14. *The* St. David's-Head 'Rock-Series' (Pembrokeshire). By James Vincent Elsden, B.Sc., F.G.S. (Read February 5th, 1908.)

[Plates XXIX–XXXII—Microscope-Sections.]

Contents.

I. Introduction.

In a former paper, communicated to this Society,[1] I gave a general description of the St. David's-Head intrusions. On that occasion I expressed the opinion that this area would repay a more detailed investigation, and I have since made a systematic examination of these rocks, both in the field and in the laboratory, confining my attention to the two large parallel intrusions forming the St. David's-Head and Carn-Llidi masses respectively. With the exception of the general account given in my former paper, these rocks do not appear to have been previously described in any detail.

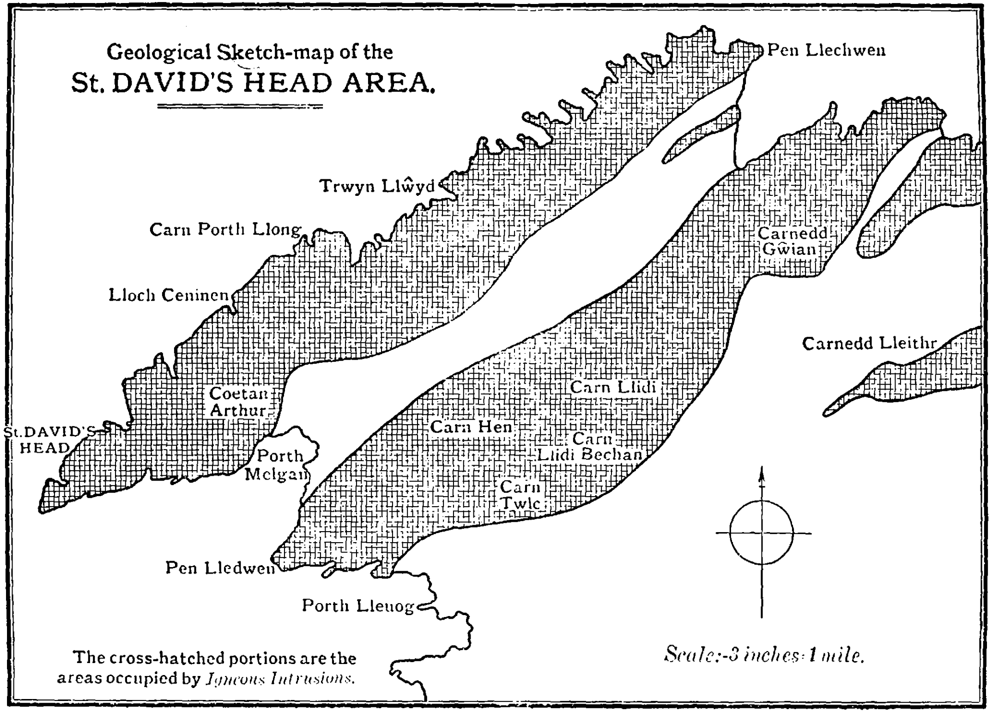
Several distinct types of rock occur in these masses, and it is the purpose of this paper to discuss their differences with the object of examining the problem of their origin. Briefly, the main point to be determined is whether these are to be regarded as an igneous complex, or whether they constitute a 'rock-series,' derived from a common magma by some process of differentiation.

II. General Description.

The two intrusions take the form of vertical sills intruded between almost perpendicular shales of Arenig age. They are composed of at least four types of rock, which, although closely allied, present marked mineralogical differences, often easily distinguishable in the field. There is a dark, basic variety, typically seen in parts of Carn Llidi, Carn Llidi Bechan, Carn Hen,

[1] 'On the Igneous Rocks occurring between St. David's Head & Strumble Head' Quart. Journ. Geol. Soc. vol. lxi (1905) p. 579.

Fig. 1.


Geological Sketch-map of the
St. DAVID'S HEAD AREA.
Pen Llechwen
Trwyn Llŵyd
Carn Porth Llong
Lloch Ceninen
Carnedd Gwian
Carnedd Lleithr
Coetan Arthur
St. DAVID'S HEAD
Porth Melgan
Carn Llidi
Carn Hen
Carn Llidi Bechan
Carn Twlc
Pen Lledwen
Porth Lleuog
The cross-hatched portions are the areas occupied by *Igneous Intrusions.*
Scale:-3 inches: 1 mile.

and occasionally at Pen Lledwen and in parts of the St. David's-Head mass. This melanocratic type is moderately coarse in grain. It stands in conspicuous contrast to a leucocratic variety, often much coarser in grain, with abundant felspar and more or less quartz. This latter type forms only occasional streaks in the Carn-Llidi mass, but in the St. David's-Head mass it occupies a far larger area and becomes the predominant variety. It is especially prominent in the strip adjoining the coast in a north-easterly direction from St. David's Head.

In addition to these apparently extreme varieties, a considerable bulk of the masses seems to be of an intermediate character, somewhat variable in colour and texture, but easily distinguishable in the field from either of the above-mentioned types. This forms the predominant rock in the Carn-Llidi mass, but in the St. David's-Head mass it is subordinate to the more acid type. Finally, there are some thin veins of a fine-grained rock looking like an aplite. These, however, do not seem to be very abundant.

The above-described types of rock might easily be looked upon as a normal result of differentiation *in situ*, as typically exemplified in the gabbro of Carrock Fell, and in many other cases where basic rocks exhibit a coarse-grained acidic core. A more detailed study in the field, however, scarcely supports this view. There is not only no border-segregation in the mass as a whole, but the acid type seems to have a somewhat capricious distribution, passing occasionally by very sudden transitions into the more basic varieties, among which it can sometimes be seen to lie in irregular bands, having a fairly-sharp line of demarcation. These acid streaks are not confined to the heart of the mass, but occasionally extend into the neighbourhood of the marginal contact-zones. In a general sense, however, they conform to the strike of the intrusions. The proportions in which the extreme types occur are locally very different, the more acid rock being far more abundant than the basic rock in the westernmost part of the Carn-Llidi mass, and in the eastern part of the St. David's-Head mass. The acid rock, in short, does not appear to represent merely the residual mother-liquor occupying the core of the intrusion.

It is desirable at this stage to examine the field-relations of these rocks in greater detail. The shales at the junctions of the intrusions are indurated, but no very extensive mineral alteration is apparent in hand-specimens. The igneous rock at the contact has a fine-grained sahlband, which can be followed for a distance of several feet into the mass. Microscopic examination shows that some assimilation of the country-rock has taken place. The character of the intrusion is considerably modified at the margins. The felspars, in small ragged laths, have an approximately-straight extinction. They are apparently more acid than those of the main mass of the rock, and appear to be oligoclase. Augite in small crystalline grains is abundant, and the iron-ores, which are but moderately developed, usually have the appearance of magnetite.

Enstatite, if it was ever present, is now represented by pale irregular patches of chloritic matter. There are also some partly-digested fragments of country-rock and some quartz-xenocrysts. The latter have corroded outlines, fringed with a shell of small augite-crystals, precisely similar to those noticed by Mr. Harker in the marginal part of the Skye gabbro (see Pl. XXX, fig. 1). These are evidently undigested remnants of the country-rock: they occur in all my slides from the contact-zone. A series of slides was prepared from this zone beneath the south-eastern flank of Carn Llidi, in order to ascertain, if possible, to what extent assimilation had taken place. Quartz-xenocrysts can thus be traced to a distance of about 6 feet from the margin, beyond which distance rhombic pyroxene begins to be well individualized, and, except in texture, the rock mineralogically resembles that of the main mass.

An interesting point in connexion with these marginal rocks is the occasional appearance of a delicate micropegmatite within 10 yards of the margin, where the grain of the rock is still fine, owing to rapid cooling. This occurrence of micropegmatite so near the margin, its general distribution throughout the more acid portions of these intrusions, and its absence from the aplite-veins, are significant in connexion with theories respecting the origin of granophyric structure.[1]

On the whole, the chief marginal modifications which these intrusions exhibit seem to be the result of rapid cooling, combined with a certain amount of assimilation of country-rock.

Structural modifications.—There are no true porphyritic crystals in the marginal zones, from which it may be inferred that the magma was intruded in a wholly liquid state. In a general sense the texture of the rock becomes coarser in proportion to the distance from the cooling surfaces; but there are cases where coarse and fine-grained rocks are in close juxtaposition. The rocks vary in texture from subophitic to granular, and are occasionally almost pan-idiomorphic (see Pl. XXX, fig. 5).

A distinct banded structure is exhibited in parts of the St. David's-Head mass. This is particularly evident in the neighbourhood of the cromlech known as Coetan Arthur, north-west of Porth Melgan. The bands consist of thin alternate layers of light and dark rock, often not more than an inch wide. On the weathered surface the light bands stand out in relief, and contrast strongly with darker and more decomposed layers between them. The strike of the foliation is approximately parallel to that of the intrusion. Thin sections of the light and dark bands show that they differ mainly in the relative proportions of their constituent minerals. In the light bands felspars and quartz predominate, while in the dark bands pyroxenes are more abundant. The distinction agrees generally with that displayed by the basic and acid types of rock described above. The minerals in the banded

[1] See R. H. Rastall, 'The Buttermere & Ennerdale Granophyre' Quart. Journ. Geol. Soc. vol. lxii (1906) p. 270.

rock show no evidence of orientation, from which it is concluded that these bands consolidated after the motion, by which they were produced, had ceased. This was not the case in other parts of the mass, as, for example, along the coast between Carn Porth Llong and Trwyn Llŵyd. Here we find evidence that some amount of movement was in progress during crystallization, in some parts a marked flow-structure being seen (Pl. XXX, fig. 4), and in other cases the crystals themselves having been broken and disturbed. These evidences of movement have only been noticed in parts of the St. David's-Head mass. In the Carn-Llidi intrusion I found no appreciable signs of banding, flow-structure, or crystallization under dynamic stress.

The occurrence of banded structure has an important bearing upon the origin of the different rock-types. Banded gabbros have been described from many localities. They have been noted by Sir Archibald Geikie and by Mr. Harker in the Cuillin Hills (Skye),[1] by the latter in the Carrock-Fell gabbro,[2] and by numerous other observers in various parts of the world. The structure seems to be best explained by fluxion in a heterogeneous magma; and the conclusion is, therefore, drawn that, in that part of the St. David's-Head intrusion where this structure is exhibited, an acid[3] and a basic magma coexisted in parallel bands, which consolidated before diffusion had time to reduce them to a state of homogeneity.

In the Carn-Llidi mass, although there seems to be no definite banding, there are acid and basic streaks, forming irregular lenticles, roughly aligned in the general direction of the intrusion. In many parts more or less perfect mixture seems to have taken place, the extreme types being then scarcely recognizable.

It is possible that local variations in viscosity played the chief part in causing these differences. Viscosity is determined not only by temperature, but also by the composition of the magma, the presence of magmatic water, and other causes, all of which factors might vary locally. Extreme fluidity, aided by a high temperature or other causes, would tend to promote diffusion and homogeneity. This result seems to have been largely realized in the neighbourhood of Carn Twlc and Carnedd Gŵian, while at Pen Lledwen, and in parts of Carn Llidi and St. David's Head, schlieren are more in evidence, as if the magma here was in a more pasty condition.

III. Characters of the Rock-Types.

In order to arrive at a more intimate knowledge of the different rock-types exhibited in this area, not only were thin slices prepared for microscopic examination, but a representative specimen of each

[1] 'The Tertiary Igneous Rocks of Skye' Mem. Geol. Surv. U. K. 1904, p. 91.

[2] Quart. Journ. Geol. Soc. vol. l (1894) p. 319.

[3] The term 'acid' is here used to denote rocks containing primary quartz. The silica-percentage is rarely high enough to entitle these rocks to a place in the acid group as generally understood.

of the types was selected for chemical analysis. I give below the results obtained, reserving for another section of this paper the discussion of the petrographical features in detail. In carrying out the chemical analyses the procedure advocated by Mr. W. F. Hillebrand was followed. The alkalies were determined by the Lawrence-Smith method, which, with proper care, is believed to give very trustworthy results. The combined water, in the presence of a considerable percentage of ferrous iron, could not be accurately determined by ignition; and either Penfield's method, or, in some cases, the method of direct absorption was accordingly followed. For the iron-estimations reduction by sulphuretted hydrogen and titration by permanganate was adopted; and titanium was estimated by the colour-method, with hydrogen-peroxide and standard titanium-solution.

(*a*) The Basic Type.

Specimens of this type collected from Carn Hen, Pen Lledwen, Carn Llidi, Carnedd Gŵian, Lloch Ceninen, and elsewhere in this area, show a close agreement in mineralogical character. The rocks consist of a basic plagioclase, rhombic and monoclinic pyroxene, ilmenite, some biotite, and a little apatite. The felspars give fairly-high extinctions measured from the albite twinning-planes, and appear to belong to the labradorite-species. Rhombic pyroxene showing marked pleochroism, but less ferriferous than hypersthene, is about equal in quantity to augite. The latter mineral is brown in colour, often shows strong basal striation, and very frequently is normally twinned. Biotite is present in all the specimens, but in relatively-small quantity. Ilmenite is but moderately abundant. In order of consolidation felspar seems invariably to have preceded the other minerals, penetrating both pyroxenes, and moulding both ilmenite and biotite.

The chemical composition of this rock was found to be as follows:—

	Per cent.	*Molecular proportions.*
SiO_2	49·67	828
TiO_2	1·13	14
Al_2O_3	12·46	121
Fe_2O_3	1·77	11
FeO	8·71	121
MnO	0·09	1
CaO	9·57	171
MgO	10·50	262
Na_2O	2·42	40
K_2O	0·63	6
P_2O_5	0·13	1
H_2O-	0·37	
H_2O+	2·82	
CO_2	trace	Specific gravity = 2·96
Total	100·27	

Calculating the mineralogical composition of this rock from the molecular proportions, the following approximate result is obtained, omitting water:—

Albite	20·9	} =40·9 Labradorite.
Anorthite	20·0	
Bronzite	22·5	
Augite	22·2	
Biotite	6·5	
Ilmenite and magnetite	4·1	
Apatite	0·3	
Total	96·5	

That this is a thoroughly-basic rock is evident. Although no olivine was recognized in any of the specimens, the invariable presence of biotite in this type and its absence from all other types is significant, and seems to suggest that at a certain concentration the orthosilicate-molecule may, in combination with potash and alumina, form biotite in place of olivine.

This rock is interesting, as being of a type not very common in the British Isles, where distinctly-basic rocks of the gabbro-class, with prominent rhombic pyroxene, have not often been noted. The analysis shows considerable resemblance to certain rocks from the United States and elsewhere, described as norites, analyses of some of which are tabulated below:—

	I.	II.	III.
SiO_2	49·67	48·23	49·28
TiO_2	1·13	1·00	0·87
Al_2O_3	12·46	18·26	15·76
Fe_2O_3	1·77	1·26	1·86
FeO	8·71	6·10	6·94
MnO	0·09	...	0·20
CaO	9·57	9·39	10·51
MgO	10·50	10·84	8·21
Na_2O	2·42	1·34	2·58
K_2O	0·63	0·73	0·76
P_2O_5	0·13	0·07	0·11
H_2O-	0·37	0·26	0·47
H_2O+	2·82	2·00	1·10
CO_2	trace	0·43	0·36
Totals	100·27	99·91	99·01

I. Biotite-norite, St. David's Head (Pembrokeshire). Analysis by A. V. Elsden.

II. Bronzite-norite, Crystal Falls (Michigan). Analysis by G. Steiger, Journ. Geol. Chicago, vol. vi (1898) p. 382.

III. Hornblende-norite, Prospect Hill, Litchfield (Conn.). Analysis by W. F. Hillebrand. Bull. U.S. Geol. Surv. No. 228 (1904) p. 43.

In my former paper I called this rock a 'biotite-norite,' and, in spite of the vague signification which the term norite has acquired, it seems the most convenient name to adopt in this case. In both chemical and mineral constitution this rock differs essentially from the normal gabbros and diabases. The analysis shows a high magnesia-percentage as compared with both the Carrock-Fell gabbro and the Whin-Sill diabase, both of which are enstatite-bearing rocks, and the rock is apparently higher in magnesia than the Skye gabbros examined by Mr. Harker.

An interesting feature also of this rock is, that by reversing the alkalies a typical absarokite-magma would result.

Illustrations of this type are shown in Pl. XXIX, figs. 1 & 2.

(*b*) The Acid Type.

The leucocratic variety, as mentioned above (p. 275), is most abundant in the St. David's-Head mass, although streaks and irregular patches occur in the Carn-Llidi mass. For chemical analysis a sample was selected from near Trwyn Llŵyd. The following is its percentage-composition:—

	Per cent.	*Molecular proportions.*
SiO_2	52·31	872
TiO_2	1·45	17
Al_2O_3	17·38	169
Fe_2O_3	2·99	18
FeO	5·21	72
MnO	0·22	3
CaO	9·95	177
MgO	3·76	94
Na_2O	3·96	64
K_2O	0·75	8
P_2O_5	0·20	1
H_2O-	0·30	
H_2O+	2·05	
CO_2	trace	
Cl	0·02	
	100·55	Specific gravity = 2·87
Less O=Cl	·01	
Total	100·54	

The theoretical mineralogical composition calculated from these figures is as follows:—

Quartz	2·1	
Orthoclase	4·4	
Albite	33·5	=60·4 Plagioclase.
Anorthite	26·9	
Augite and hornblende	17·5	
Bronzite	6·1	
Magnetite and ilmenite	6·6	
Apatite	0·4	
Total	97·5	

This type differs from the basic type of Carn Hen in its greater acidity and distinctly-higher proportion of salic minerals. Free quartz is present, and the potash indicates some orthoclase. Micro-pegmatite is fairly abundant. The felspars belong to rather acid varieties of plagioclase, although, when considered together, they scarcely reach the composition of andesine. Some zoning of the felspars may generally be noticed in the neighbourhood of quartz-areas, the inner zones being apparently more basic than the later separations. There is no biotite, but some hornblende occurs as an accessory constituent. The proportion of apatite is generally somewhat greater than is indicated in the particular sample selected for analysis.

This rock appears to be a typical enstatite-bearing quartz-gabbro. It is often very coarse in grain. The proportion of rhombic to monoclinic pyroxene varies greatly in different specimens, as also does the quantity of free silica, which is rather less than the average in the specimen analysed. It is probable that the greater viscosity of this type facilitated clotting. There is evidence, also, as mentioned above (p. 277), that some movement was going on in parts of the magma during solidification. These causes alone would account for considerable local differences in composition.

Illustrations of this type are shown in Pl. XXIX, fig. 5 & Pl. XXX, fig. 3.

(c) The Intermediate Type.

Excluding the aplite-veins, the above-described rocks seem to form respectively the basic and acid extremes of the main mass of these intrusions. A considerable proportion of the rock, however, has intermediate characters, and differs from the basic type, on the one hand, by the presence of a little more silica and the absence of biotite; and from the acid rocks, on the other, by the scarcity of hornblende and quartz, although a little of the latter mineral (probably in some cases of secondary origin) is sometimes visible. Apatite, although more conspicuous than in the basic type, is less abundant than in the acid varieties. There seems to be, also, a gradual passage from this intermediate variety into each of the extreme types, making it somewhat difficult to select a typical example for analysis. The specimen taken for this purpose is a rather compact, fine-grained rock from the eastern flank of Carn Llidi, about 10 yards from the margin.

The following is the result:—

	Per cent.	*Molecular proportions.*
SiO_2	50·55	842
TiO_2	1·58	19
Al_2O_3	15·00	144
Fe_2O_3	2·54	15
FeO	7·90	109
CaO	7·85	140
MgO	6·25	156
Na_2O	3·53	56
K_2O	1·10	11
P_2O_5	n. d.	
H_2O-	0·55	
H_2O+	3·14	Specific gravity = 2·92
Total	99·99	

Calculating from these figures, the following mineralogical composition is obtained :—

Orthoclase	6·11	
Albite	29·34	} = 50·74 Plagioclase.
Anorthite	21·40	
Augite	13·92	
Bronzite	18·54	
Ilmenite and magnetite	6·36	
Total	95·67	

It is evident from the foregoing percentages that the plagioclase is of a more basic type than that occurring in the previously-described rock. There is also a larger proportion of potash, a result which would scarcely be expected. Micropegmatite is rarely exhibited.

The resemblance between this analysis and that of a specimen of the Whin Sill, described by Dr. Teall,[1] is very striking. The two are tabulated together below for comparison :—

	Specimen from Carn Llidi.	*Whin Sill (Roman Station).*
SiO_2	50·55	50·71
TiO_2	1·58	1·92
Al_2O_3	15·00	14·78
Fe_2O_3	2·54	3·52
FeO	7·90	8·95
MnO	n. d.	0·31
CaO	7·85	8·21
MgO	6·25	5·90
Na_2O	3·53	2·76
K_2O	1·10	1·39
H_2O-	0·55	1·78
H_2O+	3·14	—
Totals	99·99	100·23
Specific gravity =	2·92	2·94

There is also a very marked similarity between the petrographical characters of these rocks, although the felspar of the St. David's-Head specimen seems to be rather more basic than the andesine of the Whin Sill. It is still more striking that the above-named specimen of the Whin-Sill rock contains bronzite, whereas the Cauldron-Snout variety, of slightly-different composition, has only the monoclinic variety of pyroxene. The presence of the rhombic variety seems here, as at St. David's Head, to have been mainly determined by the relative proportions of lime and magnesia, as suggested by Prof. J. H. L. Vogt.

Illustrations of this type are shown in Pl. XXIX, figs. 3 & 4.

[1] See Quart. Journ. Geol. Soc. vol. xl (1884) p. 654.

(*d*) The Aplite-Veins.

There are also some fine-grained veins which penetrate the acid type of the main rock. These are very thin, and by no means common. The specimen selected for analysis occurs near the northern margin of the Carn-Llidi mass, not far from Pen Lledwen. Under the microscope it is seen to consist mainly of felspar and quartz, with some disseminated iron-oxide, but without any ferromagnesian minerals. The felspars have square-shaped idiomorphic outlines and are usually rather turbid, but occasionally they show plagioclase-striation. The quartz is interstitial, and no micropegmatite is visible. The junction with the coarser gabbro seems to be well-defined in hand-specimens, but under the microscope it is less definite, the aplite passing gradually into the intersertal material of the coarser rock. It is evidently, therefore, of contemporaneous origin. These aplite-veins have not been noticed in the more basic portions of the mass, but may nevertheless occur.

A chemical analysis of this rock gave the following result:—

	Per cent.	*Molecular proportions.*
SiO_2	71·18	1186
TiO_2	0·48	144
Al_2O_3	14·89	6
Fe_2O_3	2·11	13
FeO	1·21	16
CaO	0·82	14
MgO	0·14	3
Na_2O	6·85	112
K_2O	1·70	18
H_2O-	0·24	
H_2O+	0·64	
Total	100·26	Specific gravity = 2·62

The above composition admits of the following mineral proportions:—

Quartz	22·68
Orthoclase	10·01
Albite	58·69
Anorthite	3·90
Magnetite and ilmenite	3·22
Total	98·50

In apportioning the molecules there is a small excess of alumina, ferric oxide, and magnesia, which is probably accounted for by the presence of hydrated decomposition-products of the felspar, by which the free silica would of course be proportionately reduced. The rock is evidently a soda-aplite (see Pl. XXIX, fig. 6). Since no free orthoclase can be detected microscopically, this mineral is possibly included in the albite-crystals, either in solid solution or in perthitic intergrowth. Analyses of albite-crystals often show a certain percentage both of potash and of lime.[1]

Soda-aplites of somewhat analogous composition have been described by Dr. J. D. Falconer in rocks from the Bathgate and Linlithgow Hills.[2] Our specimen is also not unlike Mr. Spurr's tonalite-aplite or yukonite, from the Yukon River.[3] Percentage analyses of these and other soda-aplites are tabulated below, for comparison:—

	I.	II.	III.	IV.	V.
SiO_2	71·18	71·26	74·79	77·00	74·21
TiO_2	0·48	0·28	0·17	0·07	0·30
Al_2O_3	14·89	11·87	12·59	13·60	14·47
Fe_2O_3	2·11	0·10	1·19 (Fe₂O₃ + FeO)	0·41	0·35
FeO	1·21	2·12		...	0·50
CaO	0·82	2·88	3·58	0·70	1·71
MgO	0·14	1·08	0·31	0·00	0·28
Na_2O	6·85	6·73	5·10	5·78	7·62
K_2O	1·70	0·05	0·21	1·50	0·10
P_2O_5	n. d.	0·10	trace	trace	0·07
H_2O-	0·24	0·62	0·09	0·23	0·15
H_2O+	0·64	2·71	1·03	0·48	0·23
Totals	100·26	99·80	99·06	99·77	99·99

I. Soda-aplite, St. David's Head (Pembrokeshire). Analysis by A. V. Elsden.

II. Segregation-vein, Kettlestoun Quarry. Described by J. D. Falconer, Trans. Roy. Soc. Edin. vol. xlv, pt. i (1906) p. 147.

III. Tonalite-aplite (yukonite). Analysis by H. N. Stokes, Bull. U.S. Geol. Surv. No. 228 (1904) p. 270.

IV. Aplite (alsbachite), Fallon Hill, Enfield (Mass.). Analysis by G. Steiger, *ibid.* p. 40.

V. Soda-granulite, Mariposa (California). Analysis by W. F. Hillebrand, *ibid.* p. 240.

As bearing upon the origin of the aplite-veins of St. David's Head, it is important to note that these do not resemble in composition the intersertal portion of the main mass. In addition to the aplite-veins there are also some conspicuous veins of quartzite, often showing great regularity and running in parallel bands in the coarser gabbros. These sometimes reach a foot in width: they must be regarded as secondary, in the present state of our knowledge.

I have now shown that in the St. David's-Head intrusions several types of rock, chemically and mineralogically distinct, are represented. These results may be summarized in the following tabular view:—

[1] See Bull. U.S. Geol. Surv. No. 228 (1904) 'Analyses of Rocks from the Laboratory of the U.S. Geol. Surv. 1880 to 1903' by F. W. Clarke, pp. 24, 41.

[2] Trans. Roy. Soc. Edin. vol. xlv, pt. i (1906) p. 147.

[3] Bull. U.S. Geol. Surv. No. 168 (1900) p. 229.

	Plagioclase.	Rhombic Pyroxene.	Monoclinic Pyroxene.	Iron-Ores.	Biotite.	Hornblende.	Apatite.	Quartz.	Orthoclase.
Basic	—	—	—	—	—		—		
Medium ...	—	—	—	—		—	—	—	—
Acid	—	—	—	—		—	—	—	—
Aplite......	—			—			—	—	—

IV. Petrographical Details.

I propose now to call attention to some features of petrographical interest shown in these rocks.

Felspars.—Beginning with the felspars, these are usually rather unsatisfactory for optical study, being generally somewhat turbid, perhaps owing to the fact that outcrop-specimens only can be examined. Where satisfactory extinctions can be measured, these point to the presence of labradorite in the most basic types; but the proportion of the albite-molecule increases in the more acid varieties, so that all gradations from labradorite through andesine to oligoclase in the zone of assimilation, and nearly pure albite in the aplite-veins, can be traced. The chemical analyses tend to confirm this; but, as the felspars of the more acid types are sometimes zoned by a species of lower refractive index than quartz, it is clear that even in the same rock they are not always of uniform composition. Orthoclase may be assumed to be a constituent of the micropegmatite, which often characteristically frames the felspars in the acid types. The alteration of the felspars presents some noteworthy features. In most cases the alteration-product is granular and opaque. Generally epidote is rare, but occasionally this mineral becomes conspicuous, as along the northern margin of the St. David's-Head mass, where veins of epidosite occur. One of the most interesting changes in the felspar, occasionally exhibited, is the development of a mineral giving rather square-shaped sections and rectangular cleavages, which seems to form in company with quartz from the breaking-down of large felspar-crystals. This mineral has not yet been identified with certainty. In my former paper, where I was relying upon indifferent material, its straight extinction, refractive index, cleavages, and birefringence led me to think that this mineral might be one of the scapolitegroup. With the more favourable specimens now available this conclusion has proved to have been wrong, for the mineral is biaxial. Dr. J. S. Flett has very kindly compared my specimens with still more favourable examples found by him in another locality. Although many of the physical characters point to prehnite, a chemical analysis will probably be necessary before a definite determination can be made (see Pl. XXX, fig. 6).

Pyroxenes.—Next to the felspars the pyroxenes are the most abundantly represented, and their characters are remarkably uniform wherever they occur. They are absent from the aplite-veins. Rhombic pyroxene is usually present, sometimes in the form of a ferriferous enstatite, with the pleochroism of bronzite; but in many cases it is represented by bastite-pseudomorphs (see Pl. XXXI, fig. 2). It also seems to be occasionally changed to a fibrous transparent pseudomorph of high birefringence, apparently one of the amphiboles. A few sphene-granules are sometimes enclosed in the rhombic pyroxenes. Enstatite generally crystallized later than the felspars, by which it is often penetrated. Generally it clearly preceded the monoclinic pyroxene; occasionally it, as certainly, followed that mineral, and encloses it (see Pl. XXX, fig. 2); while often the two forms are crystallographically intergrown, as was also observed by Dr. Teall in the Whin-Sill rock.[1] Here and there are twins, one component of which is bronzite and the other augite (see Pl. XXXII, figs. 1, 2, 3, & 5). In this case the plane of composition appears to be the orthopinacoid of the latter. The variable sequence of crystallization, and the frequent intergrowths with augite seem to lend support to the views of Prof. Vogt, who has shown that upon theoretical grounds, and on the assumption that the crystallization-curves of the ferriferous rhombic and monoclinic pyroxenes belong to Roozeboom's Type V, the sequence of these minerals should be dependent upon the relative proportions of lime and magnesia present in the magma.[2] In this case the simultaneous separation of these minerals, as shown by intergrowths and compound twins, might represent the eutectic composition. The monoclinic pyroxene is pale-brown in thin section. Usually it is remarkably free from alteration, showing no uralite-fringes, and possessing the birefringence of a perfectly-fresh ferriferous augite, the maximum value of $\gamma - \alpha$ being about 0·022, as tested by Dr. Michel Lévy's colour-diagram. The maximum extinction-angle is about 40°. No pleochroism has been detected. The most characteristic inclusions are numerous rounded fragments of a paler pyroxene, generally altered to greenish pseudomorphs. These seem often to be optically oriented parallel to the *c* axis of the crystal: to these I shall refer again. There are at least two distinct varieties of augite, distinguished by the presence or absence of a well-marked

[1] Quart. Journ. Geol. Soc. vol. xl (1884) p. 649.
[2] 'Silicatschmelzlösungen' pt. i (1903) p. 129 & *ibid.* pt. ii (1904) p. 109 (Vidensk. Selsk. Skrifter Christiania).

striation parallel to the basal plane, often called the sahlite-striation. Very rarely there seem to be imperfect indications of diallagic striation, in the form of a pinacoidal parting. The striated and unstriated types are generally both present. The striated structure can also be detected, although to a less extent, in the more ophitic types (see Pl. XXXI, figs. 5 & 6). In this respect these rocks differ from those described by Mr. Harker from Skye.[1] I have not been able to find here any corroboration of his suggestion that this structure may possibly be connected with the depth at which consolidation took place; for it is by no means confined to the heart of the intrusions. There is here good material for studying the structure in all its forms; and the conclusion seems to be necessary that, although the schillerization, by which this structure is rendered conspicuous, is a secondary feature, the structure itself is primary. That a certain amount of schillerization is necessary to develop the structure seems to be indicated by its frequent patchy occurrence in the same crystal. Occasionally it is only exhibited along the course of minute cracks and irregular fissures, where incipient alteration might be expected to take place. That the structure is not entirely secondary seems to be indicated by the occasional occurrence of striated and unstriated augite intergrown together, in which case the unstriated augite usually fringes the striated form, and is, therefore, of later growth (see Pl. XXXI, fig. 6). Examples also occur in which twinned crystals, instead of exhibiting the normal herring-bone structure, show the basal striation only upon one component. In other cases, an unstriated augite-crystal includes a corroded fragment of the striated kind. There appears, also, to be some relation between the occurrence of striated structure and the development of enstatite. Thus crystallographic intergrowths of augite and enstatite are common, but I have not observed enstatite intergrown with a striated augite. This conclusion, however, has only the support of negative evidence.

Dr. Teall, in his description of this structure in the augite of the Whin Sill, has suggested the possibility of its representing an ultra-microscopic crystallographic intergrowth of rhombic and monoclinic pyroxene, analogous to the perthitic structure of some felspars. This view is to some extent supported by the observations of Dr. A. Osann[2] and Dr. A. H. Phillips,[3] who conclude that it is due to primary polysynthetic twinning. A similar origin has been advocated by Prof. W. Wahl,[4] who detected, in specimens of diabase from Föglö (Åland), examples of augite in which the striæ, instead of continuing from edge to edge of the crystal, terminate sharply in places against the prismatic cleavage. I have noticed many such cases in the rocks now under discussion. I have also found examples such as Prof. Wahl describes, in which a

[1] 'The Tertiary Igneous Rocks of Skye' Mem. Geol. Surv. U.K. 1904, p. 110.
[2] Neues Jahrb. vol. i (1884) p. 45.
[3] Amer. Journ. Sci. ser. 4, vol. viii (1899) p. 267.
[4] 'Die Enstatitaugite' Tschermak's Min. & Petr. Mitth. n. s. vol. xxvi (1907) pp. 21, 26.

polysynthetic lamellation appears to be indicated by a different extinction-angle in alternate lamellæ.

All the foregoing observations seem to lend support to the perthitic theory. Increased interest attaches to this view in the light of the recent synthesis, by Messrs. E. T. Allen, F. E. Wright, & J. K. Clement, of a monoclinic form of magnesium-metasilicate.[1] According to them this substance is tetramorphic, the stable form being the monoclinic magnesia-pyroxene, into which all the other forms pass at temperatures above 1150° C., the change being monotropic. Enstatite was only produced at lower temperatures. Under certain conditions an orthorhombic magnesia-amphibole was formed, with a transition-point at about 400° C., when it passed into monoclinic amphibole. As MM. Fouqué and Michel-Lévy have discovered the presence of monoclinic magnesia-pyroxene in meteorites, the question arises whether this substance may not also exist in igneous rocks. Analyses by Dr. Teall,[2] and by A. V. Merian,[3] seem to show that the enstatite-molecule is present in these striated pyroxenes; and it is, therefore, not unlikely that the basal striation referred to above may be due to a minute parallel intergrowth of monoclinic magnesia-pyroxene and augite. We may carry this theory still further: Dr. Teall detected in the Whin-Sill rock a pale pyroxene of earlier formation than the augite, and similar observations have been made elsewhere.[4] I have noted this occurrence in many diabases, and in the St. David's-Head rocks the numerous circular inclusions in many of the augites seem to be of a similar nature. It is possible that all these are the monoclinic form of magnesia-pyroxene.

Iron-Ores.—The iron-ores are distributed with fair uniformity through all the types, and are never abundant. In no case has any tendency to marginal concentration been noticed. In the most basic variety they are even less conspicuous than in the more acid rocks. They occur mostly in the form of titaniferous magnetite or ilmenite, and are usually more or less altered to leucoxene. In order of separation this mineral is by no means confined to the earliest phase, but is more often moulded upon the felspars, with very irregular outlines, though occasionally exhibiting rhombohedral forms. Very commonly it forms long strips bordering other crystals, or patches partially enveloping the felspars. Pyrites in small quantity is present in a few instances.

Biotite.—Biotite is confined to the most basic types of rock, and is therefore more commonly found in the Carn-Llidi intrusion. It is always a primary constituent, is never very abundant, and invariably separated later than the felspars, upon which it is

[1] Amer. Journ. Sci. ser. 4, vol. xxii (1906) pp. 385–438. See also J. W. Judd, Quart. Journ. Geol. Soc. vol. xlii (1886) p. 65 (footnote).

[2] *Ibid.* vol. xl (1884) p. 649.

[3] Neues Jahrb. Beilage-Band iii (1885) p. 289.

[4] W. Wahl, *op. cit. passim.*

moulded (see Pl. XXIX, fig. 2). It is of a rich red-brown, with normal pleochroism, and is sometimes bleached by iron-separation. The occurrence of this mineral seems to have been strictly determined by the composition of the magma. No inclusions have been noticed in it.

Hornblende.—Hornblende, like biotite, is but sparingly represented, and, with rare exceptions, occurs only in the more acid varieties. At Carnedd Lleithr it becomes abundant, and the rock passes into the class of enstatite-diorites. It separated, in most cases, later than the pyroxenes, and occurs both in separate crystals and as an outgrowth upon augite. It is brown in colour, and seems to be always a primary constituent. Secondary hornblende (as an alteration-product of augite) is very rare in these rocks, and uralite is practically absent in all the slices. Some transparent fibrous alteration-products after enstatite may possibly be rhombic magnesia-amphibole, allied to the kupfferite described by Messrs. Allen, Wright, & Clement,[1] as the extinction is parallel to the elongation of the fibres. This point, however, requires further investigation.

Apatite.—The distribution of apatite in these rocks presents some features of interest. This mineral is not very conspicuous in the basic varieties, but becomes rather a prominent constituent of the acid types, in which it often forms crystals of considerable size. As chlorine was found in the analysis of this type, the mineral may possibly be in the form of chlor-apatite. It is noteworthy that Mr. Harker observed a similar distribution of chlor-apatite in the Skye gabbros, where it was only found in the more acid varieties.[2]

In the St. David's-Head rocks this peculiarity of distribution is also reflected in the separate slices, where the microscope shows it to be largely concentrated in the quartz-areas, and to a smaller degree in the felspars; it is rarely found in the pyroxenes. I put this curious fact to a rough quantitative test. Thus in sixteen rock-slices it was found that the number of apatite-crystals recognizable amounted to 1142, of which 824 were enclosed in quartz, 259 in felspar, 26 in pyroxenes, and 33 in other minerals. Considering the fact that quartz rarely forms more than 5 per cent. of the rock, it appears remarkable that so large a proportion of the apatite should be concentrated in the mineral which was the last to consolidate. Apatite-inclusions can be so readily recognized in the pyroxenes that they could scarcely escape detection. It is difficult to account for this curious fact, but two explanations seem possible. Either the separation of apatite was delayed by the presence of some substance which increased its solubility; or it was formed, as usual, in the early stages of consolidation, but was rejected by the

[1] Amer. Journ. Sci. ser. 4, vol. xxii (1906) p. 406.
[2] 'Tertiary Igneous Rocks of Skye' Mem. Geol. Surv. U. K. 1904 p. 113

pyroxenes owing to some peculiarity of surface-tension, leading to capillary repulsion instead of attraction. We may, in such a case, imagine, in the early stages of consolidation of the magma, a scattered dust of the minerals of first separation, in this case apatite, and a kind of selective inclusion of these in the subsequently-formed crystals. There are reasons for believing that this selective action does in fact take place in certain cases. An objection to this view, however, is that in the rocks of other localities the pyroxenes often do contain apatite-crystals in fair abundance.[1] In my opinion, the greater preponderance of apatite in the more acid rocks in the St. David's-Head area seems to point to the conclusion that the bulk of the phosphoric acid was originally contained in the acid portion of the magma.

V. Relations of the Rock-Types.

Whatever view we may take of the differentiation-process which has resulted in the various types of rock described in the foregoing pages, it is clear that these suggest a typical rock-series, primarily derived from a common magma. It will be convenient here to illustrate graphically the chemical relations of the different types. For this purpose we may use the method of Prof. Iddings,[2] plotting the silica-percentages along an abscissa, and the other oxides along ordinates erected at the successive points thus obtained. For the sake of space a part only of the complete diagram is shown (fig. 2, p. 291). It is evident, from an examination of this figure, that the curves thus obtained deviate in some cases from even an approximate linearity. We have, of course, to remember that many things may occur during the consolidation of a magma to interfere with a linear result.[3] Thus, owing to convection-currents, magmatic flow, and other causes, crystals do not necessarily remain in the positions in which they consolidated. This must be particularly true in the early stages of crystallization. It is only by making an extensive series of analyses, and by averaging the results, that these factors can be even partly eliminated. Analyses of isolated samples of rock can only be expected to give a rough approximation to the composition of the magmas from which they originated. It is probably for this reason that we find the lime-curve following a somewhat erratic course instead of conforming, as might have been expected, to those of magnesia and iron. Neither the curve for titanium nor that for potash suggests differentiation of the Carrock-Fell type, and in view of the fact that the soda-lime felspars were almost invariably among the first minerals to separate, it is difficult to explain, upon the theory of differentiation *in situ*, the large proportion of soda in the aplite-veins. The whole of the facts,

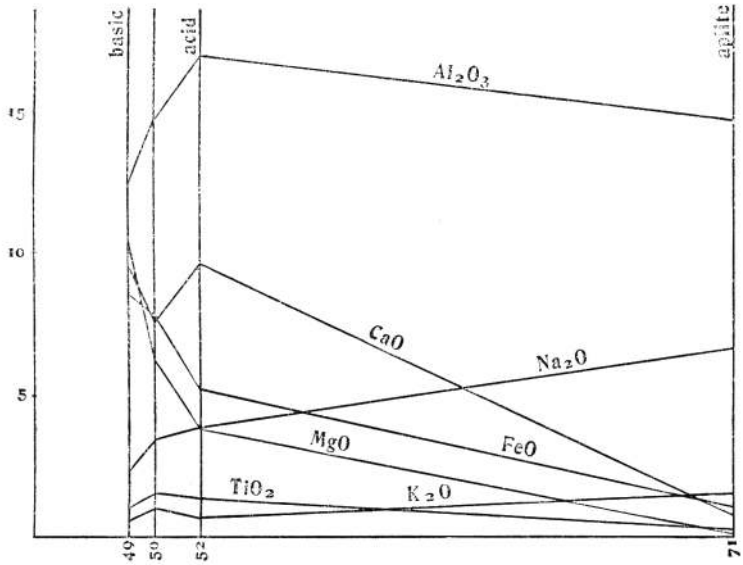
[1] See J. D. Falconer, Trans. Roy. Soc. Edin. vol. xlv (1906) p. 141.

[2] 'The Origin of Igneous Rocks' Bull. Phil. Soc. Washington, vol. xii (1892–94) pp. 89–214.

[3] Upon this point see A. Harker, 'On Igneous-Rock Series & Mixed Igneous Rocks' Journ. Geol. Chicago, vol. viii (1900) p. 389.

indeed, seem to be opposed to the theory of differentiation *in situ*. Acid streaks form a characteristic feature in many basic intrusions, as, for example, the coarse pegmatoid veins at Penmaenmawr, the core of the Whin-Sill intrusion, the coarse veins in the Rowley-Rag mass, etc. In all these cases, however, there is a deficiency in the acid veins of the minerals of early separation. This is not the case in the rocks now under consideration. When we consider the distribution of the felspars, the titaniferous iron-ores, and other facts connected with the sequence of crystallization of these rocks, it is impossible to look upon the quartz-bearing rocks of this series

Fig. 2.—*Diagram illustrating the chemical relations of the various types of the St. David's-Head 'rock-series.'*



as the acid residuum or mother-liquor of a partly-consolidated magma. Perhaps the greatest difficulty in accepting this view, however, is the mode of occurrence of these different types as seen in the field. In many places these are found to pass one into the other by quite sudden transitions; and in the banded rocks we have evidence that two magmas coexisted side by side, in streaky lines drawn out by flow during their injection.

I am driven, therefore, to the conclusion that t h i s i s a c a s e o f i n t r u s i o n o f a m i x e d m a g m a f r o m a m a g m a - b a s i n i n w h i c h a p a r t i a l g r a v i t y - d i f f e r e n t i a t i o n h a d a l r e a d y t a k e n p l a c e. The different degrees of re-admixture, which subsequently occurred, were possibly determined, to a great extent, by local variations in viscosity.

The range of specific gravities of these rock-types accords well with the hypothesis of a differentiated magma-basin. This is shown by the following table:—

	Specific gravity.
Aplite	2·62
Quartz-enstatite-diorite	2·87
Enstatite-diabase	2·92
Biotite-norite	2·96

The extreme basic phase of this series would be a pyroxenite, which might be expected to occur in connexion with these intrusions. Although none of my specimens can be referred to this type, it is approximately represented by the dark streaks in the banded varieties.

VI. Age of the Intrusions.

It remains to consider whether any conclusions can be drawn as to the age of these intrusions. In connexion with this point it is significant that, although the Arenig strata have been sharply folded, the igneous masses show no sign of movement since their consolidation. In the field there is a conspicuous absence of shear-planes and other signs of fracture. Under the microscope the constituent minerals are remarkably free from any of the usual evidences of dynamic metamorphism. I take this to be an indication that no profound earth-movements have affected this region since the consolidation of the injected rocks. The key, therefore, to the age of these intrusions seems to lie in the period of the last great disturbance which completed the tilting of the Cambrian and Ordovician rocks of Pembrokeshire, and compressed them against the pre-Cambrian ridge of St. David's, to the axis of which their strike is approximately parallel. Now, the Llanrian lavas, lying a few miles farther north, are of Llandeilo and Bala age, and these rocks have been affected by this compression. The St. David's-Head intrusions are, therefore, evidently younger than the Bala period, and may have been injected during the post-Bala disturbances. At the same time, the possibility that they may be of post-Carboniferous, or even of still later age, cannot be altogether excluded.

VII. Summary and Conclusion.

I will now briefly recapitulate the conclusions suggested by the preceding investigation:—

(1) The St. David's-Head and Carn-Llidi intrusions are of complex composition, ranging from a basic biotite-norite to an acid quartz-enstatite-diorite, and finally soda-aplite. Throughout all the types, except the aplite-veins, there is a high magnesia-percentage.

(2) The extreme types sometimes pass sharply one into the other, at other times are mixed in various proportions.

(3) They do not represent a composite intrusion, but simultaneous intrusions of an imperfectly-mixed magma.

(4) There is no evidence of differentiation *in situ*, the facts suggesting a common origin from a differentiated magma-basin.

(5) The aplite-veins may represent the most acid phase of this differentiated magma.

(6) Petrographically the rocks are of considerable interest, as exhibiting types not very commonly occurring in the British Isles. They also afford unusual facilities for the study of both rhombic and monoclinic pyroxenes, and appear to throw light upon the origin of the sahlite-striation in the latter.

(7) The probable age of the intrusions is not greater than that of the earth-movements which folded the Arenig strata in this district.

(8) The observations recorded in the foregoing pages seem to point to the conclusion that acid streaks and cores in basic igneous rocks may not always be due to differentiation *in situ*.

In conclusion, I desire to express my obligation to my son, Mr. A. V. Elsden, B.Sc., F.I.C., for invaluable assistance in carrying out the chemical work connected with this paper.

EXPLANATION OF PLATES XXIX–XXXII.

[All the figures are taken with a 1-inch objective, ordinary light.]

Plate XXIX.

Fig. 1. Bi tite-norite, Carn Llidi, showing rhombic and monoclinic pyroxene, plagioclase and iron-ore. Rhombic pyroxene occupies the centre of the field, and is mottled owing to alteration. (× 15 diameters.) See p. 279.

2. The same, showing biotite in the centre of the field, and in the lower right-hand corner. (× 20 diameters.) See p. 288.

3. Bronzite-diorite, Carn Llidi, showing a large bronzite-crystal on the right-hand margin, and augite developed into hornblende in the lower left-hand corner. The remainder of the field is occupied with augite, plagioclase, and opaque iron-ore. (× 20 diameters.) See p. 282.

4. Diabase, Carn Llidi, showing augite, plagioclase, and opaque iron-ore. The augites show basal striation, with patchy schillerization. (× 15 diameters.) See p. 282

5. Quartz-diabase, St. David's Head, showing a large augite-crystal in the lower right-hand corner, with a fringe of hornblende on the left margin. A large plagioclase-crystal occupies the top left portion, and there is some interstitial micropegmatite. (× 20 diameters.) See p. 281.

6. Soda-aplite, Pen Lledwen, showing albite, quartz, and a little iron-ore. (× 15 diameters.) See p. 283.

Plate XXX.

Fig. 1. Quartz-xenocryst, with augite-fringe, from the marginal zone. (× 20 diameters.) See p. 276.

2. Marginal zone a little farther in than fig. 1, showing the development of enstatite towards the left centre. (× 15 diameters.) See p. 276.

3. Granophyric variety, St. David's Head, showing zoned felspar, fringed by micropegmatite. (× 20 diameters.) See p. 285.

Fig. 4. Rock from Trwyn Llŵyd, showing fluxion-structure. Crystals of rhombic and monoclinic pyroxene, plagioclase, and opaque iron-ore are elongated in the direction of flow. (× 20 diameters.) See p. 277.

5. Rock from Porth Melgan, showing idiomorphic pyroxenes. (× 20 diameters.) See p. 276.

6. Specimen from the central ridge of the St. David's-Head mass, showing felspar-alteration. Near the right-hand margin a plagioclase-crystal is seen, partly replaced by quartz and a mineral presumed to be prehnite. (× 20 diameters.) See p. 285.

PLATE XXXI.

Fig. 1. Large rhombic pyroxene, typically developed in the basic varieties. The specimen is from Carn Llidi. (× 15 diameters.) See p. 286.

2. A similar crystal, enclosing felspars. (× 15 diameters.) See p. 286.

3. Intermediate type, showing rhombic and monoclinic pyroxene, and plagioclase. The order of crystallization is here plainly revealed. The large augite-crystal on the right exhibits basal striation. (× 15 diameters.) See p. 286.

4. A large crystal of rhombic pyroxene occupies the bottom of the field, plagioclase the centre, and monoclinic pyroxenes, with basal striation, the top. (× 15 diameters.) See p. 287.

5. On the left a large crystal of augite, with basal striation, shows partial schillerization. The remainder of the field is occupied by plagioclase, and chloritic alteration-products. (× 15 diameters.) See p. 287.

6. The greater part of the field is occupied by a large crystal of augite with basal striation, optically intergrown at the bottom with an unstriated augite-crystal. (× 15 diameters.) See p. 287.

PLATE XXXII.

Fig. 1. The upper margin of the slice shows an interlocked twin-crystal of rhombic and monoclinic pyroxene, the composition-plane being the orthopinacoid of the latter. The section is cut approximately parallel to the clinopinacoid, the augite extinguishing at about 35° to the twinning-plane. (× 10 diameters.) See p. 286.

2. At the bottom of the field is a twin-crystal, consisting of rhombic and monoclinic pyroxene. The remainder of the field is made up of rhombic and monoclinic pyroxene, plagioclase, and quartz. (× 15 diameters.) See p. 286.

3. In the top left-hand corner is a twin of rhombic and monoclinic pyroxene cut transversely. The rest of the field contains plagioclase, augite developed into enstatite, and opaque iron-ore. (× 20 diameters.) See p. 286.

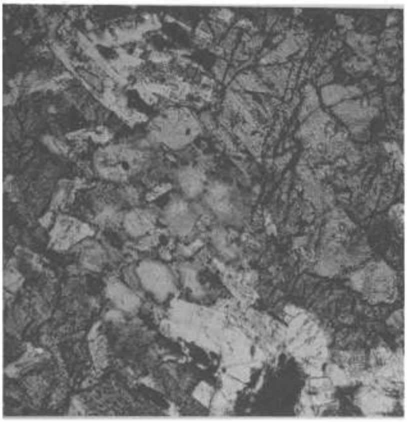
4. This shows parallel development of rhombic and monoclinic pyroxene, in the upper portion of the field. (× 15 diameters.) See p. 286.

5. This shows three twins of rhombic and monoclinic pyroxene, all cut transversely to the *c* axis. (× 15 diameters.) See p. 286.

6. Section illustrating reversed order of crystallization, pyroxene preceding felspar. (× 20 diameters.) See p. 286.

DISCUSSION.

Dr. J. S. FLETT said that this paper was of the greatest interest to him, as he had had occasion to investigate two sets of rocks which had many points in common with those described. By whatever names they might be called—quartz-norites, quartz-gabbros, hypersthene-diabases, quartz-diabases, sahlite-diabases, quartz-dolerites, etc.—they all consisted of rhombic pyroxene,



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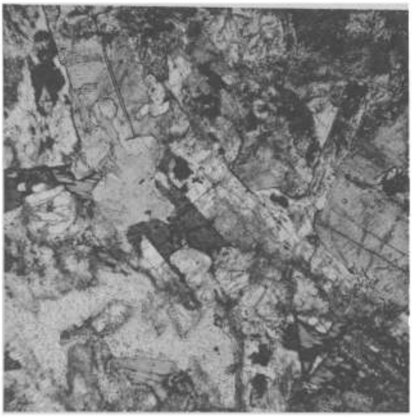

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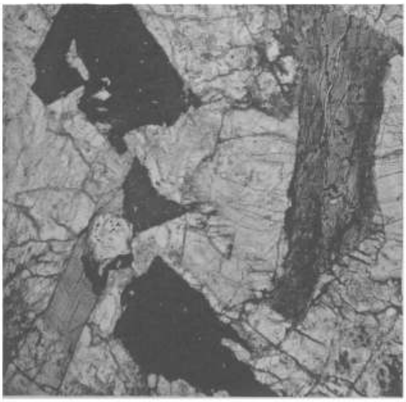

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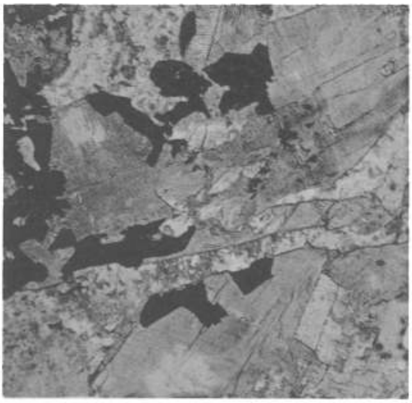

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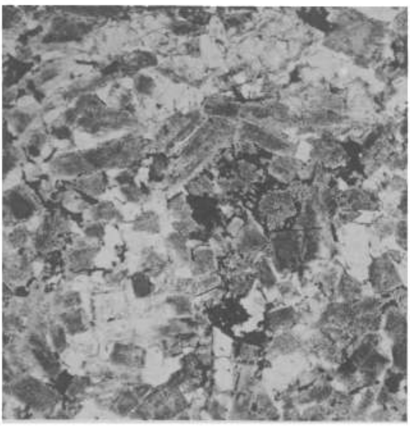

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J. V. Elsden, Photomicro. *Bemrose, Collo., Derby.*

IGNEOUS ROCKS OF ST. DAVID'S HEAD.

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J. V. Elsden, Photomicro. *Bemrose, Collo., Derby.*

IGNEOUS ROCKS OF ST. DAVID'S HEAD.

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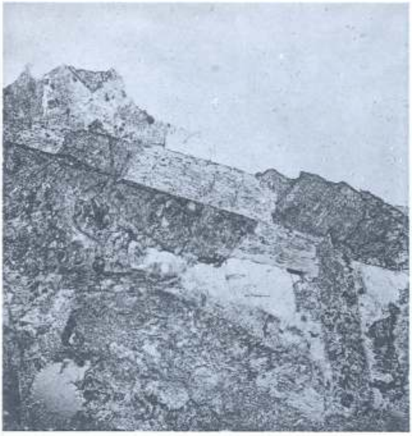
J. V. Elsden, Photomicro. *Bemrose, Collo., Derby.*

IGNEOUS ROCKS OF ST. DAVID'S HEAD.



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J. V. Elsden, Photomicro. *Bemrose, Collo., Derby.*

IGNEOUS ROCKS OF ST. DAVID'S HEAD.

two varieties of augite, plagioclase-felspar, quartz, and micropegmatite; they had arisen at three different epochs from three distinct British magmas. They occurred in the Ordovician of Wales, in the late Carboniferous of Scotland and the North of England (Whin Sill), and as Tertiary intrusions in Arran, Argyllshire, and other parts of the West of Scotland. Many of the features of the Welsh rocks which the Author had described were repeated in the most curious fashion in the Scottish quartz-diabase sills. The older augite of these rocks was a very interesting mineral; it had the pleochroism and many of the characters of hypersthene, but was monoclinic with an extinction-angle of about 40°. Dr. Wahl had recently published an investigation of this mineral (sahlite, magnesium-diopside, enstatite-augite), showing that it had often a very small axial angle and exhibited great variations in this respect. In the Scottish rocks the speaker's experience was that the axial angle of the older augite was smaller than that of the second augite, but often not much less. Recently, however, on examining sections of the Whin Sill from Belford (Northumberland), he had observed that the sahlite, which was very abundant in that rock, was often uniaxial, an example of a mineral of monoclinic symmetry, optically uniaxial, and with its single optic axis making an angle of 40° with its principal crystallographic axis.

Mr. J. Allan Thomson mentioned, as a confirmation of the hypothesis that the previous speaker had put forward, the demonstration by Prof. Vogt that enstatite and diopside formed a discontinuous series of mixed crystals. This could be more easily understood if the enstatite entering into the diopside-molecule were monoclinic. Prof. Vogt had placed the enstatite-diopside series in Type IV of Roozeboom's types of mixed crystals, one of his arguments being that enstatite was never posterior to diopside in crystallization. They had seen, however, in the Author's figures a plate of enstatite pœcilitically enclosing augite.

Dr. F. H. Hatch enquired as to the nature of the felspars, whether they were anorthoclase or albite.

Mr. E. B. Bailey remarked that the Scottish Permo-Carboniferous quartz-dolerites showed an exactly similar association of basic, intermediate, and 'acid' types, the dark and light patches frequently occurring side by side, without any evidence of flow-structure, indicating differentiation *in situ*. The principle involved appeared to be the immiscibility of the extreme products at a temperature slightly above the consolidation-point of the rock. The speaker drew attention to the analyses of the three types, by Mr. G. S. Blake, quoted by Dr. Falconer in his excellent paper on the petrology of the Bathgate Hills, which furnished a very perfect example of 'straight-line' variation, thus strengthening the Author's conclusions.

Mr. H. H. Thomas observed, with reference to the age of the St. David's-Head rocks, that they were clearly intrusive into Arenig sediments. In West Pembrokeshire there were several horizons in the Ordovician System marked by volcanic activity, but it seemed improbable that that of the St. David's-Head rocks corresponded with any of them. The Author had observed that the complex had suffered no movement since its consolidation, and in view of the extensive post-Carboniferous disturbances which had affected the district to the south-east the speaker considered that the intrusion most likely took place in post-Carboniferous time.

The AUTHOR, in reply, thanked Dr. Flett for his interesting remarks on the recurrence of eruptions of similar types of rock in different geological periods, and he was glad to have his support with regard to the nomenclature of the rocks, and other points mentioned in the paper. As to the relative order of crystallization of enstatite and augite, alluded to by Mr. Allan Thomson, the view of Prof. Vogt, that the separation of augite before enstatite was impossible on theoretical grounds, referred particularly to iron-free enstatite, and not to the ferriferous varieties described in the paper. In reply to Dr. Hatch, he said that the felspars in the aplite-veins appeared to be solely albite. With respect to Mr. Bailey's reference to non-consolute magmas, this theory certainly had support from recent discoveries in physical chemistry, but the evidence in the St. David's-Head intrusions scarcely warranted the assumption of a separation of the magma into two or more non-consolute magmas *in situ*. Mr. Thomas referred to the possible age of the intrusions, upon which the Author's evidence was admittedly obscure, the only clear point being the complete absence of any sign of earth-movements since the consolidation of the rocks in question. In conclusion, the Author thanked the Fellows for their kind reception of his paper.