded rocks that occur between St. David's and Porth-lisky lie on the flanks of the granite, and strike with the ridge instead of across it,

* Mr. Tawney, who had the advantage of being guided over the locality by Dr. Hicks himself, regarded the calcareous bands as "due to the decomposition caused by water filtering down joints, removing alkaline silicates, and depositing carbonates of lime and magnesia" (Proc. Bristol Nat. Soc., N. S. vol. ii. pt. 2, p. 116). I cannot doubt that this is the true explanation of the limestone and dolomite bands described by Dr. Hicks from this locality.

† In connexion with this southward prolongation of the conglomerate, we must look on the mass at Ogof-llesugn as having been torn off from the main body, which must lie somewhere beneath the granite.

‡ Quart. Journ. Geol. Soc. vol. xxxiv. p. 154; see also vol. xxxiii. p. 230 (1877).

so that they must be measured at right angles to the line taken by Dr. Hicks. I am not aware of any method by which we can measure the thickness of a square mile of granite.

To the phenomena of contact-metamorphosis I shall return in the second part of this paper (p. 317). The evidence now brought forward is, I submit, amply sufficient to prove that, whether studied in hand-specimens, in microscopic slices, or in the numerous natural sections which show its geotectonic relations, the "Dimetian" group of Dr. Hicks, instead of being a ridge of Pre-Cambrian metamorphic rock, is really a boss of eruptive granite, later in date than the Cambrian strata through which it has been intruded, and that the term "Dimetian," so far at least as regards its original locality, must be abandoned.

2. "Arvonian."

The rocks grouped under this name by Dr. Hicks at St David's are thus described by him.

"The rocks now included in this group I originally associated with the Dimetian; but in the year 1878 * I separated them from the latter, under the above name.

"On the Survey Maps they are coloured generally as felstones and porphyries, usually intrusive amongst Cambrian or Lower Silurian rocks. They consist in reality of flows of rhyolitic lavas, alternating with felsitic breccias and hälleflintas. The strike is from N. to S., and, hence, discordant to those newer rocks with which they are usually surrounded, as also to the underlying Dimetians. Like the Dimetian, this is a highly acid group, being mainly made up of the types of rocks known as the quartzo-felspathic. But, instead of being like these, chiefly of clastic origin, we have here a great series of acid lavas mixed up with a comparatively small proportion only of rock of a clastic nature. In colour these lavas vary from being very dark (almost black) to a light grey, and from deep red or violet to flesh-colour. The flow-structure is usually well marked, and in many cases the spherulitic structure also. A large number are porphyritic, from the minute crystals of felspar or quartz. The hälleflintas are more siliceous-looking than the rhyolites, and have a horny-looking texture and fracture. Under the microscope they are still more easily distinguishable. Their chief peculiarity, perhaps, consists in the manner in which some of the quartz becomes separated away into nests, so as to give the rock a curious pseudo-porphyritic appearance; whilst the intervening parts exhibit the appearance of a micro-crystalline mass of quartz grains, with intervening felsite. The breccias usually consist of fragments of lavas and hälleflintas, like those in association with them, and the pieces angular.

"This group, therefore, is characterized by being for the most part made up of acid lavas, breccias, and compact siliceous rocks of the hälleflinta type, and as usually having the strike in a direction from N. to S."†.

* [Quart. Journ. Geol. Soc. vol. xxxv. p. 285 (1879).]

† Proc. Geol. Assoc. vol. vii. no. i. p. 62 (1881).

In the definition of the lithological characters here ascribed to the rocks in question I am disposed generally to agree. These mineral masses are partly eruptive quartz-porphyries, and partly highly siliceous strata of sedimentary origin to which the names hälleflinta, hornfels, porcellanite, chert, Kieselschiefer, adinole, &c. might in different places be applied. But here my agreement ends. Instead of finding evidence that these rocks lie with a discordant strike unconformably against the so-called "Dimetian" below, and are covered unconformably by Cambrian or "Pebidian" beds above, Mr. Peach and I discovered that Dr. Hicks had really created a separate stratigraphical "group" out of the zone of quartz-porphyry bosses and dykes with the accompanying indurated sedimentary rocks that surround the central core of granite.

I shall discuss the phenomena of intrusion and metamorphism in the second part of this paper. There are only two questions that need be considered here. In the first place, Dr. Hicks asserts that his "Arvonian" rocks usually present a north and south strike, and are unconformable to his "Dimetian" group. This assertion has been virtually disproved by the evidence which I have now advanced as to the true nature of what he calls "Dimetian." But, for the sake of precision, I may here state that my colleague and I made careful observations of the strike of the rocks all round the granite, and found the dominant trend to be parallel with the granite ridge—that is, generally in a north-easterly and south-westerly direction. Where the average strike changes, it is rather towards east and west than towards north and south, as is more especially noticeable on the coast between Ogof-llesugn and Caerbwdy. Nowhere could we detect a prevalent north-and-south strike, nor, any general tendency in the rocks to strike at the granite.

The quartz porphyries, which appear to constitute a great part of the so-called "Arvonian group," show no strike. They are really as devoid of any semblance of bedding as an eruptive rock can well be. Dr. Hicks remarks that the junction of the "Arvonian" and "Dimetian" rocks is to be seen at St. David's; but he immediately adds that there is a line of fault at the locality between the two groups. He describes the "Arvonian" rocks as "striking up towards the ridge" and "the lowest beds" as being visible near the Deanery. The rocks exposed over that area are of a type not unfrequently observable round the edge of the granite and doubtless connected with it, to which I shall refer more in detail in Part II. They are entirely amorphous, eruptive masses, without the least trace of any kind of bedding. On the road-side between the Deanery and Rock House, among the numerous joints there is one set that runs in a north-and-south direction, the joint-planes being inclined at right angles towards the west. This was the only structure that I could discover which might have suggested the idea of bedding.

In the second place, Dr. Hicks alludes to the view expressed on the Survey Maps that the igneous rocks in question are intrusive, but only to dismiss it without further notice and to substitute for it the statement that "they consist in reality of flows of rhyolitic

lavas, alternating with felsitic breccias and hälleflintas"*. In another paper he writes that "they were marked on the Geological Survey Maps as intrusive felstones; but a very cursory examination proved that they were not of that nature, and that they were in reality bedded sedimentary rocks which had undergone metamorphic change"†. Passing over the discordance between these two emendations of the Survey Maps, I would observe that the author in dismissing the view taken by the officers of the Survey and substituting for it another of his own, offers no observations of any kind in support of his emendations. He simply declares the rocks to be rhyolitic lavas (meaning evidently, streams of lava that have flowed out at the surface), but mentions no character by which they are to be distinguished from intrusive masses. In a previous paper, indeed, he had admitted that they were "possibly intrusive"‡, though at the same time he regarded them as "appearing distinctly to lie in the line of bedding of their associated quartz rocks." He would seem to have been led to regard them finally as lavas, from a remark made to him by Professor Bonney that they most resemble a lava-flow §. I presume it was the presence of fluxion-structure in them that suggested this identification; but I shall subsequently show how fallacious this presumed test is for the purpose of distinguishing the superficial from the more deep-seated manifestations of volcanic matter. To go no further than the region of St. David's, I find spherulitic structure and fluxion structure in the most obviously intrusive dykes.

In every example in this district where the actual contact of the porphyries with the surrounding stratified rocks can be seen, the porphyries are distinctly intrusive. In the quarries north of the Church Schools the fine tuffs and schists or shales, which are undoubtedly a portion of Dr. Hicks's "Pebidian" group, are much indurated close to the prophyry, which traverses them obliquely to their bedding. But this alteration insensibly dies away as the strata are followed northward; and at a distance of about sixty or seventy yards they assume their usual characters of fine tuff. The actual intrusion of one of the quartz-porphyries as a dyke or elvan through the strata, however, may be seen in the noble section among the cliffs south of Nun's Chapel. Other examples occur further west, near Treginnis. The behaviour and structure of these rocks will be discussed in Part II., in connexion with the metamorphism of the district.

Dr. Hicks associates certain breccias with his rhyolites as contemporaneous components of the "Arvonian group." But there can be no doubt that they are portions of the volcanic (or what he terms his "Pebidian") group which have been invaded by the porphyries and have been much indurated. They can be seen north of

* Proc. Geol. Assoc. vol. vii. pt. 1, p. 62 (1881).
† Quart. Journ. Geol. Soc. vol. xxxv. p. 286 (1878).
‡ Quart. Journ. Geol. Soc. vol. xxxiv. p. 153 (1878).
§ Ibid. p. 154.

the Church Schools forming part of that group, also on the south side of the ridge near Nun's Chapel.

So far, therefore, as regards the evidence to be obtained at St. David's itself, there is no foundation whatever for the institution of a separate group under the name of "Arvonian." The rocks so called by Dr. Hicks are portions of his "Pebidian" group invaded and altered by a central core of granite and abundant dykes or bosses of quartz porphyry*. What the "Pebidian" group really is must now be considered.

3. "Pebidian."

The general characters of this group of rocks at St. David's are thus summarized by Dr. Hicks:—

"Most of the rocks in this group differ from those already described, though occasionally there is a certain amount of resemblance remaining. Instead of the acid types prevailing, as in the previously named groups, we find the basic types more largely developed. Basic lavas and breccias now predominate over the rhyolites; and the clastic rocks are more micaceous, chloritic, and talcose. On the Survey Maps these rocks are coloured as altered Cambrian, and partially as intrusive greenstones. On more careful examination the so-called greenstones turn out to be bands of indurated volcanic ashes, and contemporaneous basic lava-flows. Agglomerates and breccias occur in great thicknesses in the group; and the fragments are chiefly, except in the lowest beds, of a basic character. Chloritic, talcose, felspathic and micaceous schistose rocks occur also at various horizons, and occasionally purple and green slates. Serpentinous bands are also sometimes found, as well as veins of jasper, epidote, and asbestos. Some of the finer and more quartzose beds assume a gneissose appearance, and others are porcellanitic.

"The strike in this group is from about N.E. to S.W., and hence nearly in accordance with that in the overlying Cambrian rocks. That this group, however, must have been in much the same condition in which it is found, before a grain of the Cambrian rocks was deposited, is perfectly clear from the fact that the conglomerates at the base of the latter are very largely made up of rolled pebbles and rounded fragments identical with the rocks below. An actual unconformity between the two groups is also seen at several points.

"This group consists of a far more varied series than the two former, and doubtless would exhibit a still greater diversity if fully exposed; for it is perfectly clear that, in consequence of the rapid

* The intrusive character of the quartz porphyry south of Nun's Chapel is admitted by Dr. Hicks in his paper of 1877 (Quart. Journ. Geol. Soc. vol. xxxiii. p. 236). He gives a section showing it cutting through the rocks (his "Pebidian"), and says that it does not penetrate the Cambrian beds above. But at its western end, where it descends to the beach, it approaches the conglomerate, and would probably be found piercing it if the beach could be cleared of the fallen débris. I shall show that this rock is precisely similar in petrographical character to the so-called "Arvonian" porphyries of St. David's (p. 315).

overlapping of the sections by the Cambrian rocks, much is hidden from view" *.

I accept generally the lithological descriptions here given, but with important modifications to be afterwards stated. There can be no doubt that the group is almost entirely of volcanic origin—formed principally of various tuffs with bands of olivine diabase and occasional intrusive masses of quartz porphyry. I have already shown that the volcanic nature of these rocks was clearly recognized by my predecessor, Sir A. C. Ramsay, in his original map and section, and in his early MS. report on the St. David's area, and that he afterwards allowed this view to be set aside in favour of the opinion that the peculiar bedded rocks on the west side of the granite ridge are altered Cambrian strata through which intrusive "greenstones" have been injected, It is this view which is expressed upon the second and latest edition of the Survey Map and Section. I at once acknowledge that in this respect the present Map and Section are seriously in error, and that Dr. Hicks deserves the thanks of geologists for having, as it were, rediscovered probably the oldest group of palæozoic volcanic masses yet known in this country.

Reserving for the second part of this paper what I have to add to the published descriptions of these rocks, I proceed at once to consider the evidence for their forming a distinct Pre-Cambrian group lying unconformably on the groups below, and covered unconformably by the Cambrian strata above, as has been so repeatedly asserted by Dr. Hicks.

In this instance, again, I have been unable to discover in his published papers references to any sections where the proof of the alleged unconformability between the so-called "Pebidian" and "Arvonian" rocks can be seen. The unconformability, if it existed, might be proved (1) by actual sections showing the line of junction, (2) by detailed mapping of the ground and the detection of proofs of overlap and discordance, or (3) by the evidence of included fragments. Dr. Hicks asserts that "resting unconformably upon the whole [Arvonian Group] are the great agglomerates of Clegyr Hill, the base-beds of the Pebidian, which are made up of masses of Dimetian rocks, of quartz felsites, spherulitic felstones, and hälleflintas, and all in the condition in which they are now found composing the underlying ridges. From this evidence it is tolerably clear that the position of the Arvonian or hälleflinta group is intermediate between the Dimetian and the Pebidian, and that there is, at least in this area, very clear proof of unconformity and hence of lapse of time having intervened" †. In this passage he enumerates two of the three kinds of proof just referred to as indicative of the discordance in question.

Again my companion and I sought diligently for any trace of the alleged evidence, but completely without success. Like the other assertions with which I have been dealing, its groundlessness became more apparent at every step of the investigation. There is not only

* Proc. Geol. Assoc. vol. vii. p. 63.

† Quart. Journ. Geol. Soc. vol. xxxv. pp. 289, 290 (1879).

no vestige of an unconformability, but the volcanic groups which Dr. Hicks has included in his "Pebidian" can be seen in many places graduating insensibly into the altered shales which form a great part of his so-called "Arvonian." In fact the latter group, as above stated, consists of portions of the volcanic breccias and tuffs (that is, the "Pebidian" strata) where these are invaded by quartz porphyry. This is well seen in the series of quarries north from the Church Schools, where, as already remarked, a perfect graduation can be traced from highly altered shales and tuffs, next the intrusive quartz porphyries, northward into the normal condition of these strata in the district. The assertion that the Pebidian strata are made up chiefly of "Dimetian" fragments must, from the evidence already adduced as to the late date and intrusive nature of the "Dimetian" mass, be founded on error of observation. I need hardly say that, after the most patient search, neither Mr. Peach nor myself could detect anywhere in these tuffs and breccias the smallest fragment which, by the utmost stretch of fancy, could be referred to the granite of the "Dimetian" ridge. There occur indeed, abundant lapilli of felsite, as I shall more fully describe in the sequel; but these fragments can readily be discriminated from the material forming the eruptive porphyry dykes and bosses.

But the most extraordinary statement in the passage just cited is that in which the writer asserts that the great agglomerates of Clegyr Hill rest unconformably upon his "Arvonian" group. The agglomerates in question are well seen on the road-side east of Clegyr Bridge, where they dip towards S.S.E. at 65°, and are interbanded with siliceous layers (hälleflintas). These siliceous bands are precisely the same as those seen near the quartz porphyries north of the Board-Schools, on the shore at Nun's Chapel, and elsewhere. They are characteristic of the volcanic group where it is traversed by intrusive siliceous eruptive rocks, and particularly of a zone that lies not far below the conglomerate to be referred to in a later part of this paper. The presence of these bands in what Dr. Hicks himself cites as typical "Pebidian" agglomerates is an important fact, in still further proving that, at St. David's itself, "Pebidian" and "Arvonian" are only different names for the same series of rocks.

On Clegyr Hill the same agglomerate, interbedded with fine tuff and bands of siliceous schist, and traversed by a dyke or boss of spherulitic quartz porphyry, appears to dip towards the N.W. at 40°–50°—that is, actually towards the rocks which it is said to overlie. Nothing is seen at the surface for a distance of nearly a quarter of a mile, when the observer finds that a few square yards of quartz porphyry have been laid bare in a quarry to the south of Trepewit, while, about thirty yards distant, fine tuff, nearly vertical, but preserving the normal E.N.E. strike, is seen on the road-side. Yet Dr. Hicks boldly asserts not only that the rocks of Clegyr Hill overlie the porphyry, but that they do so unconformably!

4. Relation of "Pebidian" to Cambrian rocks.

The unconformability between the top of the "Pebidian" rocks and the conglomerate which Dr. Hicks assumes to be the base of the Cambrian system likewise disappears on examination. As before, he rests upon presumed discordance in the dip and strike of the rocks, and on the alleged presence of fragments of the older rocks in the younger. But both these tests fail him.

In the first place it can be conclusively shown that in dip and strike the volcanic group and the overlying conglomerate, sandstone, and shales are perfectly conformable throughout. Mr. Peach and I proved this by numerous measurements all over the district. We observed that, at the locality on Ramsey Sound, near Castell, mentioned by Dr. Hicks as showing the unconformability of the conglomerate, there has been a slight local disturbance of the strata. The beds below the conglomerate have been bent up, and the conglomerate itself has been pushed over them. Seen from the top of the cliff the conglomerate lies in part on their edges. But when examined on the spot the unconformability disappears, and the strata below the conglomerate are found at a little distance from the disturbance to be perfectly conformable with it. The same complete conformability is well exposed on the face of the next projecting cliff southward.

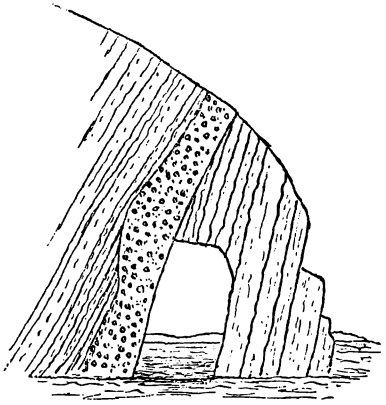
At another locality, on the coast south of Caer-fai, also referred to by Dr. Hicks, there is an apparent discordance between the conglomerate and the beds below it. But here again the seeming unconformability at once disappears on examination. It is an instance of the familiar phenomenon of what has been called "contemporaneous erosion." Every field-geologist knows that this structure constantly occurs among pebbly strata, from the most recent valley-gravels to the most ancient sedimentary rocks yet known. Were it to be used as indicative of serious unconformability, we might have half a dozen discordant formations in a single gravel-pit. But the section at Caer-fai, as shown in fig. 7, might as well be taken to prove unconformability above the conglomerate as below it. In reality these are merely common local accidents of sedimentation, and, but for their relation to the question now under discussion, would not be worthy of special notice.

Dr. Hicks, in one of his papers, remarks that the "line of strike of the Cambrian rocks appears at first sight to be nearly identical with that of the underlying Pebidian beds; but when examined carefully it will be seen that in no case is it truly so, but that the conglomerates overlap the beds irregularly and at different points in the succession" *. In another paper he states that the Cambrian conglomerate overlaps the "Pebidian" group altogether, so as to rest upon the "Dimetian" rocks †.

I was not surprised by these statements when I found that he had wholly missed the structure of the ground between Ramsey Sound and the granite ridge. At first an observer traversing

* Quart. Journ. Geol. Soc. vol. xxxiv. p. 159 (1878).
† *Ibid.* vol. xxxiii. p. 230 (1877).

Fig. 7.—*Contemporaneous Erosion accompanying Cambrian Conglomerates. Caer-fai, St. David's* .*



the coast-section, or looking at the occasional exposures inland, and finding that all the tuffs, breccias, and diabase sheets dip steadily in a north-westerly direction, would infer that he is crossing a continuous succession of beds, the highest being at the north-west end and the lowest at the south-east end of the section. This natural inference has been drawn by Dr. Hicks, and may partly account for some of the errors into which he has fallen. Further comparison, however, would have shown him that the strata are here isoclinally folded; that is, they have been thrown into an anticline, which has been bent over to the south-east, so that the strata in the south-eastern half of the fold are inverted (figs. 1 & 2, p. 268). That this is the case, was proved by Mr. Peach and myself in the identification of the same beds on the two sides of the arch. In particular, the peculiar group of shales or schists immediately below the conglomerate on Ramsey Sound reappears at Porth-lisky. The conglomerate accompanies them; but at the latter locality it has been cut out by the granite. It appears, however, a short way inland in the Allan valley, and on the east side of the granite at Ogof-llesugn. The reversed dip continues along the coast-line; but the beds are eventually seen to right themselves, and they appear in normal order to the east of Caer-fai. I shall return to this interesting structure in the second part of this paper (p. 302)†.

* Dr. Hicks figures this junction as an unconformability of the Cambrian conglomerates on the Pebidian Beds. But he reverses the visible dip, making the rocks inclined towards the sea instead of towards the land (Quart. Journ. Geol. Soc. vol. xxxiii. p. 236). This subject is again referred to in the text.

† It may be proper to notice here that the structure above described proves that Dr. Hicks's estimate of the visible thickness of his "Pebidian" group is greatly exaggerated. He makes the thickness at least 8000 feet (Quart. Journ. Geol. Soc. vol. xxxiv. p. 159). Were the beds absolutely vertical all the way, they could not be more than 4000 feet; for they extend across a belt which, to

In the second place, Dr. Hicks has stated more than once that the Cambrian conglomerates are largely made up of the underlying "Pre-Cambrian" rocks *. As the result of a most careful examination of the conglomerate belt along both sides of the fold, I feel myself warranted in stated confidently that it contains not a single pebble of the characteristic granite of the St. David's ridge. The actual composition of the conglomerates will be best understood from the percentages taken by Mr. Peach on the west side, and by myself on the east side of the fold.

Percentage of Stones in the Cambrian Conglomerates.

West side of Isocline.		East side of Isocline.	
Quartzite (often red)	70	Quartzite (generally red)	59
Quartz	25	Quartz	35
Diabase	4	Diabase	4
Greywacke	1	Greywacke	1
		Red Jasper	1
	100		100

Thus, of the component pebbles not less than about ninety-five per cent. are of quartzite or quartz. There are certainly no rocks visible in the district whence these pebbles could have been derived. On the other hand, the quartzite resembles the familiar material that forms so conspicuous a feature in the conglomerates and pebble-beds of all geological ages in this country, and the original source of which it is so difficult to fix. The only fragments of undoubtedly local derivation are the few pieces of diabase. These came from some of the lavas in the volcanic series below. But such pebbles would naturally continue to be washed off any volcanic islets still rising above the water, until the last mass of lava or consolidated tuff had disappeared. Their presence lends no support whatever to the idea of unconformability. It is well known that similar

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the S.W. of St. David's, is only three quarters of a mile broad. The visible portion of them cannot be thicker than 2000 feet, but is almost certainly less than that. The bottom, however, is not reached, so that they may attain a considerably greater thickness than can be actually seen.

* His descriptions of the composition of the conglomerate have varied considerably from year to year. In 1871, in conjunction with Professor Harkness, he described it as "composed chiefly of well-rounded masses of quartz imbedded in a purple matrix," which is a sufficiently accurate diagnosis. In 1877 (Quart. Journ. Geol. Soc. vol. xxxiii. p. 238) he asserted that "the true Cambrian conglomerates undoubtedly contain masses of the underlying rocks in their altered state," the conglomerates themselves being unaltered. In 1878 (Q. J. G. S. vol. xxxiv. p. 162) he stated that they are largely made up of the "Pebidian" rocks. And again, in 1881, "the conglomerates at the base [of the Cambrian rocks] are very largely made up of rolled pebbles and rounded fragments identical with the [Pebidian] rocks below" (Proc. Geol. Assoc. vol. vii. p. 63). As there is a singular uniformity in the character of this conglomerate throughout the district, the variation in these lithological descriptions is remarkable. The first notice of this rock appears to have been that by De la Beche, in the paper already cited, where he speaks of it as a "quartzose conglomerate resembling one of Old Red Sandstone." (Trans. Geol. Soc. ser. 2, vol. ii. p. 9.)

fragments continue to appear in the comformable sedimentary deposits that overlie ancient volcanic rocks. The relation of the conglomerate to the rocks underneath is nowhere better seen than in the excellent exposure of the band on the west side of the diabase crag at Rhosson. The conglomerate there rests almost immediately on the igneous rock, yet 95 per cent. of its pebbles are of quartzite and quartz, only 4 per cent. being diabase, and these derived from some different sheet than that immediately below *.

As a part of the arguments from included fragments, reference may be made to Dr. Hicks's statement that the volcanic group must have been much in its present lithological condition before a grain of the Cambrian rocks was deposited. The rocks of that group were called "Altered Cambrian" on the Survey Map, doubtless because it was recognized that, whatever might have been their original condition, they had undergone considerable alteration. This altered condition is one of the first features of the rocks to arrest attention. It is not universal, indeed, and is by no means uniform, but in certain bands is so marked that the strata have passed into true silky schists with well-developed foliation. This alteration will be more fully dwelt upon in Part II.

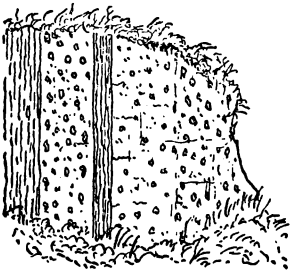
Now, if it could be shown that the metamorphism stops short below the conglomerate, not affecting the beds above that horizon, I admit that the fact might be plausibly used to sustain an attempt to draw a strong line between the conglomerate and the rocks below it. But no such restriction exists. The shales far above the conglomerate have undergone as complete an alteration, and present examples of schists as perfectly foliated as those in the volcanic group beneath. Fine silvery and silky schists are intercalated among grey and purple sandstones that overlie the quartz conglomerate at Porth-Seli, at the south end of Whitesand Bay, and at other localities (see Part II. p. 311).

The facts now stated would be sufficient to disprove the assertion that there is any break in the succession of deposits at the base of the conglomerate. But to complete the argument one further destructive fact remains to be noticed, viz. that the volcanic beds do not cease below the conglomerate, but are interstratified with it and appear above it. In proof of this statement I may refer to the sections on both sides of the fold where this perfect passage can be seen. On the shore of Ramsey Sound, at the headland of Castell, the red shales and sandstones with *Lingulella primæva*, which lie not far above the conglomerate, are banded with thin seams of sandy tuff, some of the shales being also full of diffused tuffaceous material, as if from slight discharges of fine volcanic dust during the last stages of eruption in the district.

Again, on the east side of the isocline in the valley of the river Allan, the interesting section shown in fig. 8 may be seen at the upper end of the first field north from the bridge near Lower Mill.

* This locality is referred to by Dr. Hicks (Q. J. G. S. vol. xxxiii. p. 237, 1877) as showing the unconformability of the conglomerate on the rocks below. I cannot conceive how such an assertion can have been made.

Fig. 8.—*Section showing the Interstratification of Tuff and Conglomerate above Lower Mill, St. David's.*



a b c d e

The conglomerate, as there exposed, is regularly interstratified with tuff. The beds are vertical. On the left side of the little quarry as we enter it, layers of fine reddish tuff (*a*)* are succeeded by a band of quartz conglomerate (*b*) of the usual character. Parallel to this conglomerate comes a band, about six inches thick, of fine tuff (*c*), followed by ashy sandstone (*d*), which graduates into conglomerate (*e*). No more complete evidence could be desired of the perfect inosculation of the conglomerate with the volcanic group. On the coast at Nun's Chapel similar evidence presents itself. The conglomerate there contains some thin seams of tuff, and is intercalated between a series of dull green agglomerates and tuffs and some greenish shales and sandstones with layers of tuff.

There is evidence that though volcanic action became dormant (or at least exceedingly feeble) in the interval immediately succeeding that in which the conglomerate was laid down, it reappeared at a later part of the Cambrian period. Thus, about three miles east from St. David's, on the road south from Felin-canot, near Whitchurch, beds of volcanic tuff may be seen overlying Cambrian grits. Again, in a deep valley (Cwm Mawr) between Pointz Castle and Newgale Bridge, on the coast, six miles east from St. David's, a coarse volcanic tuff or agglomerate and ashy sandstone is interstratified in beds which must be high up in the Lower Cambrian formation, certainly far above any of the beds near St. David's. This rock presents petrographical characters somewhat different from those of the tuffs in the volcanic group above described (see Part II.). These intercalations, which were noticed by Mr. Peach and myself as we passed the localities, show that occasional eruptions took place during the deposition of later stages of the Cambrian groups. A more exhaustive search of the whole region would doubtless bring to light other volcanic zones on different horizons, and enable us to connect the volcanic episode of St. David's with that of the Lower Silurian period in North Pembrokeshire.

It follows, from the facts now detailed, that the volcanic group of

* Red tuff of precisely the same character conformably underlies the conglomerate on the east side of the fold above Caerbwdy Mill.

strata named "Pebidian" by Dr. Hicks passes regularly upwards into the fossiliferous Cambrian formations, from which it cannot be dissevered, and with which it must be classed. There is no more reason why a strong line should be drawn between the sedimentary and volcanic groups here than in any other part of the geological record of Great Britain. The intercalation of massive volcanic groups is well known in the Silurian, Old Red Sandstone, Carboniferous and Permian systems. The Cambrian volcanic group of St. David's is in every respect comparable to one of these, but with an added interest from its high antiquity. It no more deserves to be ranked as a separate formation with a distinctive name than the thick group of tuffs and lavas in the Arenig Series of North Wales, or that in the Old Red Sandstone of Central Scotland. The term "Pebidian," therefore, is unnecessary, and, having been assigned to a group of rocks erroneously believed to be Pre-Cambrian, ought to drop out of geological literature.

5. Conclusion.

At the begining of this paper I stated my readiness to concede that the maps of the Geological Survey, originally prepared thirty or forty years ago, may now stand in need of correction, and that in this spirit I went to St. David's, being fully persuaded that, in regard to the map of that district in particular, very serious modifications would be required. As the result of my resurvey, I find that the true meaning of the volcanic group at the bottom of the Cambrian strata there exposed, though partly recognized in the first edition of the Map and Section, had been subsequently lost sight of, these rocks having been erroneously renamed by the Survey "Altered Cambrian" with intrusive sheets of "greenstone." I have freely admitted this to be an important error. But it should be remembered that the error was made nearly thirty years ago. Such, meanwhile, has been the progress of petrography that a mistake of the kind could not have occurred had the map been surveyed during the last fifteen years.

Again, were the area to be resurveyed now, we should not colour as one continuous belt of intrusive rock the long slip of country from the coast near St. David's north-eastward to beyond Llanhowell. We should endeavour as far as possible to represent only those portions of eruptive rock which are actually visible, or unquestionably exist underneath the surface, leaving the intervening spaces on the map to be coloured with the tint used for the general stratified formation of each area. We should prefer to indicate in this way that there are detached dykes and bosses along a certain area of extravasation, rather than to mass the whole as one continuous belt. But this would be, after all, a question of detail or style of mapping. The officers of the Survey were certainly correct in regarding the crystalline rocks, which they named syenite and felstone, as intrusive through the Cambrian strata; and this is the main question in the present discussion.

In concluding this part of my paper, I am bound emphatically to declare that the map of the St. David's district, as surveyed by De la Beche, Ramsay, and Aveline, is in its essential features correct. Dr. Hicks has denied its accuracy, and has even gone so far as to assert that "a very cursory examination" suffices to show its errors. One would have thought that something more than a "very cursory examination" would have been required to upset the mapping laboriously worked out by men who, from long years of training, had acquired an almost unrivalled skill in field-geology. At all events we might fairly have expected that, instead of merely declaring the map to be wrong, Dr. Hicks would take every care to show why, after prolonged consideration, he could not accept the conclusions of his predecessors. Their long years of geological experience, I venture to think, entitled their work, whether right or wrong, to more than a summary dismissal. But the same treatment which Dr. Hicks meted out to them in the St. David's area, he has consistently continued in his subsequent excursions over Wales. Having apparently convinced himself—on what grounds I have endeavoured to show—that the rocks coloured on the Survey Maps as felstone or quartz porphyry must belong to his "Arvonian" group (that is to say, are not intrusive in the Cambrian or Lower Silurian strata, but prominences of Pre-Cambrian age), he has proceeded to apply this conviction to the Geological Survey maps all over Wales. With the most complete disregard of the evidence by which the officers of the Survey were led to regard certain rocks as intrusive, he simply turns the felstones, syenites, &c. into metamorphic and volcanic Pre-Cambrian masses*. I have deliberately restricted myself in this paper to the discussion of the St. David's district; and I therefore offer no opinion as to the validity of the Pre-Cambrian areas cited by Dr. Hicks in other parts of Wales. But I am sure that geologists generally will support me when I contend that it is not by the "cursory examination" of wide areas that the country can be remapped. This was not the style in which the Survey Maps were constructed; nor is it the style

* It will be a work of some labour to follow Dr. Hicks in his rapid traverses of Wales, with the view of testing his corrections of the work of his predecessors. Mr. Peach and I had time to visit a few of the areas he has renamed, and always with the same result. Thus, on the coast near Newgale, about eight miles east of St. David's, he describes a mass of Pre-Cambrian beds, chiefly "felstones," "flanked by Cambrian conglomerates containing pebbles identical with the rocks below" (Quart. Journ. Geol. Soc. vol. xxxv. p. 160). All that we could find was an eruptive rock penetrating and altering black Cambrian shales. Again, he describes the quartz felsites of Roche Castle as belonging to his "Arvonian" groups (Quart. Journ. Geol. Soc. vol. xxxv. p. 286). If bedding exists in this rock, I can see no reason why every eruptive rock should not be regarded as bedded, or why, on the same ground, several unconformable Pre-Cambrian formations might not be made out in any good-sized granite-quarry. It is interesting to remember that the true structure and intrusive character of the Trefgarn (Roche-castle) rock were shown in 1836, by Murchison (*ante*, p. 263). In the 'Silurian System' (p. 402) he says in reference to it that, "though offering no traces of true bedding, the compact felstone of Trefgarn is divided into rude prisms by two sets of planes or vertical and horizontal joints giving rise to square-topped masses like ruins."

in which they should be corrected. The intrusive character and comparatively late origin of the eruptive rocks were deliberately asserted by my colleagues after prolonged examination. Had this view been erroneous, it ought to have been disproved by a detailed review of the evidence on which it was based. I have gone fully into the assertions made by Dr. Hicks himself in regard to the area of St. David's, and have proved them to be untenable. If this is the result of the critical examination of his typical Pre-Cambrian district, over which he has spent most time, I can hardly anticipate that his more rapid traverses elsewhere will, when properly tested, be found to have been more successful.

Part II.

Apart from the controversy as to their position in geological chronology, the rocks of St. David's present features of interest and importance not only in the palæozoic history of Britain, but in regard to general theoretical questions. They include, for example, perhaps the oldest group of lavas and tuffs the relative date of which is known. They have been subjected to a process of metamorphism which has affected only certain beds or kinds of rock. They have been penetrated by masses of granite and quartz porphyry, round which another kind of metamorphism has been manifested. At a later period they have been injected with diabase dykes, which are specially abundant in the central boss of granite. Evidently, therefore, they offer much material for study, and especially in regard to the two great geological problems of vulcanism and metamorphism. Though my original design included no more than the examination necessary to satisfy me regarding the disputed questions of the geological age and structure of the St. David's district, it naturally led to many observations of more than merely local interest. As contributions towards a more exhaustive memoir, it may be useful to collect these observations made in the field with my colleague Mr. Peach, and subsequently extended with Mr. Topley. I shall embody with them the conclusions to which subsequent reflection on the subject has led me. One of the most laborious parts of the research has been the microscopic investigation of the rocks collected by us at St. David's. I have studied upwards of one hundred slices of these rocks prepared for the microscope, and have had a large additional number cut from rocks of other regions for the purpose of comparison*. The results of the study are included in the following pages. It is gratifying to be able to state at the outset that, in so far as investigations among the rocks of St. David's have been published, I can confirm generally the descriptions given of the microscopic structure of these rocks by Professors Bonney and Judd, Mr. Davies and Mr. Tawney. But of the larger number of the rocks no account, as far as I am aware, has yet been given. I am also glad to record that the examination of the microscopic structure of the rocks af-

* These slices were prepared, in the petrological laboratories of the Geological Survey in London and Edinburgh, by A. Macconochie, R. Lunn, and J. Rhodes.

fords the most complete confirmation of the results obtained by us in our observations in the field.

1. Order of Succession of the Rocks.

The extent of the coast-sections, and the repetition of the strata on two sides of an axis of plication, combine to furnish the most satisfactory data for compiling a vertical table of the rocks. But the base of the whole series is not seen. As the line of fold seems to be dying out towards the south-west, it probably for a time brings up progressively lower beds as it is traced inland in the opposite direction, until it flattens out and disappears. The oldest rocks visible to the west and south-west of St. David's belong to the interesting volcanic group referred to in preceding pages. From these a continuous passage can be traced upwards into the purple, grey, and green sandstones and shales from which Dr. Hicks has obtained so abundant a Lower Cambrian fauna. The following groups of strata, from their easily recognizable lithological characters, may be taken as a convenient series for enabling the observer to trace out the general geological structure of the district.

Group of Lower Cambrian (Harlech) strata at St. David's, in descending order.

4. Purple and greenish grits, sandstones, and shales.
3. Green and red shales and sandstones, tuffaceous in parts.
2. Quartz conglomerate.
1. Volcanic group (tuffs, schists, lavas, &c.).

1. *Volcanic Group.*

The rocks comprised in this group present so many points of interest that they deserve, and would well reward, a much more detailed study than I have had an opportunity of giving to them. They are the oldest visible portions of the Cambrian system in the St. David's district. They consist almost wholly of volcanic materials, consolidated tuffs and breccias with contemporaneously erupted and subsequently intruded massive rocks. They are exposed in so many sections, and so continuously, both along the shore-cliffs and inland, that their succession and structure could be worked out with little difficulty. If not the oldest group of truly volcanic masses in Western Europe, they (and their equivalents in other parts of Wales) are, as I have said, at least the oldest of which the precise stratigraphical place in the geological record is known. They thus furnish important evidence to the student of the history of volcanic action.

In my examination of these rocks in the field, I was especially struck by their general resemblance to volcanic masses of later Palæozoic date. Many of the lavas and tuffs are in outward characters quite undistinguishable from those of the Lower Old Red Sandstone and Carboniferous systems of Central Scotland. So many points

of detail may be observed to be common to the rocks of the two areas as to indicate that volcanic phenomena must have recurred under much the same conditions throughout Palæozoic time in the British area.

The visible thickness of the volcanic group in the St. David's district appears to be about eighteen hundred feet; but as its base is not brought up to the surface, the total amount may be greater. A continuous section of the rocks is exposed on the sea-cliff between Ogfeydd-duon on Ramsey Sound and the east side of Porth-lisky. This section repeats the members of the group on each side of the isocline, the axis of which must cut the coast-line somewhere between Pen-maen-melyn and Pen-y-foel. I had not time to attempt a detailed examination of the successive members of the group as exhibited in this section; but the main subdivisions appeared to me to be as follows, in descending order: —

4. Fine tuffs and silky schists (occasional breccias and agglomerates), seen at Porth-lisky and Nun's Chapel on the east side, and at Ogfeydd-duon on the west side of the fold. At the latter locality only the upper beds are well exposed.

3. Diabase sheets with intruded quartz porphyry and hardened tuffs, Pen-maen-melyn, Pen-y-foel. The lavas are considerably thicker on the west side.

2. Compact green granular tuff. Inland from old copper-mine at Pen-maen-melyn, and near Pen-y-foel.

1. Thick purplish-red green-flecked tuff, with abundant small lapilli of felsite. This conspicuous rock, in many successive and somewhat variable beds, extends nearly the whole way between the headland at Pen-maen-melyn and Pen-y-foel. It dips at high angles towards the N.W., and shows intercalated shaly bands. It must occupy the centre of the fold; so that the south-eastern dips are inverted ones, and the rocks on that side are a repetition of what is seen on the north-western side of the axis.

From this merely tentative stratigraphical arrangement it is evident how large a proportion of the whole mass of the volcanic group consists of tuffs.

Tuffs.—These predominant members of the group present many varieties of colour, from dark purple, through tints of brick-red and lilac, to pale pink, yellow, and creamy white, but not unfrequently assume various shades of dull green. They vary likewise in texture from somewhat coarse breccias or agglomerates, through many gradations, into fine silky schists in which the tuffaceous character is almost lost. Generally they are distinctly granular, presenting to the naked eye abundant angular and subangular lapilli, among which broken crystals of a white, somewhat kaolinized, felspar and fragments of fine-grained felsite are often conspicuous. Examination on the ground suggested that the greater part of the tuffs has been derived from the explosion of basic rocks similar in character to the diabases now found associated with them. This appeared to me to be particularly the case with the purple, red, and dark-green varieties, which constitute so large a proportion of the whole. On the other hand,

I was inclined to regard the paler varieties, both in the form of fine tuffs and of breccias, as having probably resulted mainly from the destruction of more siliceous lavas, probably of fine-grained felsites or other acid rocks. These inferences in the field have now been confirmed by chemical analysis and microscopic examination.

That many of the tuffs are due to the destruction of diabase lavas may be surmised from their close general external resemblance to these rocks, and from the way in which they are associated with the contemporaneous sheets of diabase. Some of the dull dark-purple tuffs below the crag of Rhosson, and again to the north of Clegyr Foig, might almost at first sight be mistaken for truly eruptive rocks. Typical specimens taken from different parts of the district were analyzed for me by my colleague, Mr. J. S. Grant Wilson, in the laboratory of the Geological Survey, Edinburgh, and by my friend M. Renard, of the Royal Museum, Brussels, with the following results.

Analyses of Basic Tuffs from the St. David's District.

I. Purplish-red shaly tuff from below the olivine-diabase crag, Rhosson. (Analyzed by Mr. Wilson.)

II. Dull purple and green tuff from the lowest group of tuffs between Pen-maen-melyn and Pen-y-foel. (Analyzed by Mr. Wilson.)

III. Greenish, shaly, finely granular tuff from the road-side, north of Board Schools, St. David's. (Analyzed by M. Renard.) This specimen was chosen as one of the intermediate varieties between the basic and acid types; and the position thus assigned to it is confirmed by the analysis.

	I.	II.	III.
Silica	51·25	48·11	61·54
Alumina	20·41	13·30	16·30
Ferric oxide	3·02	3·70	4·40
Ferrous oxide	3·91	8·10	3·66
Manganous oxide	0·21	1·43	0·32
Lime	4·53	8·48	3·08
Magnesia	7·22	9·51	2·99
Potash	2·93	1·57	1·62
Soda	1·82	1·96	2·81
Loss on ignition and water	5·02	4·21	2·99
	100·32	100·37	99·71
Specific gravity	2·84	2·92	

Comparing the composition of Nos. I. and II. of these analyses with those of the diabases given on p. 303, we readily perceive how the tuffs might have been derived from lavas like those of Rhosson and Clegyr Foig. The differences between them are not greater than might be expected, if such were the source of the tuffs. There would be a partial decomposition of the volcanic dust and lapilli by the water into which they fell; and there might also be an intermingling with the ordinary non-volcanic sediment that happened to be in course of transit and deposit in the locality at the time of the

eruption. No. III. shows a considerably larger ratio of silica, as was inferred on the ground from its macroscopic characters. It has probably resulted from the admixture of a proportion of felsite detritus with the predominant more basic materials; and it may also have undergone some amount of decomposition before being covered up and compressed into stone.

The occurrence of such basic tuffs in rocks of so high an antiquity is a fact of great interest in the study of the history of volcanic action. But it is further deserving of attention that in the midst of those tuffs there are others of a thoroughly acid character. That felsitic lavas were present in the eruptive vents of the period is shown by the scattered felsitic lapilli in some of the dark-red basic tuffs, and by their abundance in the paler varieties. Even to the naked eye some of the green, white, and yellowish tuffs are obviously composed in large measure of felsitic detritus. I have been favoured by M. Renard and Mr. Wilson with the following analyses of typical specimens.

Analyses of Felsitic Tuffs from the St. David's District.

IV. Greenish felsitic breccia, Clegyr Hill (Mr. Wilson). This rock is composed of angular fragments of various felsites imbedded in a greenish base.

V. Grey granular felsitic tuff: the last bed visible, north of the bridge, over the Allan river, north from the Schools, St. David's (Mr. Wilson).

VI. Pale pinkish-white, finely schistose tuff, a characteristic sample of the "Porth-lisky schists" (M. Renard).

	IV.	V.	VI.
Silica	80·59	73·42	72·63
Alumina	11·29	12·09	16·23
Ferric oxide	0·28	0·91	2·70
Ferrous oxide	1·41	3·13	0·48
Manganous oxide	trace	0·25	...
Lime	0·52	2·94	0·18
Magnesia	0·95	1·12	1·36
Potash	2·98	1·67	3·35
Soda	0·72	3·88	0·15
Loss on ignition and water	1·96	1·28	3·04
	100·70	100·69	100·12
Specific gravity	2·55	2·74	...

I have had a series of thin slices made from characteristic specimens of the tuffs, taken from all parts of the group. It is one of the most interesting series of volcanic rocks I have ever had an opportunity of studying. Some of the more important details may here be given.

Many varieties of texture can be traced, from large-grained breccias like that of Clegyr Hill to fine schistose mudstones or sericitic schists like those of Porth-lisky. One of the most remarkable tuffs

is that already referred to (p. 295) as No. 2 in the series of the volcanic group. A specimen, taken from near Pen-y-foel, is externally dirty-green, compact, and tolerably homogeneous, but presenting distinct evidence of its clastic character (Plate IX. fig. 1). Under the microscope it is found to be composed mainly of lapilli of a rock somewhat different from any other which I have met with either in the tuffs or among the interbedded or intrusive sheets. This rock is marked by the abundance and freshness of its plagioclase (an unusual feature in the volcanic group of St. David's); by the large, well-defined crystals (one of which measured 0·022 inch by 0·0125 inch) of augite; by large crystals replaced by viridite, but having the external form of olivine; by the absence or scantiness of any base or ground-mass; and, in many of the lapilli, by the abundance of spherical cells, either empty or filled up as amygdules with decomposition-products. These spherical vapour-vesicles, so characteristic of the lapilli in many Palæozoic volcanic vents, were found in one fragment, where they were particularly abundant, to range from a minimum of 0·0008 inch to a maximum of 0·0033 inch, with a mean of about 0·0018 (Plate IX. fig. 2). The rock from which these lapilli have been derived comes nearest to one of the diabases from the same part of the district (which will afterwards be referred to), but shows a closer approach to the basalt rocks.

Another interesting tuff is that of which the analysis (No. II.) has already been given. It occurs not far from the horizon of the rock just described. Under a low power it is seen to be composed mainly of fragments of diabase like the rocks of Rhosson and Clegyr Foig. These fragments are subangular, or irregular in shape, and vary considerably in size. They are sometimes finely cellular—the cavities, as in the rock just described, being spherical. The plagioclase crystals in the diabase lapilli are everywhere conspicuous: so also is the augite, which occurs in larger forms than in the rock of Rhosson or Clegyr Foig. Next in abundance to these basic fragments are rounded or subangular pieces of felsite. These weather out in conspicuous grey rough projections on the exposed face of the rock; under the microscope they are seen to consist of fine granular felsite, which shows a ground-mass remaining dark between crossed nicols, but with luminous points and filaments, and an occasional spherulite giving the usual cross in polarized light. Lapilli of an older tuff may here and there be detected. A few angular and subangular grains of quartz are scattered through the rock. The lapilli appear to be bound together by a finely granular dirty-green substance. The presence of the quartz grains and of the felsite lapilli must raise the proportion of silica, which no doubt, but for these admixtures, would have been a good deal less than 48·11 per cent., the amount determined by Mr. Wilson's analysis.

As a type of the felsitic tuffs, I may refer to the rock already described as No. V. of the foregoing analyses. It is composed mainly of fragments of various felsites, many of which show good fluxion-structure. Large, and usually broken, crystals of orthoclase are dispersed among the other ingredients. Here and there a fragment

of diabase may be detected; but I could find no trace of pieces of the peculiar micro-crystalline spherulitic quartz porphyries of St. David's. There is but little that could be called matrix cementing the lapilli together. The presence of fragments of diabase may possibly reduce the proportion of silica and increase that of magnesia, as compared with what would otherwise have been present in the rock.

Some of the tuffs appear to have been a kind of volcanic mud. A specimen of this nature collected from the road-side section, north of the Board School, presents a finely granular paste enclosing abundant angular and subangular lapilli of diabase, a smaller proportion of felsite (sometimes displaying perfect fluxion-structure), broken plagioclase crystals, and a greenish micaceous mineral which has been subsequently developed out of the matrix between the lapilli.

Though they lie above the main volcanic group, I may refer here to the thin bands of tuff at Castell, of which, from their interest in relation to the true Cambrian age of the volcanic group, I have had a number of slices made for microscopic investigation (Plate IX. fig. 3). They are not quite so fresh as the tuff that occurs in thicker masses; but their volcanic origin is readily observable. One band appears to be made up of the débris of some basic rock like the diabase of the district, through which detached plagioclase crystals are scattered. The lapilli are subangular; and around their border a granular deposit of hæmatite has taken place, giving a red colour to the rock. Another band presents small angular lapilli, almost entirely composed of a substance which to the naked eye, or with a lens, is dull, white, and clay-like, easily scratched, and slightly unctuous to the touch. Under the microscope, with a low power, it becomes pale greyish green and transparent, and is seen to consist in large part of altered felspar crystals, partially kaolinized and partially changed into white mica and calcite. These scattered crystals are true volcanic lapilli, and have not been derived from the mechanical waste of any preexisting volcanic rock. In the tuffs interstratified with the conglomerate, at the quarry above Porth-clais, though much decomposed, crystals of plagioclase can likewise still be traced. These beds are also true tuffs, and not mere detritus due to mechanical degradation.

The general result of this study of the microscopic structure of the tuffs may be briefly summed up as follows:—

1. They are almost wholly composed of fragments of eruptive rocks, sometimes rounded, but usually angular or subangular. In the more granular varieties very little matrix is present; it consists of fine débris of the same materials. No detached microliths occur, such as are common among modern volcanic ashes; but there are abundant ejected crystals. In these respects the Cambrian tuffs are quite like those of the other Palæozoic systems. A mingling of grains of quartz-sand may indicate the intermixture of ordinary with volcanic sediment.

2. They may be divided into two groups—one composed mainly of fragments of diabase or other similar basic rocks, the other of

felsite. The former group may have been derived from the explosion of such rocks as the diabase-sheets of the district. The felsitic tuffs have not been observed to contain any fragments of the microcrystalline quartz porphyries of St. David's. They have been derived from true fine-grained felsites. There are various intermediate varieties, due to the mingling in various proportions of the two kinds of débris.

3. They are marked by the presence of some characteristic features of the volcanic vents of later Palæozoic time, and in particular by presenting the following peculiarities :—(*a*) minutely cellular lapilli with spherical cells; (*b*) lapilli with well-developed fluxion structure; (*c*) lapilli consisting of a pale green serpentinous substance resembling altered palagonite; (*d*) lapilli derived from the destruction of older tuffs; and (*e*) lapilli consisting of ejected crystals, especially of felspars, sometimes entire, frequently broken.

4. They frequently show that they have undergone metamorphism, by the development of a pale greenish micaceous mineral between the lapilli, the change advancing until the fine tuffs occasionally pass into fine silky hydromica schists. To this metamorphism further reference will be made in the sequel.

I was unable to observe any evidence that the basic and siliceous tuffs characterize two distinct periods of vulcanicity. From the foregoing analyses it appears that some of the oldest visible tuffs which are seen between Pen-maen-melyn and Pen-y-foel contain only 48·11 per cent. of silica; a specimen from Porth-lisky yielded 72·63 per cent. of that ingredient. Specimens taken even from adjacent beds show great differences in the percentage of silica, as may be seen in the analyses Nos. III. and V.

This alternation of basic and siliceous fragmental materials has its parallel in the neighbouring eruptive rocks, some of which are olivine diabases containing only 45 per cent. of silica, while others are highly siliceous quartz porphyries. But all the siliceous eruptive rocks, so far as I have been able to discover, are intrusive, and belong, I believe, to a much later period than that of the volcanic group; in no single instance did they appear to me to be true superficial lava-flows. On the other hand, the basic eruptive rocks occur both as contemporaneous sheets and as intrusive masses. The presence of both siliceous and basic lavas in the Cambrian volcanic reservoirs, however, is proved by the character of the tuffs. It would appear that while the basic lavas were most abundant during the volcanic period recorded by the rocks of St. David's, furnishing the material for most of the fragmental eruptions, and pouring out at the surface in streams of molten rock, the siliceous lavas did not flow forth at the surface, but were copiously discharged in the form of dust and lapilli.

The rise of both basic and acid lavas at different periods in the same or adjoining vents, so familiar in recent volcanic phenomena, thus appears to have also characterized some of the oldest examples of volcanic action. An interesting parallel may be traced between the succession of events at St. David's and that which has occurred

in the volcanic group of the Lower Old Red Sandstone of the Pentland Hills, near Edinburgh. In the latter area the volcanic accumulations attain a depth of more than 5000 feet, and are composed of successive sheets of basic lavas, with alternations of felsitic tuffs, in which the proportion of silica ranges between 60 and 70 per cent. Intrusive veins of felsite intersect these tuffs and porphyrites; but no case has there been observed of any such rock having been poured out as a superficial lava-stream.

Though the volcanic group of St. David's consists almost wholly of volcanic materials, the tuffs contain evidence that ordinary sedimentation was not entirely interrupted by the volcanic discharges. Thus, in the Allan valley, west from the Cathedral, one of the schistose tuffs is full of well-rounded pebbles of white quartz. Occasional shaly bands indicate the deposit of mud with the tuffs.

Seams of pale silky schist occur among the tuffs, similar in texture and composition to bands that lie on various horizons among the Cambrian sandstones and shales. These may originally have been fine volcanic dust or mud. One of the most prevalent features, indeed, among the finer varieties of tuff is the development in them of a fine foliation, whereby they pass into silky schists, and might be classed with the sericite schists of metamorphic districts. This structure will be described in connexion with the later changes which the rocks of the district have undergone.

Uppermost Zone of Schists, Shales, Siliceous Bands (*Adinole, Kieselschiefer*).—In the first part of this paper (p. 279) reference has been made to a remarkable band of strata lying between the volcanic group and the quartz conglomerate, and serving, from its peculiar lithological characters, as a convenient, because easily recognizable, horizon for tracing out the structure of the district. It must be considered as part of the volcanic group, but with an admixture of non-volcanic sedimentary material. It probably indicates the resumption of ordinary sedimentation as volcanic action became gradually feebler.

The component rocks of this zone are fine tuffs, passing, on the one hand, into fine grey shales, and, on the other, into pale schists, but occasionally including bands of coarser tuff, seams of quartzose sandstone or quartzite, and abundant siliceous aggregations.

The schists are exceedingly fine, silvery, hydromica schists, unctuous to the touch. They pass into fine tuffs and into shale; indeed, they must be regarded as a metamorphosed condition of beds that were originally fine tuffs and shales. They vary very much in their power of resisting disintegration, some portions standing their ground well, as in Ramsey Sound, other parts decaying into a soft, white, or yellow clay, as at Porth-lisky.

One of the most conspicuous features of this zone in the St. David's district is the remarkable abundance of its siliceous aggregations. The material of which these consist varies considerably in colour, texture, structure, and composition. In some instances it occurs in bands having a finely granular texture like beds of altered shale; in others the bands are flinty and translucent. It

may be observed also in detached nodules and in strings and veins crossing the bedding of the strata.

To this substance various names might be given, according to the varying circumstances under which it is found. Much of it might be classed with the "siliceous schist" or "Kieselschiefer" of the older petrographers; some of it assumes the characters of the "Hornschiefer" found in areas of contact-metamorphism. In other places it resembles the eurites or hälleflintas of regional metamorphic areas. Occasionally it becomes almost sufficiently flinty and translucent to deserve the name of chert. From the analysis kindly made of it for me by M. Renard, some portions answer exactly to Beudant's "adinole"—a term which has been revived by German petrographers. It is obviously not a definite chemical compound, nor has it any uniform microscopic structure. It includes the "hälleflintas" of Dr. Hicks.

To what extent the silica of these aggregations is due to original deposition, is a problem to which I shall recur in the sequel. From the fact that the cherty material ramifies in veins across the bedding, its introduction must certainly, to some extent at least, be later than the deposition of the shales and tuffs which it traverses. I shall be able to show, indeed, when describing it more fully in a later part of this paper, that its appearance has certainly been, in some cases, later than that of the quartz porphyries, and that its production has been connected with the general process of extrusion of the highly silicated rocks of the granite tract.

Lavas of the Volcanic Group.—There remain for notice here the sheets of eruptive rocks that occur among the tuffs. Excluding the granites and porphyries (to which a special section of this paper will be devoted), two kinds of eruptive rocks are associated with the volcanic zone. One of these is certainly intrusive and of late date, viz. dykes and veins of diabase, which will be described in later pages. The other kind occurs in long parallel sheets, some of which, if not all, are true contemporaneous lava-streams, erupted at intervals during the accumulation of the volcanic group. They form prominent crags to the west of St. David's, such as Clegyr Foig, Rhosson, and the rocky ground rising from the eastern shores of Ramsey Sound. Their dip and strike coincide with those of the tuffs above and below them. It is possible that some of these sheets may be intrusive along the bedding of the tuffs; and in one or two cases I observed indications of what, on further and more careful exploration, may prove to be disruption across the bedding.

But it is the interbedded sheets that possess the chief interest as superficial lava-streams of such venerable antiquity. They present many of the ordinary features of true lava-flows. In particular a slaggy structure may be detected at the bottom of a sheet, the vesicles being here and there lengthened in the direction of flow. Some of the sheets are in part amygdaloidal. The alternation of these sheets with tuffs, evidently derived from lavas of similar character, is another argument in favour of their contemporaneous date. One of the best localities for studying these features lies

between Clegyr Foig and the coast, west of Rhosson, where the following section may be observed.

The eruptive rocks thicken towards the south-west, as if the main vents had lain in that direction. There are doubtless intrusive as well as contemporaneously interbedded masses in the rough ground between Pen-maen-melyn and Treginnis. To separate these out would be a most interesting and beautiful piece of mapping for any competent geologist in possession of a good map on a sufficiently large scale.

The interbedded lavas, so far as I have had an opportunity of studying them, appear to present remarkable uniformity of petrographical characters. Macroscopically they are dull, fine-grained to compact, sparingly porphyritic, ranging in colour from an epidote-green to dull blackish-green and dark chocolate-brown. Some of them are finely porphyritic from the presence of small glistening surfaces which present the colour and metallic lustre of hæmatite and yield its characteristic streak. Obviously basic rocks, they present, as I have said, a close resemblance to many of the porphyrites of the Lower Old Red Sandstone and Carboniferous districts of Scotland. So marked is this likeness that Mr. Peach and I at once classed them as porphyrites, so far as their characters could be judged of in the field. Subsequent microscopic study of them, while showing that the resemblance descends even to minute details, has brought to light some features that are seldom seen in the Scottish examples, and has led me to class these rocks with the diabases.

Two of the most conspicuous rocks of this class in the district, those of Rhosson and Clegyr Foig, have been analyzed by Mr. Wilson, with the following results.

Analyses of Diabases from St. David's by Mr. J. S. Grant Wilson.

	Rhosson.	Clegyr Foig.
Silica	45·92	45·38
Alumina	18·16	16·62
Ferric oxide	1·18	4·06
Ferrous oxide	9·27	8·63
Manganous oxide	0·19	0·14
Lime	7·19	8·19
Magnesia	10·07	9·41
Potash	1·78	0·71
Soda	2·12	2·20
Loss on ignition and water	4·22	4·34
Insoluble residue	0·04	0·08
	100·14	99·76
Specific gravity	2·96	2·99

The strikingly basic composition of the rocks is well brought out by these analyses. It may be difficult at first to believe that the specimens were not taken from some modern basalts. That the lavas

of the Cambrian period possessed such a composition, however, is put beyond question by the analyses of the basic tuffs already given; so that it is not necessary to endeavour to discover a late and intrusive origin for the sheets of Rhosson and Clegyr Foig.

I have examined under the microscope thin slices taken from the rock at both the localities just named, also from the crag south of Castell, and from the cliffs at the southern end of the promontory between Ramsey Sound and Pen-y-foel (Plate IX. fig. 4). In all of these the general composition is alike. There is a variable quantity of a base, which under a $\frac{1}{5}$ objective is resolved into ill-defined coalescent globulites and fibre-like bodies, which remain dark when rotated between crossed nicols. In some varieties, as in part of Rhosson Crag, the base is nearly lost in the crowd of crystalline constituents; in others, as in the crag south of Castell, it forms a large part of the whole mass, and may be seen in distinct spaces free from any crystalline particles. Through this base are diffused, in vast numbers, irregularly shaped grains of augite, seldom showing crystalline faces with measurable interfacial angles. These grains, or granules, may perhaps average about 0·003 inch in diameter. Plagioclase is generally hardly to be recognized, though here and there a crystal with characteristic twinning may be detected in the base. Magnetite occurs abundantly—its minute octahedra, with their peculiar colour and lustre, being apparent with reflected light on the fresher specimens, though apt to be lost as diffused ferruginous blotches in the more decomposed varieties. But perhaps the most remarkable ingredient is olivine. I have referred to the red hæmatitic crystals which, even to the naked eye, are visible, dispersed through the ground-mass of these rocks. With a lens these may be observed to be orthorhombic in form and to be evidently pseudomorphs after some mineral which has been converted chiefly into hæmatite. I have often noticed red pseudomorphs (ferrite, as they have been called) in Carboniferous and Old Red Sandstone porphyrites, where in some cases they appear to be after hornblende, and in others after augite, but occasionally are suggestive of olivine, though with no trace of the original substance of that mineral. In the lava associated with the tuffs at the south end of the promontory between Ramsey Sound and Pen-y-foel, however, I find some large, well-developed pseudomorphs, which are certainly after olivine. They have the characteristic contour of that mineral and its peculiar transverse curved and irregular fractures. The average length of these pseudomorphs was found, from the measurement of six examples, to be 0·023 inch, the largest being 0·034, and the smallest 0·014. Seen by transmitted light they present a structureless pale-green material nearly inert in polarized light, round the borders and across fissures in which an opaque substance has been developed, as serpentine has been in the familiar alteration of olivine. The pale-green matter may be the result of a first alteration, subsequently replaced along the borders and across the fissures by the dark substance. With reflected light the latter is found to be bright brick-red. It is evidently chiefly hæmatite. Every stage may be traced,

from orthorhombic forms with the incipient development of transverse fissures filled with hæmatite, to others of distorted shapes in which the ferruginous matter occupies the whole or nearly the whole of the mould of the original crystal.

The rocks now described differ from the Palæozoic porphyrites with which I am acquainted in the less abundance of their microscopic base, in the comparatively inconspicuous development of felspars, and the absence of large porphyritic felspars, in the extraordinary prominence of the augite, and in the presence of olivine. In composition and structure they are essentially forms of olivine diabase.

I cannot pretend at present to offer more than a mere outline-sketch of the petrography of the Cambrian volcanic group of St. David's; but from the data here brought forward it will, I think, be apparent that the rocks of that group possess exceptional interest from the extraordinary combination of modern types of structure with so remote an antiquity.

2. *The Quartz Conglomerate.*

The lithological characters of this band and its stratigraphical relations to the beds beneath it have been sufficiently described in Part I. (p. 286). It is essentially a mass of rolled pebbles of quartzite and quartz, imbedded in a reddish ferruginous and quartzose matrix. The pebbles vary up to occasional blocks as large as a man's head or larger; but their average size is probably less than that of a walnut. The conglomerate band continues as a persistent and easily recognizable horizon through the St. David's district, but presents noticeable variations in thickness and in coarseness of materials. The pebbly beds are lenticular, rapidly wedging out and passing into fine grit and sandstone. In some places the total thickness of the band dwindles down to possibly not more than two or three feet; in others, as on the south-east of St. David's, it swells out to more than one hundred feet. I have alluded in the first part of this paper to the perfect conformability of the conglomerate with the top of the volcanic group, and to the intercalation of bands of tuff in it (fig. 8, p. 290). These facts prove that no abrupt break can be traced between the volcanic group and the conglomerate. I have also referred to the presence of occasional seams of rolled quartz pebbles in the tuffs, as indicating that the conditions of deposit to which the conglomerate was due had begun to appear even during the volcanic period. It is obvious, however, that the intercalation of the marked band of quartz conglomerate points to an important change in the sedimentation of the time. It suggests some interesting questions of general interest, to which reference may here be made.

There can be no doubt that conglomerates frequently mark the natural base of a series of sedimentary deposits. They do so more especially where they are formed of materials that have had an obviously local origin, and where they rest unconformably on the

rocks below, from the waste of which they may have been mainly derived. In such cases they must be regarded as littoral deposits; and in this respect they possess importance from the light they throw on former geographical conditions. But it is equally certain that pebble-beds and conglomerates have again and again been intercalated, without discordance of any kind, in the midst of a continuous and strictly conformable series of sandy and even of muddy and calcareous deposits, often marked throughout by a community of fossil contents. In such positions they may possess local value as stratigraphical horizons, but they evidently cannot be regarded as marking important geological breaks in the succession either of formations or of organic remains. Under these conditions they present certain common features that recur over and over again throughout the stratified formations of the earth's crust. Unlike the basal conglomerates just referred to, they are composed of well waterworn pebbles, for the most part comparatively small in size, derived from some distant and, in many cases, unknown source, and consisting usually of quartz, quartzite, or other exceptionally durable rocks.

These features are characteristically displayed in the conglomerate of St. David's, which is the earliest of the British examples yet known. A long list of similar intercalated pebbly bands might be drawn up from all the later geological systems down to the shingle beds of the present sea-bottom; but a few examples may be cited in illustration*.

The Lower Silurian rocks of Anglesey contain bands of conglomerate made up of pebbles of quartzite, sometimes from 6 to 8 inches in diameter, and mostly well rounded†. Conglomerates of quartz and black slate occur high up in the Skiddaw Slates‡. Conglomerate bands of white quartzite and vein-quartz occur in the "Plynlimmon Group" of Central Wales§.

In the Old Red Sandstone, bands of quartz conglomerate appear on many different horizons. One of the most striking examples is the coarse and thick mass that comes in conformably above the fine Ludlow shales and mudstones of Lanark and Ayrshire.

In the Carboniferous system lines of quartz conglomerate occur on many platforms. The Carboniferous Limestone contains excellent examples in the north of England, hundreds of feet above the base of the formation. The Millstone Grit affords a familiar illustration; and occasional instances occur in the Coal-measures.

The Bunter pebble-beds, composed of white and liver-coloured quartz, are notable examples of the occurrence of conformable conglomerates in a continuous series of sediments, with occasional

* I am indebted to Mr. W. Topley for kindly furnishing me with most of the references in the list given above, which have been supplied from the field-notes of my colleagues in the Survey, Messrs. Bristow, Whitaker, H. B. Woodward, Goodchild, De Rance, Ussher, and Strahan.

† Ramsay, Geology of North Wales (Geol. Surv. Mem. vol. iii.), 2nd edit. p. 247

‡ J. C. Ward, Geol. Mag. dec. 2, vol. vi. p. 51.

§ W. Keeping, Quart. Journ. Geol. Soc. vol. xxxvii. p. 156.

illustrations of contemporaneous erosion. The Budleigh-Salterton pebble-bed and its continuation through the middle of the Triassic system is another well-known case.

In the Jurassic series of Yorkshire examples of intercalated conglomerate have been noted *.

The conglomerates of the Weald generally occur near the top of the sandstone beds and are succeeded by shales †. The conglomerates of Faringdon and Godalming &c. exhibit similar phenomena in the Neocomian series.

Of the Tertiary illustrations I need refer only to the pebble-beds of the London basin ‡, and the thick shingle-accumulations of the Marine Series of Bournemouth §.

Every geologist who has studied the subject in the field must be familiar with the way in which the same far-transported pebbles have been used over and over again in successive formations. In some cases, as, for example, in the later conglomerates of the Isle of Arran, it is possible to distinguish the freshly derived fragments from those that had already done duty in an earlier conglomerate.

It is evident, then, that the intercalation of a conglomerate band in the midst of a continuous series of sediments has been of frequent occurrence in the geological past. Sometimes no change has taken place in the general character of the sedimentation after the conglomerate was deposited; in other cases the sediment laid down above the conglomerate differs in composition or texture, or in both, from that which lies below. We may infer from these facts that the occurrence of a pebbly zone in a conformable series of strata, need have no more geological significance than the shifting shingle banks on the bed of the English Channel at the present day. Undoubtedly such a band of conglomerate points to a change in the system of currents by which sediment was transported, the change sometimes giving way to the former conditions, sometimes introducing new ones; but it furnishes no sufficient ground for an important stratigraphical boundary line.

3. *Zone of Green and Red Shales, Sandstones and fine Tuffs.*

This zone is chiefly important because it offers well-marked lithological characters, capable of being employed in working out the stratigraphical succession and general structure of the district. In mapping the ground, indeed, Mr. Peach and I found it convenient to distinguish two bands in this zone, viz. a lower set of green, and an upper set of red beds. But the line of demarcation is not always sharply defined between them, though they can be readily observed in their respective positions on both sides of the axis. They are

* C. Fox Strangways and G. Barrow, Mem. Geol. Survey, 'Geology of Whitby and Scarborough,' p. 38.

† W. Topley, Mem. Geol. Survey, 'Geology of the Weald,' pp. 56, 59, 64, &c.

‡ W. Whitaker, Mem. Geol. Survey, vol. iv. 'Geology of the London Basin,' pp. 207, 222–224, 233.

§ J. S. Gardner, Quart. Journ. Geol. Soc. vol. xxxv. p. 215.

specially well developed and marked off from each other on the coast-line south of St. David's. They may also be studied at Castell, on Ramsey Sound.

One of the most interesting lithological features in these strata is the presence in them of diffused volcanic dust and of layers of fine tuff. Some of the red shales are full of this material, which here and there is gathered into the thin seams or ribs of which the microscopic characters have already been described. This diffused volcanic detritus marks, no doubt, the enfeebled discharges of fine dust towards the close of the volcanic episode in the Lower Cambrian period at St. David's. It would be difficult to find an instance of a more perfect transition from a series of thoroughly volcanic masses into a series of ordinary mechanical sediments.

It is further to be noted that in this zone, as discovered by Dr. Hicks, well-preserved specimens of *Lingulella primæva* occur* There can, therefore, be no doubt as to the place of the strata in the geological record. The red sandstones and shales pass up insensibly into a thick overlying mass of fossiliferous purple and green sandstone, assigned by Dr. Hicks to the Harlech Group. It is not needful here to pursue further the upward stratigraphical succession.

2. Geological Structure of the District.

The existence of an anticlinal axis in the Cambrian beds at St. David's is indicated upon the Geological Survey Map, which does not, however, distinguish the different zones of rock in such a way as to show the line of axis, or to afford data for measuring the thickness of the beds. As I have already pointed out, there is not only a great arch of the strata here, but the south-eastern half of the arch has been inverted. As the determination of this isoclinal fold is a point of fundamental importance in the structure of the district, some further details regarding it may here be given (see figs. 1 & 2, p. 268).

On the west side of the district the succession of beds can be followed from the headland of Point St. John without interruption, along the shores of Ramsey Sound, for about a mile south-eastward. The strata of sandstone and shale, traversed here and there by eruptive rocks, dip in a general north-westerly direction. Hence there is a steadily descending section until near Castell, where the shore trends toward the south-west, and coincides with the general direction of the strike of the beds. Whether we follow the coast-line round into Porth-lisky, or strike inland across the promontory to that bay, we encounter a thick series of tuffs (with bands of diabase and occasional intrusive elvans or veins of quartz porphyry) presenting the same general dip towards W.N.W. or N.W. The angles of inclination are generally high, though here and there they fall as low as 40° or even less.

No one visiting this section for the first time would suspect that one half of it is only a repetition of the other half; but when the

* Quart. Journ. Geol. Soc. vol. xxxi. p. 168.

same zones can be recognized on each side of the promontory the existence and nature of the fold are made apparent. We need not look, indeed, for more than a general agreement in the repetition of the volcanic part of the Section. Volcanic accumulations are so characteristically inconstant that the series on each side of the fold might quite well be entirely different. The coarse tuffs and breccias were doubtless thrown up in heaps round the vents from which they were discharged. The lavas must have formed submarine banks or reefs of but limited extent. Not only, therefore, might we expect that the succession of volcanic masses on one side of the axis would differ from that on the other, but there might very well be local overlaps of the conglomerate upon the irregularities of the volcanic masses. West of Treginnis-uchaf, where the prolongation of the Rhosson diabase reaches the shore, there seems to be an instance of this kind, the conglomerate ending against the diabase bank on one side but reappearing on the other. Such a structure, however, is obviously quite different from an unconformability. Even at the locality just referred to the conglomerate is succeeded by fine volcanic tuff, showing that, though the conditions of sedimentation had considerably changed, volcanic action still continued.

Even in the volcanic group, however, some leading features are repeated on either side of the fold. The Pen-maen-melyn lavas reappear, though in diminished proportion, on the east side near Pen-y-foel. The diabase sheet at Rhosson may be the same as that of Clegyr Foig. The Porth-lisky schists are partially exposed on the coast of Ramsey Sound at Ogfeydd-duon; and the conglomerate with its overlying groups is easily traced on either side of the fold *.

Various eruptive masses have been protruded through the stratified rocks. It is possible, as I have already suggested, that some of the diabase sheets in the volcanic group may be intrusive; but if so, they must still, no doubt, be classed as belonging to the volcanic period, like the intrusive rocks associated with the contemporaneous volcanic series in the Carboniferous system of Central Scotland.

Of much later date are the granite and quartz-porphyries. For reasons to be afterwards given I class these two groups of highly silicated rocks together. A reference to the Map (Pl. VIII. p. 268) will show that the granite has risen through the eastern limb of the isocline, considerably disturbing the symmetry of the structure. In a general sense the longer axis of the granite mass corresponds with the domi-

* The repetition of the same petrographical character has been admitted by Dr. Hicks himself, as may be seen in the sections published by him in his paper of May 1878 (Quart. Journ. Geol. Soc. vol. xxxiv. p. 166). In Nos. 1 and 2 of these sections subdivisions 1, 2, 3, 4, 5 and 6 are described in nearly the same words as subdivisions 8, 10 and 11. It is interesting to find that he makes the Cambrian conglomerate to be underlain by the same succession of beds at Llanhowell and Caerbwdy, though those localities are upwards of three miles apart. This would hardly be likely to occur were there an unconformability between the conglomerate and the rocks below it. [At the reading of this paper Mr. Peach exhibited Dr. Hicks's section, coloured in accordance with what we believe to be the true structure of the ground; and he showed how entirely that section is explicable on the idea of an inverted anticline.]

nant strike of the stratified rocks without strictly conforming to it. I have shown how the granite cuts into successive zones of the Cambrian series, until it invades the group of greenish sandstones and shales lying above the conglomerate. The most serious disturbance of the regularity of the beds on the south-eastern side of the fold occurs in the Allan valley between Rhoscribed and Porthclais. There appears to be a minor plication between the two projections of granite, as expressed on fig. 1, p. 268. Beyond this local disturbance the strata can be followed eastward until the reversed dip of the isocline changes to vertical; and the beds rapidly lessen in inclination as group after group of the Lower Cambrian series appears in normal order.

The St. David's area is one of the numerous tracts of Pembrokeshire where eruptive masses have risen in a general north-east and south-west direction parallel with the principal stratified rocks. Round the granite are grouped various quartz porphyries; and similar rocks probably continue to rise in detached bosses or dykes along the same line of extravasation towards the north-east.

From the way in which the granite and porphyries traverse the stratified rocks, it may be confidently inferred that they are of later date than the general plication. At the same time there is evidence of movement subsequent to the intrusion of these rocks; for slickensurfaces may often be noticed on their joints.

In the first part of this paper I have admitted that minor local displacements may have occurred here and there along the edge of the granite; but they do not in any way affect the general geological structure of the district. That no large or important faults occur is made quite certain by the remarkably clear coast-section, and by the evidence of the transverse valley of the Allan river, in which, in spite of the intrusion of the granite, the normal succession of beds can be distinctly recognized. If, indeed, the granite could be eliminated from the district, the various groups of strata on either side of it would close up into their usual order.

The latest rocks are the dykes of diabase, by which all the others are traversed. These show occasionally a kind of cleavage or fine-jointing, which may perhaps point to renewed lateral pressure after their extrusion.

Cleavage was not observed to characterize the stratified rocks, though we noticed a few feeble examples of it. But the fine foliation already referred to is conspicuous in the volcanic group and on several horizons in the groups overlying the conglomerate. To this structure I shall devote a separate section of the paper.

3. The Foliation of the District.

A fine foliation, arising from the development of micaceous minerals along the planes of stratification, has been extensively developed in the volcanic group, and likewise in the groups of ordinary sedimentary strata overlying the conglomerate. It has affected many of the fine tuffs, the paste of certain coarser tuffs, and some of the

shales. Where it occurs, the rock is usually pale apple-green to pearl-grey, but occasionally of a pinkish tint, with a silky lustre, soapy feel, and finely schistose texture. These characters have been developed here and there along particular lines or in certain bands of rock, the beds above and below exhibiting no appreciable trace of them. A specimen taken from one of the foliated beds might be supposed to have come from the sericite schists, or fine hydro-mica schists of a district in which regional metamorphism has been well and widely developed. Yet the beds immediately above and below are ordinary tuffs, shales, or sandstones.

I have had thin slices prepared from specimens collected from different horizons, to show various stages in the development of this foliation (Pl. IX. figs. 5 & 6). Some of these are from the section on the road-side north from the St. David's Schools; others from the schists at Porth-lisky and from the same group at Ogfeydd-duon on Ramsey Sound. Others, illustrating the alteration of the beds above the conglomerate, were taken from schistose bands among the ordinary strata at Porth-seli; at the Life-boat House, Porth Stinian; and at Porth Cadnaw, a little south from St. John's Point. I can offer, at present, only the general results of a first study of these slides; but the examination has convinced me that the district is one from which a more exhaustive research could not fail to derive much fresh insight into the early stages of regional metamorphism.

The original clastic character of the rocks is still everywhere traceable, but is less distinct among the lower and older portions of the series. This probably arises from the original mineral constitution and state of aggregation of the fine fragmentary materials, rather than from relative age and depth. The base of the schists appears, under the microscope, as a felted aggregate mainly composed of minute scales of a nearly colourless mica. These scales are grouped linearly along the planes of foliation, which coincide in general direction with those of bedding. They wrap round the clastic granules, and are not unfrequently interlaced into short folia. The mineral thus developed in the process of foliation is doubtless one of the hydrous micas, so frequently observable in the metamorphic schists; it may be sericite. Next in abundance to it is an opaque granular substance with no recognizable crystalline form, which has, as it were, been pushed aside by the crystallization of the mica, and is disposed in lenticular and coalescent folia along the general planes of foliation. It is the presence of these sharply defined streaks of black dust which gives so much precision to the line of foliation in many of the slides. Another mineral of secondary or metamorphic origin is bright green, fibrous, and granular, tufted or vermicular. From these characters and its behaviour in polarized light, I have little doubt that it is chlorite. It occurs in oval or eye-like nests, but occasionally is prolonged into folia, and sometimes takes the place of the nearly colourless mica. Its fibres are usually disposed transversely to the longer axis of the aggregates. In one slide (Ogfeydd-duon) abundant crystals of pyrites have been developed along some of the folia; in another (Life-boat House), minute

grains of what appears to be magnetite are dispersed through the base.

Of the clastic fragments still recognizable, quartz is most conspicuous. It presents the usual characters of sand-grains, with lines of fluid inclusions. These grains usually show sharp borders.

Among the schists of the volcanic group there occur small fragments of felsite, with less sharply defined margins, which I cannot doubt were originally volcanic lapilli. I conjecture also that the ovoid aggregates of chlorite may represent the augite and olivine of the more basic fragments. The schists, it will be remembered, are interstratified among tuffs in which felsite and porphyrite lapilli are quite distinct.

The schists intercalated among the sandstones and shales above the conglomerate, present essentially the same structure and the same ingredients as those among the tuffs below. So close, indeed, is the resemblance, that I am inclined to look upon these schists as having been originally fine tuffs. They contain, as might be supposed, a larger proportion of quartz-sand; but their sericitic constituent is well developed.

One further microscopic character may be referred to. A slide taken from a band of fine schist, among the tuffs beyond the bridge over the Allan to the north of the Board Schools, shows an incipient crumpling of the folia (Pl. X. fig. 7). Some of the lines of black dust are bent back upon themselves in the way so familiar in mica schist and gneiss. Instances also occur where a similar crumpling is presented by the sericite and chlorite.

There cannot, I think, be any hesitation in affirming that the foliation of these fine schists has had nothing whatever to do with the protrusion of the granite and quartz porphyries. It is not specially developed near these rocks, and, on the other hand, is admirably exhibited at a distance from them. I am inclined to believe that not only is the foliation independent of the eruptive rocks, but it took place long before their protrusion. It was probably connected with plication, as appears to have been so generally the case in areas where rocks have been subject to this kind of metamorphism. The eruptive rocks themselves show no trace of foliation; but they could hardly have escaped this change had they already been in position when the schistose structure was being superinduced upon the adjoining strata.

What renders the foliation of the St. David's area so interesting is its feeble development, and its singularly sporadic and almost capricious distribution. In many places one cannot always decide whether to regard a given rock as a true foliated schist or simply as a shale. The same part of a group is shaly at one locality and schistose at another. Some strata seem to have been able to resist the change throughout the district; the red shales above the conglomerate, for example, remain true shales, though some of the bands of tuff intercalated in them show faint foliation. Others, again, have been prone to change. This appears to have been particularly the case with some kinds of fine volcanic débris. The microscopic

examination suggests, indeed, that all the schists were originally tuffs. The green and grey shales lying below and above the conglomerate, which include such excellent examples of fine silky schists, were not improbably derived in large measure from fine volcanic sediment.

My second visit to St. David's was especially intended to obtain further data regarding this question. But I am not yet able to throw much light upon it. There can, I think, be no doubt that, in so far as the production of a true foliated structure depended upon the operation of influences entirely outside of the rocks themselves, closely adjacent strata must have been under practically the same conditions. The pressure, tension, and temperature can hardly have sensibly differed in contiguous rocks. If, therefore, all the rocks were subjected to the same processes, any resulting differences in their present aspect and structure must, I should imagine, be due to some original variety in the chemical composition and physical structure of the rocks themselves. Certain layers or particular kinds of fine detritus, more especially some of the finely comminuted volcanic dust, have been specially susceptible of change along the planes of deposit; and sericite, chlorite, pyrites, and magnetite have been developed along those planes, so as to produce a marked foliation.

In the St. David's district we seem to stand in presence of some of the initial stages of that still mysterious process by which wide regions of sedimentary strata have been changed into crystalline schists.

4. The Granite, Quartz Porphyry, and accompanying Metamorphism.

In the first part of this paper sufficient evidence has been adduced to show that at St. David's a central boss of eruptive granite, with associated peripheral dykes, elvans, or amorphous intrusions of quartz porphyry, has been protruded through the Cambrian strata. I purpose now to supplement that evidence by discussing more fully the structure and relations of the eruptive rocks, and the influence they have exerted upon the stratified formations through which they have arisen.

The granite, as has been already shown, lies on the eastern limb of the isocline, where it invades the various rock groups up to the zone of green shales and sandstones that lies some way above the quartz conglomerate. The porphyries are grouped round the central boss of granite, and appear to be intimately connected with it, like the elvans of granite districts. I shall first describe the petrographical characters of these rocks, and then give some account of the metamorphism associated with them.

Of the granite I have had a good series of thin slices prepared from characteristic specimens taken from all parts of the district, and have subjected them to microscopic examination (Plate X. fig. 11). To the descriptions already given by Prof. Bonney, Mr. Davies,

and Mr. Tawney I have but little to add regarding the structure of the mass in its central typical portions. It is a thoroughly crystallized compound, with the distinctive micropegmatite structure of a true granite. The quartz is specially abundant in some places, and always presents the characteristic forms of this mineral in granite. The felspars are all more or less kaolinized; striated forms may be detected among the more predominant orthoclase; while here and there a little microcline (a species so characteristic of granite) may be observed. In none of my slides have I found any mica; but in all of them there is an abundant bright grass-green mineral, often in tufts and vermicular aggregates. Most of this green constituent appears to be chlorite. Nests of epidote may also be detected, some of it possibly replacing original mica. The presence of chlorite and epidote, and the turbid condition of the felspars prove the rock to have undergone considerable alteration.

The microscopic structure of the rock remains tolerably uniform. Towards the margin of the mass, however, the texture is apt to become finer-grained, though this change is not always observable. At Porth-lisky, where the greater closeness of grain in the marginal parts is well seen, portions of the rock assume a structure approaching that of graphic granite, and are much veined with calcite. It is here that the bands of sparry carbonates described by Dr. Hicks occur. His so-called "quartz schists" are likewise portions of the graphic condition of the granite*.

In the course of my study of crystalline rocks in the field, I have never met with the graphic structure except in veins. If the beach could be quite laid bare at Porth-lisky, it is probable that the graphic structure there visible might be found to belong really to veins connected with the main mass of the granite.

The same graphic structure is well displayed in the veins of lighter, finer-grained granite, or segregation-veins which traverse the main mass in so many places. These veins (known to German geologists by the glass-makers' term "Schlieren,"—threads or ribbons) are quite distinctive of granite, and do not occur among gneisses and schists. Their presence in the rock of St. David's is, in itself, sufficient to prove that rock to be an eruptive granite.

At the northern end of the ridge the granite is succeeded by masses of quartz porphyry. No continuous section can here be traced; but there are numerous exposures of rock between Bryn-y-garn and the valley near the cathedral. At Bryn-y-garn itself, the granite appears in its most typical form. A little to the north, at Rock House, what appears to the naked eye as an extremely small-grained granite, approaching to felsite, can be seen. At the bottom of the slope, on the roadside leading south-westwards from St. David's, a rock with still closer texture may be observed.

A series of thin slices prepared from these rocks leaves no doubt on my mind that there is here a transition from the granite of the

* Quart. Journ. Geol. Soc. vol. xxxiv. p. 154. Professor Bonney observed the graphic structure in these rocks, though he was disposed to consider them as of metamorphic origin

ridge into microcrystalline and spherulitic porphyry. The rock seen at Rock House is granitic in texture, and consists of the same minerals as the adjacent granite of Bryn-y-garn, but in smaller forms. The quartz and felspar, in a kind of granular micropegmatitic intermixture, constitute nearly the whole mass; but the chlorite is also present in tufted bright green aggregates. The rock on the roadside is still more finely crystalline. It forms a stage between granite and true felsite. Its ground-mass presents a microcrystalline aggregate of quartz and felspar, similar to that of the Church-School quarries, through which also spherulites are distributed. The same chloritic constituent so characteristic of the granite, is still recognizable here. Short of an actual section showing the gradations of the one rock into the other, I do not think that better evidence could be found that the granite is directly connected with the porphyries that lie along its border.

This intimate relationship is further illustrated by a study of the minute structure of the porphyries. Some of these rocks have been described in Dr. Hicks's papers by Professor Judd and Mr. Davies, and elsewhere by Mr. Tawney. Mr. Davies has shown the thoroughly crystalline nature of the ground-mass of the rock at the Church-School quarries. My observations not only confirm his description, but extend it to all the porphyry masses of the district. In none of them have I noticed any true felsitic base, though this may yet be found. Their ground-mass, between the spherulites to be immediately referred to, is entirely microcrystalline, and is resolvable into a granular intermixture of quartz and orthoclase. The rocks are quartz porphyries, but with a remarkable development of spherulites, which, following Vogelsang's terminology, are felso-spherulites. This spherulitic structure has been developed in altogether exceptional perfection and beauty (Plate X. fig. 9)—so much so, indeed, that the spherulitic quartz porphyries of St. David's are no doubt destined to become as classical examples of this structure, and as much sought after for collections of microscopic petrography, as the pitchstone of Arran now is for its microliths. They have been well described by Mr. Davies as they occur in the Church-School quarries *. He has pointed out the want of peripheral definition of the spherulites in the rock at that locality, the absence in them of a central nucleus, and their tendency to group themselves around the quartz and felspar crystals. Instances, however, of sharp borders to the spherulites may be found in this rock, and still more conspicuously in the mass exposed at the centre of the cove below Nun's Chapel. The rock at the latter locality is finely spherulitic, the spherulites having a distinct dark border, and many of them standing isolated in the base. Though the base is somewhat decomposed, the spherulites are still tolerably fresh, and react in the usual way on polarized light, giving a distinct black cross between crossed prisms (Plate X. fig. 10).

The development of these spherulites is one of the problems which will require a more exhaustive study of the St. David's rocks, and the solution of which can hardly fail to throw light on the relations

* Quart. Journ. Geol. Soc. vol. xxxiv p. 164, xxv p 293.

between granite and lava-form rocks. I may observe in connexion with this subject, that while microcrystalline structure appears to run through all the porphyries, spherulites are not always present. In the dyke or elvan of Nun's Chapel, for example, while some portions of the mass are spherulitic, others are merely microcrystalline. The spherulitic structure, however, appears to be only exceptionally absent. It occurs not only in large elvans, like those of Nun's Chapel and the Church-School quarries, but even in small veins, such as that which traverses the agglomerate on Clegyr Hill and that which cuts across the tuffs near Pen-y-foel.

To the porphyries a distinctly porphyritic structure is given by the presence in them of abundant macroscopic quartz blebs or crystals. These are sometimes dihexahedral, usually with somewhat blunted angles; but they also assume irregular rounded forms, occasionally enclosing portions of the base. Porphyritic crystals of plagioclase are common in many of the rocks.

Some portions of the porphyries where these quartzes and felspars do not appear might be classed as felsites on a cursory inspection. But they all possess the microcrystalline ground-mass. They cannot be confounded with the felsites of which fragments occur in the tuffs.

Traces of fluxion-structure are discernible in the elvan of Nun's Chapel. The shales at that locality have been invaded by intrusive veins and bands of a rock now much decomposed, but which appears to have been a quartz porphyry. It consists of a decayed ground-mass with much diffused brown matter disposed in lines that sweep round the abundant large quartzes. If it was connected with the adjoining elvan it may show a further stage towards the development of a felsitic rock. But though I have had several slices made from my specimens, they show a rock rather too much decayed to warrant any deductions from them until better examples have been procured.

Proceeding now from their petrographical to their geotectonic characters, I have to remark that the porphyries occur as bosses, elvans, or veins cutting through all horizons of the volcanic group, and in one case apparently, if not actually, reaching the quartz conglomerate. One of the best exposures of this intrusive character may be seen in the cliff below Nun's Chapel, where the elvan, already so often referred to, runs along the face of the cliff through the uppermost zone of the volcanic group. On the whole its direction is parallel with the strike of the beds. That it is not strictly so, but that the porphyry cuts irregularly through the strata, is well shown at many places*. On one conspicuous precipice the porphyry mass has a thickness of from forty to fifty feet, and lies at an angle of 35°, cutting through the strata, which are inclined, with reversed dip to the northward or towards the land, at from 65° to 70°.

Apparently in connexion with this dyke a network of intrusions of the peculiar decomposed quartz porphyry above referred to may be observed in the shales along the face of the cliff immediately below Nun's Chapel. On the whole the intruded material has forced its

* Dr. Hicks has figured this intrusive mass (Quart. Journ. Geol. Soc. vol. xxxiii. p. 236).

way along the bedding-planes of the shales, but has also broken across them, sending out finger-like branches. At first I took the rock for a tuff; and it was not until I noticed that it was porphyritic with quartz, and that it intersected the shales, that I recognized its true character. Some portions are veined with, and contain lenticular seams of the siliceous substance to be immediately described, in which may be detected the doubly terminated quartz and the felspar crystals of the rock.

The association of quartz porphyry with granite is so familiar a fact as to need no further comment here. I would only add that in the granite district of Criffel and Galway there are masses of quartz porphyry presenting the closest resemblance to those of St. David's. Like the granite with which they are connected, they have risen through Lower Silurian strata.

I now come to the metamorphism that has attended the intrusion of the granite and porphyries. The district of St. David's is too limited in extent to furnish data for a full discussion of this subject. The facts there attainable ought to be extended by observations of the line of junction of the eruptive and sedimentary rocks in the rest of Pembrokeshire. I would therefore at present offer only such a slight sketch as the material in my possession seems to warrant.

The metamorphism traceable near the granite and quartz porphyries appears to consist partly in induration due to the introduction of new mineral matter, notably silica, into the strata, partly in the development of crystals or a crystalline rearrangement of the materials of the adjacent rocks.

In dealing with the amount of change superinduced upon stratified masses by granite which has been intruded into them, we have two factors in the question to consider—the petrographical structure and composition of the rocks affected, and the character and particularly the bulk of the eruptive mass. In regard to the first of these two points I may remark that quartz and quartzose rocks present little scope for metamorphic action. Secondary quartz may be deposited in their fissures, or between their particles; but unless they contain some silicate or other mineral matter which may be susceptible of recomposition and recrystallization, they may show no further change than mere induration from introduced silica, or from the solution and recementing of their component grains.

With respect to the part played by the granite, it must be remembered that marked metamorphism does not always accompany intrusions of this rock *. If the mass of granite be small, there may be

* In this country examples may be found where little or no alteration is perceptible round the margin of the granite that has undoubtedly been erupted through the adjoining strata. Round the smaller granite bosses of Galloway this is observable among the more quartzose greywackes. The granite of Arran, though so large a mass, only slightly affects the surrounding rocks. On the continent numerous instances have been observed where no contact-metamorphism occurs round truly eruptive granite. My friend M. Renard has kindly supplied me with the following illustrations:—Petschau in Bohemia, where the contact of granite and shale is as sharp as if cut with a knife; Greifenheim; Ile de Michau (Côtes du Nord); banks of the Irtisch.

no distinct metamorphism at all. But even a large mass may produce little alteration. There seems to be some relation between the mineral constitution of the granite and the nature and amount of the metamorphism which it may superinduce *.

The importance of noting these two conditions of the problem is well shown at St. David's. The granite mass there is but of small dimensions, and it is where it narrows into minor projections that its contact with the adjacent rock is chiefly exposed. These are precisely the circumstances under which only a feeble degree of metamorphism might be expected. On the other hand, where the rocks next the granite have not been much decomposed, they are found to be quartz conglomerate, or quartzose grit, in which little or no trace of alteration need be looked for.

The best natural section for noting the alteration produced by the granite is that exposed on the cliff at Ogof-llesugn. The conglomerate has there been indurated into the consistency of quartzite, breaking readily across the pebbles. The grits in the Allan valley have been similarly affected, but in a less degree. Microscopic preparations of these rocks show a structure like that of the quartzites of the Highlands. The quartz grains and pebbles have suffered no apparent change, except that in some places they have been much fractured. A deposit of secondary quartz may be observed running in veins through the rock. Where the pebbles have been fractured, disrupted portions are imbedded in a matrix in which, besides crystalline quartz, an indistinctly fibrous substance occurs, which may be chalcedony.

The shales and fine grit near the granite at Porth-clais are beautifully foliated, lines of the bright-green chloritic ingredient already referred to being especially prominent between the bands of quartz-grains. But, for reasons already given, I believe that this foliation has not resulted from the influence of the granite. At the same time there may be room for inquiry whether the effect of the granite may not have been to set up a new foliation, which, where it coincided in direction with the first, might intensify it.

From a specimen of fine shale or schist taken from near the granite on the right bank of the river, I have had several slices prepared. In these the first foliation is excellently shown; but the folia have been ruptured and shifted by, as it were, a series of closely parallel faults, along which a new but more feeble foliation has been developed by the production of a fine white mica (Plate X. fig. 8).

The alteration round the granite appears not to extend many yards away from the eruptive rock; but the sections are few and limited in extent; and in some places, owing to small local slips, the strata now abutting on the granite may have been originally at some little distance from it. In the case of the porphyries, however, the sections are far more numerous and extensive. The metamorphism associated with these rocks is also more marked. It consists

* Professor Zirkel informs me that in his experience granites with white mica alter the surrounding rocks little, or not at all, and that it is the granites with black mica that produce most of the metamorphism.

in a partial bleaching of the rocks, in their induration into a flinty substance, and in the development of a microcrystalline structure in them. This alteration has been effected partly along the planes of bedding, and partly across them. The feeblest degree of change is marked by a slight induration of the shale or grit, the clastic nature of the rock being still obvious. From this condition successive stages may be traced until the rock appears in milk-white, flint-like masses, homogeneous, translucent, and breaking with a splintery to conchoidal fracture.

These changes are most conspicuously seen in the uppermost zone of the volcanic group, but are not confined to it. They appear wherever the porphyries have invaded the rocks. The best locality for their study is the coast-section at Nun's Chapel, where they attain a remarkable development in the zone of fine tuffs and shales below the quartz conglomerate. They are shown also among the corresponding strata at Ogfeydd-duon, on Ramsey sound. At first the latter locality seemed to be an exception to the rule that this kind of metamorphism is connected with the protrusion of the quartz porphyries; but, searching the ground in the neighbourhood, I afterwards found the prominent and massive porphyry crags of Treginnis. On a lower horizon the alteration has been well developed in the agglomerate of Clegyr, where also there are intrusive dykes of spherulitic porphyry. And, on a still lower platform, similar induration accompanies the quartziferous porphyry of the Board Schools. From the published descriptions, the association of highly siliceous bands (porcellanite, hälleflinta, kieselschiefer, adinole, or whatever they may be called) with masses of felsite and quartz porphyry would appear to be of common occurrence in Wales.

The sections that exhibit most clearly the metamorphism associated with the porphyries are those which have been cut by the sea along the coast from Nun's Chapel eastward. In the first stages of change the shales are indurated, begin to lose the distinctness of their bedding, and break with a splintery fracture. Gradually they become feebly translucent on the edge, like the porcellanite or kieselschiefer of contact metamorphism. The granular texture passes into one like that of hornstone, and the edges become more translucent, until, losing by degrees all obvious trace of clastic structure, the rock presents a translucency, fracture, and lustre like those of flint or chert. The colours of these various conditions of the siliceous material range through shades of dirty grey and bluish and greenish grey to milky white. The alteration having been developed more particularly along the bedding of the strata, the indurated layers appear mostly as bands interstratified with the schists, shales, or tuffs. So evenly, indeed, are these layers interposed that they may readily be regarded as original deposits, formed contemporaneously with the strata among which they lie. They vary from thin laminæ to bands a foot or more in thickness. Some of them are regularly banded in alternate layers of more granular and more flinty texture. It is deserving of remark that, owing to the tilted position of the beds, the indurated bands are usually highly inclined or vertical, presenting occasionally

a resemblance to mineral veins. Traced along the strike, they are found to be lenticular walls imbedded in and shading off into shales and fine tuffs.

The material composing these vertical bands occurs likewise in nodules or concretions varying from the size of a pin's to that of a man's head or larger. These are particularly abundant in a bed of grey shale, the laminæ of which bend round them, as if nodules of some kind had lain there when the sediment was being deposited. A gradation in size and in development seems to be traceable among these included masses. In some cases they are represented by cavities lined with limonite. In proportion as they increase in size they grow more flinty in texture, until they assume the same pale milk-white translucent character found among the bedded masses. One of the concretions which M. Renard has kindly analyzed for me has the subjoined composition.

Analysis of Concretion (Adinole) Nun's Chapel, St. David's.
By M. Renard.

SiO_2	78·62
Al_2O_3	13·67
Fe_2O_3	1·22
MnO	trace.
MgO	trace.
CaO	0·30
K_2O	0·26
Na_2O	5·80
Loss	0·63
	100·50

The layer of shale next one of the thick bands, or round a concretion, is frequently dull, dark green in colour, and compact in texture, so that on a wet face of rock the contrast between it and the adjoining pale indurated substance is well marked.

There is still a third form in which the same cherty material occurs. It may be seen ramifying through the shales in strings and winding veins, that strike across the stratification of the surrounding beds. It is there welded, as it were, into the shale, the laminæ of which pass into it. Faint lines may even be detected here and there passing across the veins in the line of the laminæ of the shale, on either side, as if they were a survival of these laminæ. In the veins, as in the bands and concretions, the portions next the shale are more granular than the central parts, which as before, become flinty, milk-white and translucent.

Dr. Hicks and Mr. Davies have compared these compact flinty aggregates with the hälleflintas of Scandinavia. They are undoubtedly products of metamorphism; and their chemical composition as well as minute structure probably varies from place to place. The rock, analyzed by M. Renard corresponds both in composition and in

petrographical characters with the petrosilex of Sala in Sweden, to which, as already remarked, Beudant gave the name of "adinole" *.

The microscopic structure of some of the bands has been described by Mr. Davies and Dr. Hicks †. The latter author remarks that the chief peculiarity of the rock consists in the way in which the quartz is separated into nests.

In the slices which have been prepared in the Geological Survey laboratories the more granular varieties are evidently fine shales or tuffs, in which the clastic materials are quite distinct, though the matrix separating them shows an incipient, feebly developed microcrystalline structure. The more flint-like varieties display a more perfectly microcrystalline base. The constituents of the base appear to be chiefly felspars and quartz. They are here and there aggregated into patches of coarse crystallization, among which large well-striated plagioclase is occasionally conspicuous. One of the most interesting slides was prepared from a pale, milk-white, flint-like mass, taken from the coast below Nun's Chapel. It presents the usual finely granular microcrystalline base, which remains of a pale bluish tint between crossed prisms. The slide is traversed by two parallel veins of quartz, one of which measures $\frac{1}{20}$ of an inch in diameter and is quite visible to the naked eye. Other minute threads of the same substance appear under the microscope. The most remarkable feature in this quartz-vein is the fact that it is crowded with liquid inclusions, arranged in approximately parallel partitions which run across the breadth of the vein. Each inclusion has a bubble; and in some cases the bubbles rotate or vibrate as we watch them in the field of the microscope.

In trying to realize what has been the origin of these highly compact siliceous aggregates, we see that they have been specially developed among fine tuffs and shales or schists. From the analysis of the acid tuffs above given, it is certain that some bands contain above 70 per cent of silica; the specimen of adinole from Nun's Chapel, analyzed by M. Renard, contains, as we have seen, 78·62 per cent. of that ingredient. In some instances the whole of the silica may have been present in the rock before its alteration.

But whether or not silica has been subsequently introduced into the flinty bands of St. David's, it is evident that they cannot be due entirely to original deposition. In the first place the material of the bands and of the concretions is so precisely the same as that of the transverse and ramifying veins that we must connect the three modes of occurrence together as parts of one general process of alteration, and must conclude that, at least in their present condition, these microcrystalline aggregates must be later in date than the rocks in which they lie.

In the second place, the same flinty substance traverses the quartz porphyry of Nun's Chapel. In the veins which, in connexion with that rock, ramify into the adjacent shale, it is here and there conspicuous. One of my microscopic slides from the elvan itself

* Traité de Minéralogie (2nd edit., 1832), vol. ii. p. 126.

† Quart. Journ. Geol. Soc. vol. xxxv. pp. 285 *et seq.*

shows a tendency towards the aggregation of granular crystalline quartz into nests and fine threads traversing the base, as if the quartz porphyry had been in some measure affected by the same process which has resulted in the production of the siliceous aggregations. Mr. Davies has also pointed out that in the felsite of Roche Castle abundant fissures filled with crystalline quartz occur, together with bands of fibrous chalcedony *.

From the marked development of the siliceous microcrystalline aggregations near the dykes and bosses of porphyry, and their paucity or absence elsewhere, I infer that they are connected with the protrusion of that rock. That water was present, probably in considerable quantity, in the magma out of which the porphyries solidified, is shown by the liquid inclusions in the quartz of these rocks. Hot water or aqueous vapour no doubt continued to escape from the eruptive masses long after they had become solid. This water, probably sometimes charged with alkaline materials, sometimes with dissolved silica, would most readily escape along the highly inclined planes of stratification. Moreover the interstitial water present in the beds, or which might reach them from the surface, would come within the influence of the heat of the eruptive rock.

That the changes which produced the present microcrystalline texture and diffusion of quartz in these rocks took place in the presence of water, and under considerable pressure, is proved by the important fact to which I have referred, that the quartz of the fine veins that traverse the adinole is crowded with liquid inclusions with freely moving bubbles.

The presence of water being thus established, it is obvious that the nature of the metamorphism which it might set up would depend not only on its own chemical activity and that of the substances dissolved in it, but also upon the chemical composition of the rocks affected. Some of the strata must undoubtedly have been more liable to undergo alteration than others. Probably those which have suffered most, consisted originally of finely divided felsite dust. Such a condition would offer peculiar facilities for alteration by water under pressure. The presence of quartz-grains here and there in the sediment might determine the deposit of additional silica round these centres. The water permeating the rock would, no doubt, also fill the fine fissures with the same material. A crystalline rearrangement of the felspathic constituents was likewise set on foot, with the result of producing a finely crystalline mass through which larger crystals, especially of plagioclase, have been developed. From the marked proportion of soda in the analysis of the adinole from Nun's Chapel, some of the felspar thus developed is obviously albite. We may suppose that the alkali was, in great measure, supplied during the process of metamorphism. The analysis further shows that there must be free silica as well as more alumina than is required for the constitution of the felspar.

The subject is too wide for adequate discussion here. But, from the data which I have now brought forward, it will be evident that

* Quart. Journ. Geol. Soc. vol. xxxv. p. 291.

important additions to our knowledge of metamorphism may be looked for from a further study of the rocks of St. David's.

5. The Diabase Dykes and Intrusive Sheets.

The latest rocks of the St. David's district are the dykes and intrusive sheets of diabase, which have been referred to in Part I. as traversing all the other formations. The dykes are specially abundant in the granite. One or two may be detected in almost every artificial opening which has been made in that rock; while on the coast-section they are here and there profusely abundant. They are likewise frequent in the quartz porphyries, as may be seen in the quarries near the schools, and still more conspicuously on the cliff south of Nun's Chapel, where, at a picturesque sea-worn cave, four dykes, varying from one to nine feet broad, cut through the elvan. They occur also in the volcanic group and in the sandstones and shales above the conglomerate, but become fewer in number as they recede from the granite centre.

In external characters, the rock composing these dykes and sheets may be described as usually a dull dirty-green or yellowish brown mass, to which the old name of "wacke" might appropriately be given. It exhibits the texture and mode of weathering of the more distinctly crystalline members of the basalt family. It is occasionally amygdaloidal or cellular, the kernels or cavities being arranged parallel with the sides of the dyke. Here and there a rudely prismatic structure extends between the walls.

To the descriptions of the microscopic structure of this rock already given by Prof. Judd, Mr. Davies, and Mr. Tawney I have but little to add. It is a diabase, but more allied in structure to true basalt than the olivine diabase of the volcanic group. It especially differs from the older rock in the abundance and freshness of its felspars, in the comparative scarcity of its augite, and in the absence of olivine. The magnesian silicates are very generally replaced by green decomposition-products diffused through the mass. An occasional crystal of hornblende, recognizable by its cleavages and dichroism, may be detected.

I may add that some of these diabase dykes present excellent examples of fluxion-structure. Mr. Tawney noticed this in one of those traversing the granite at Porth-lisky *. A thin slice which I have had cut from probably the same dyke, and showing the contact of the rock with the granite, reveals the streaming of the plagioclase prisms along the wall of the dyke. I have found the same arrangement in the narrow dyke that cuts through the shales south of Castell. But the most beautiful example among my slides was taken from a dyke in the shales, in a small cove to the east of Nun's Chapel. The shale and eruptive rock are in contact; and the small acicular prisms of felspar, besides ranging themselves in line parallel to the side of the dyke, stream round the larger felspar crystals (Plate X. fig. 12).

* Proc. Nat. Hist. Soc. Bristol, vol. ii. pt. 2, p. 115 (1879).

Some of the dykes or veins are only three inches broad. They send out fingers, and sometimes break abruptly across from one line to another. They appear generally to have followed the lines of joint in the granite, as Mr. Tawney has observed *; consequently they must be posterior to the development of the system of jointing in that rock. In many places, particularly in the quarries in the Allan valley, between St. David's and Porth-clais, there is evidence of great pressure having been exercised on the rocks subsequent to the intrusion of the dykes; for the latter are much jointed and slickensided, and even a rude kind of cleavage may occasionally be observed in them.

Besides the abundant dykes, there has been a more limited extrusion of the same material in sheets parallel (or approximately so) to the bedding of the sandstones and shales. These sheets are well displayed at St. John's Point, where evidence of their being intrusive, and not truly bedded, may be seen along the fine cliffs which have been cut by the waves on this part of the coast-line.

6. Conclusion.

In concluding these observations, I may present a brief summary of what appears to me to have been the geological history of the St. David's district.

At some remote epoch in the Lower Cambrian period active volcanic vents, probably submarine, existed in the west of Pembrokeshire. From these vents successive showers of volcanic detritus and occasional streams of lava are emitted, until a pile of volcanic material at least 1800 feet thick had accumulated. Most of the discharges of dust and stones were due to the disruption of basic lavas; but at successive intervals copious showers of felsitic débris were also erupted. All the lavas poured out at the surface appear to have been of a basic character (olivine diabase). As volcanic activity died out, ordinary sedimentation was resumed, and the rest of the Harlech and succeeding groups of the Cambrian system were deposited.

At a later period the whole of these rock-groups, which had been laid down continuously without discordance, were subjected to disturbance, the principal effect of which was to throw them into an arch, and to bend over this arch into an isocline, with a general inclination towards the north-west. The strata likewise underwent a wide-spread foliation, which, in accordance with the structure and composition of the rocks affected, was chiefly developed in certain kinds of material.

Subsequent to these changes the south-eastern side of the fold was invaded by the rise of a mass of granite with the usual peripheral quartz porphyries. Accompanying and outlasting this intrusion, a process of metamorphism went on, the effect of which has been to change fine felsitic tuffs or shales into hard flinty translucent masses, and to superinduce in them a finely crystalline structure

* Proc. Nat. Hist. Soc. Bristol, vol. ii. pt. 2, p. 115 (1879).

with the development of porphyritic-felspar crystals and veins and threads of crystalline quartz.

It is suggested for future inquiry whether the granite and accompanying porphyries can possibly represent the roots of any of the palæozoic volcanoes which played so important a part in the geological history of Pembrokeshire, as well as in the rest of Wales, during the Lower Silurian period.

The last episode is that of the diabase dykes, which represent the third and final outbreak of eruptive rocks in the St. David's district. These dykes rise particularly through the central core of granite, as through an old area of weakness. Whether they were connected with any outpouring of lava at the surface cannot be decided; nor does there appear to be any evidence that might lead even to an approximation to their relative geological date.

EXPLANATION OF PLATES VIII.–X.

PLATE VIII.

Geological Sketch map of the St. David's district (p. 268).

PLATE IX.*

Fig. 1. Microscopic section of volcanic tuff, near Pen-y-foel, St. David's. × 25 diameters. (See p. 298.)

2. Ditto of fragment of lava in tuff, Pen-y-foel, × 100 diam. The large crystal shows the perfect form occasionally assumed by the augite in the lapilli of the basic tuffs. The finely cellular structure is also represented. (See p. 298.)

3. Ditto of band of tuff from red shales, with *Lingulella primæva*, Castell, Ramsey Sound, viewed by polarized light, with crossed nicols. The half marked A, × 50 diam.; that marked B × 100 diam. The portions here drawn were selected to show the way in which scattered felspars occur among the other lapilli. (See p. 299.)

4. Ditto of olivine diabase from near Pen-y-foel, × 100 diam., showing the remarkably well developed forms presented by the olivine. (See p. 304.)

5. Ditto of schist, roadside north of St. David's, × 100 diameters. The granular-shaded parts are the abundant green chloritic constituent, separated into elongated nests, between which the foliation is well marked. Here and there orthoclase, magnetite, or other mineral has crystallized out. (See p. 311.)

6. Ditto of schist, Ogfeydd-duon, × 100 diam. Among the constituents occasional rounded grains of quartz appear, as on the right-hand margin of the slide. (See p. 311.)

PLATE X.

Fig. 7. Microscopic section of schist, with crumpled folia, from roadside section north of St. David's, × 100 diam. (See p. 312.)

8. Ditto of schist, with refoliation, from Porth-clais, × 25 diam.

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* The drawings from which these plates of microscopic structure have been prepared were made for me by my colleague Mr. F. W. Rudler, to whom my best thanks are due.

The older foliation is seen in the bands that run from the lower to the upper margin of the drawing. These bands have been disrupted, and a second feebler foliation has been developed along the lines drawn across the section from side to side. (See p. 318.)

Fig. 9. Microscopic section of spherulitic quartz porphyry, from Board Schools, St. David's, viewed under polarized light, with crossed nicols, × 25 diam. (See p. 315.) One of the large quartz crystals appears in the upper left-hand corner. The beautifully perfect spherulites are surrounded by the microcrystalline base.

10. Ditto of spherulitic quartz porphyry, from below Nun's Chapel, St. David's, polarized light, crossed nicols, × 100 diam. This drawing (magnified four times as much as fig. 9) shows the structure of one of the more finely spherulitic porphyries, the very variable size of the spherulites, their isolation in the finely crystalline base, and the presence of rounded blebs of quartz, one of which appears on the left-hand margin of the drawing. (See p. 315.)

11. Ditto of granite from Bryn-y-Garn, polarized light, crossed nicols, × 25 diam., showing the distinctly granitic structure of the rock. (See p. 313.)

12. Ditto of a diabase dyke, showing fluxion-structure, from cove east of Nun's Chapel, × 50 diam. The upper part of the drawing marks the zone of contact between the diabase and the stratified rock; and immediately beyond it the numerous well-formed plagioclase crystals appear, first parallel to the wall and then streaming round what was originally a crystal, possibly of hornblende, but is now a mass of chlorite and other decomposition-products. (See p. 323.)

In the course of the discussion after the reading of PART II. of this paper Prof. RENARD stated that he had had a collection of specimens and of microscopic slides from the rocks of St. David's submitted to him by the author, and had examined them in concert with Professor Zirkel, of Leipzig, and Professor Wichmann, of Utrecht. The conclusions arrived at regarding them were as follows :—

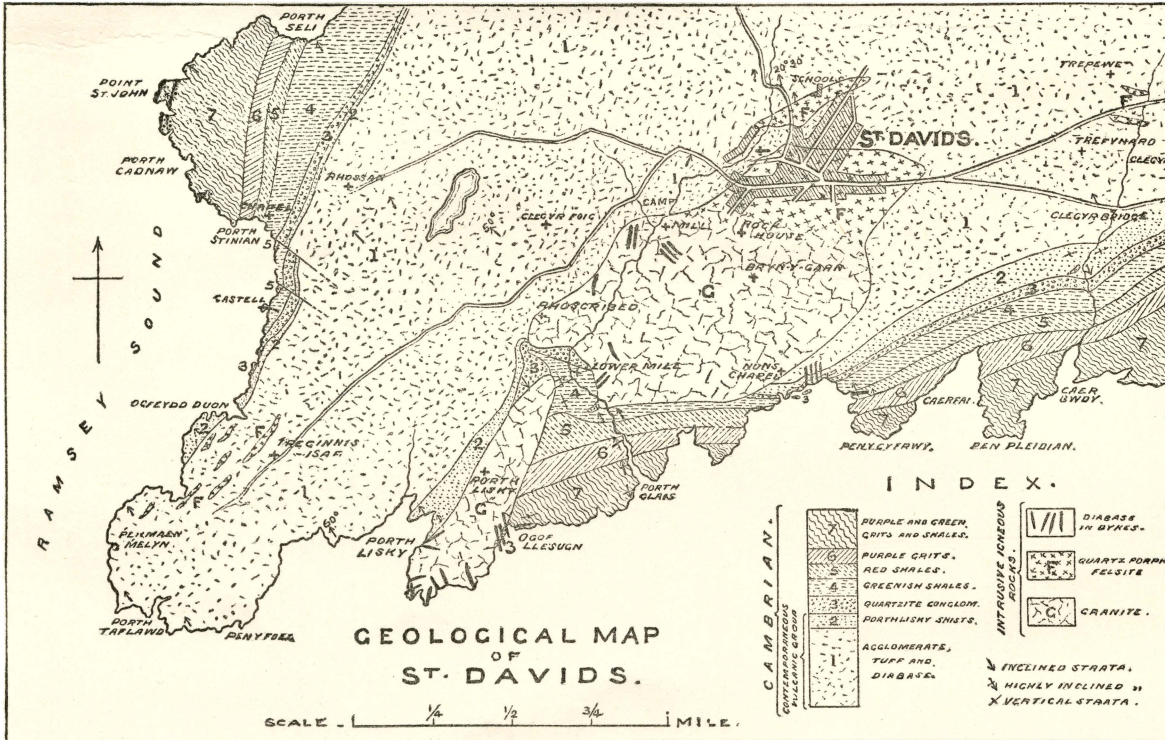
1. The so-called "Dimetian" rock of St. David's is unquestionably a true granite.

2. The quartz porphyries are just such rocks as might be expected to occur as apophyses of the granite; and the specimens from Bryn-y-Garn, Rock House, and St. David's left no doubt on our minds that such is really their origin. They cannot be confounded with rhyolitic lavas.

3. The conglomerate from the granite-contact shows secondary quartz between its pebbles.

4. The bands of fine tuff found intercalated with, and on various horizons above, the conglomerate, consist of true tuff, and cannot have been derived from the mere superficial waste of older volcanic rocks.

5. Fine foliation is well developed among the strata above the conglomerate as well as in the volcanic group below.



Quart. Journ. Geol. Soc. Vol. XXXIX. Pl. VIII.
[*To face* p. 268.

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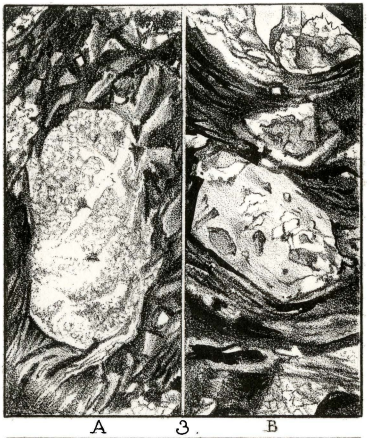

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F. W. Rudler, del. ad nat. Mintern Bros. lith.

ROCK SECTIONS. ST DAVID'S.

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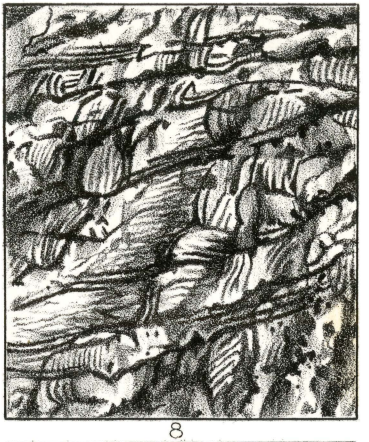

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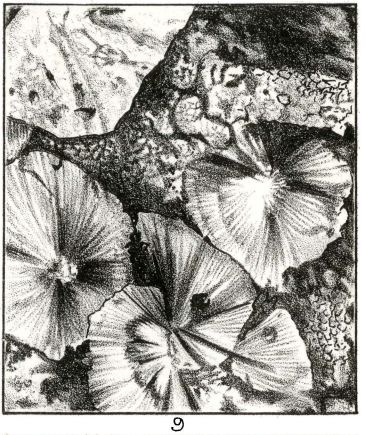

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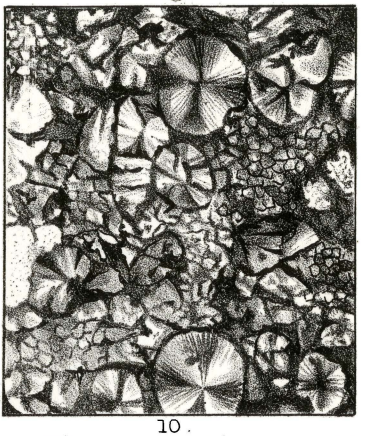

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ROCK SECTIONS. ST DAVID'S.