IV.—THE TWO MAGMAS OF STRATHBOGIE AND LOWER BANFFSHIRE.

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THE field-work upon which this communication is based was carried out in 1917 and 1918, in preparation for the Geological Survey map of Sheet 86 (Huntly).

In the Strathbogie district of Aberdeenshire and in Lower Banffshire¹ two series of igneous rocks have a wide distribution. The earlier of these series was intruded prior to the movements which caused the foliation and schistosity of the Dalradian sediments, the later after these movements had ceased. The object of this paper is to detail the diversity of original rock types constituting the Older Series, to delineate their magmatic sequence, and to compare them, both in order of intrusion and in petrographic characters, with the similarly diversified Younger Series.

1. THE OLDER SERIES.

Igneous rocks of prefoliation age have a wide distribution in this district, as will be seen from the Sketch-map. These Older rocks are mostly altered to serpentine, tremolitic serpentine, epidiorite, amphibolite, hornblende-schist, and augen-gneiss, but it has been found possible to trace back the serpentines to pyroxene and olivine rocks, the epidiorite, amphibolite, and hornblende-schist to gabbro and enstatite gabbro, and the augen-gneiss to granite. The most important locality of the Older Series from this point of view is that of Portsoy, Banffshire. The rocks of this locality have been described many years ago by Jameson,² Cunningham,³ and Heddle.⁴

The non-felspathic ultrabasic members of the Older Series are usually in the condition of serpentine, occasionally well foliated but more often massive. Throughout the district, however, rocks composed wholly of monoclinic pyroxene are strongly developed and can be found in all stages of transformation to serpentinitous and tremolitic derivatives. Such anchi-monomineralic rocks form independent intrusions, and since they are cut by epidiorite may be considered as the earliest manifestation of the Older igneous activity. Type localities are at Portsoy, at Whitehill west of Rothiemay Station, and on both flanks of Evron Hill. The pyroxenite is a coarse massive greenish-grey non-foliated rock which in thin slice is seen to consist of large interlocking crystal plates of a pale-coloured augite. No felspar has been seen in the rock. Occasionally olivine in small grains is scattered sporadically throughout the rock and may have been locally predominant. Enstatite and hornblende, probably primary, also occur at certain localities. There is never any banding of the constituents, collection of olivine in layers or fluxional arrangements of the

¹ Further notes on these districts will appear in the *Summary of Progress of the Geological Survey of Great Britain for 1918*.

² R. Jameson, *Mineralogy of the Scottish Isles, etc.*, 1800, vol. ii, p. 270 et seq.

³ Hay Cunningham, "Geognostic Account of Banffshire": *Trans. High. and Agric. Soc. Scot.*, ser. II, vol. viii, p. 447, 1842.

⁴ M. F. Heddle, "Chapters on the Mineralogy of Scotland": *Trans. Roy. Soc. Edin.*, vols. xxvii-xxix, 1876-80.

crystals. The position of such pyroxenite masses as are associated with epidiorites, etc., seems in no case due to gravitative differentiation. These pyroxenites by their alteration produce

Sketch-map, showing distribution of Older and Younger Igneous Rocks in Strathbogie and Lower Banffshire.

a mixture of tremolite and serpentine, and in the olivine-rich types homogeneous serpentine usually results. The tremolite of the pyroxene rocks has been developed under pressure from the solid augite, the large crystals of which are crushed and distorted, the amount of tremolite present being in intimate relation to the degree of crushing suffered by the rock.

At Portsoy a second independent intrusion of a monomineralic rock is furnished by a small mass of anorthosite. This coarse-grained greenish-grey rock is composed almost entirely of labradorite feldspar in crushed augen between excessively fine-grained cataclastic granules of similar feldspar. Scarce chlorite, rare epidote, and talc complete the rock. This anorthosite is undoubtedly an independent intrusive mass, and is against Dalradian limestone and schist on one side and a pyroxenite on the other.

The great majority of Older basic rocks is derived from a gabbro which is found well preserved at Portsoy. This parent rock of the epidiorites and amphibolites is a coarse gabbro composed of labradorite, augite, apatite, and iron oxides, with secondary hornblende and biotite. The rather elongated crystals of labradorite are saussuritized and slightly crushed. The ophitic augite is marginally altered to the fibrous or compact hornblende of the epidiorites.

Primary modifications of this gabbro are common, but form only local variations in the gabbro mass. By the dwindling of the feldspar content and by the incoming of olivine, a rock is formed in which the original constituents were olivine, diallage, and scarce labradorite. The olivine, now entirely replaced by pilitic tremolite, quartz, chalcedony, and carbonates, formed rounded grains poikilitic in large diallage plates which are in process of alteration to hornblende and biotite. The feldspar is a scarce rather fresh basic plagioclase. Compound reaction rims between the olivine and feldspar are occasionally developed and are exactly similar to those found in certain types of the Younger Series. The rock is occasionally crushed.

In the Burn of Durn at Portsoy an enstatite gabbro is found in which a colourless enstatite is predominant over the monoclinic pyroxene. Both species of pyroxene are partially or completely altered to a pale-green hornblende, and cataclastic effects are common in the plagioclases.

Bands and streaks of a rock more acid than the predominant type are found in the gabbro of Portsoy. Such dioritic types are composed of a medium plagioclase, quartz, and biotite.

Primary banding is common in the Portsoy gabbro. This is of two types, the first being formed by alternations of two rocks, the second by alternations of two minerals. The first type consists of bands of a labradorite rock with a little hornblende secondary from pyroxene, alternating with bands of hornblendic (originally pyroxenic) rock with subordinate plagioclase. This complementary banding is undoubtedly original. Those rocks to which the name gabbro schist may be applied show a delicate banding of light coloured saussuritized labradorite and of dark secondary hornblende enclosing augen of diallage. This banding is due to movement

during consolidation, and the effect of the subsequent cataclasis has been to emphasize the banded nature of the rock, which in structure then resembles the foliated gabbro described and figured by Teall.¹ All banding is parallel to the stress lines of the country.

The olivine-pyroxene-felspar rock, enstatite-gabbro, diorite, and banded gabbros do not form independent intrusions, but are small parts of a heterogeneous intrusion whose predominant member is ordinary gabbro. No differentiation in place can be demonstrated and it is considered that this heterogeneity is due to differentiation before intrusion. All the varieties of the gabbro pass into epidiorites by the complete replacement of their pyroxene by secondary hornblende. From the epidiorites are derived the widespread amphibolites by a still more abundant development of secondary hornblende and the concomitant recrystallization of the original labradorite into a mosaic of clear acid plagioclase. These two types, displaying no marked foliation, are predominant in the Older basic series as now found. By the development of cataclastic foliation the hornblende-schists are produced.

The acid members of the Older Series are exemplified by the augen-gneisses of Portsoy and Windyhills. In these rocks large lens-shaped patches of microcline and orthoclase, with subordinate oligoclase, are set in a cataclastic groundmass of granular quartz and felspar with shreds of primary biotite, and much secondary muscovite along shear planes. The original rock was a biotite microcline granite.

The magmatic sequence of the Older Series is, as usual, one of decreasing basicity or of increasing alkalinity. The main magma was largely gabbroic in nature and has been intruded as a heterogeneous magma due to differentiation in a lower basin, and now displays the varied types of predominant gabbro, scarce olivine-pyroxene-felspar rock, scarce enstatite-gabbro, scarce diorite, with banded felspathic and pyroxenic portions. The manner of differentiation cannot be stated, but no degree of differentiation in situ has taken place. The anchi-monomineralic rocks are earlier than the gabbro; one of these independent intrusions is composed of the femic constituents, the other of the felspathic constituent of the original gabbroic magma from which they have split. The acid differentiate is quite late and consists of an alkali-granite. The areal relations for this district of the three divisions are ultrabasic rocks 2.6 square miles, basic 15.6 square miles, and acid 1.55 square miles. The basic rocks are much cut out by the Younger Series, and the area formerly occupied by them may be approximately double that given above.

The Older Series must be considered with regard to Dr. N. L. Bowen's² recent work on differentiation by the sorting and collection of crystals in a crystallizing magma. At Portsoy among the Older

¹ J. J. H. Teall, *GEOL. MAG.*, 1886, Pl. XIII, p. 481; *British Petrography*, 1888, pls. xxvi, xliii.

² N. L. Bowen, "The Last Stages in the Evolution of the Igneous Rocks": *Journal of Geology*, vol. xxiii, supplement, pp. 1-91, 1915. "The Problem of the Anorthosites": *ibid.*, vol. xxv, p. 209, 1917.

Series, and as will be seen later at Huntly among the Younger Series, it can be shown that differentiation has not taken place in situ. The absence of gravitative separation and of continuous variation and the presence of independent monomineralic intrusions point to the conclusion that differentiation took place in a lower magma basin. The main intrusion was undoubtedly one of a heterogeneous,¹ predominantly gabbroic, magma, and from this magma had already been separated off the two monomineralic types—pyroxenite and anorthosite. On Bowen's theory, such separation of monomineralic types would be by the collection of masses of crystals of pyroxene and of labradorite, and therefore, if such monomineralic rocks were intruded as independent masses, their origin would be demonstrated by cataclastic structures. Such structures are, of course, apparent in the monomineralic rocks of Portsoy, but these rocks were affected by the regional folding and, in common with all the igneous rocks of the Older Series, show evidences of crushing stresses. How, then, are these crush effects due to later folding to be distinguished from those due to intrusion as a mass of crystals? Orientation of crystal plates has never been seen in the massive pyroxenites of this series, there is no segregation of olivine into layers, and the crystals of pyroxene form interlocking junctions. The sporadic olivine is often interstitial to the pyroxene. In the author's opinion, the crushing seen in the pyroxenite is best explained as due to the effects of regional folding on a solid and cold rock. Similarly the crushing of the anorthosite is exactly like that of the augen-gneisses. Until further knowledge is obtainable concerning the immiscibility of silicate magmas,² especially under pressure, and also concerning the role of mineralizers, particularly of magmatic water, in ultrabasic rocks, the question of the origin of the monomineralic rocks of the Older Series must be left open. On the whole, however, the writer considers some kind of separation of a magma into liquid phases to be demanded by the field relations of the Older Series of this district. Such a separation of liquid phases would be afforded by the operation of liquid immiscibility, or by the refusion of a solidified magma basin already differentiated, perhaps by crystallization. Such a refusion was postulated by Martin Schweig³ and has lately been favoured by Dr. Harker,⁴ but the cause of the rise in the isogeotherms evoked by the latter is unexplained. Liquid immiscibility, therefore, until proved impossible, should be considered as a process probably effective in magmatic differentiation.

2. THE YOUNGER SERIES.

The Younger Series of the Strathbogie district forms an elongated mass with a north and south trend, a direction parallel to the

¹ Cf. Geikie & Teall, "On the Banded Nature of some Tertiary Gabbros in the Isle of Skye": *Q.J.G.S.*, vol. 1, p. 656, 1894.

² Cf. R. A. Daly, *Igneous Rocks and their Origin*, 1914, pp. 225, 226. "Genesis of Alkaline Rocks": *Journ. Geol.*, vol. xxvi, pp. 123, 124, 1918.

³ M. Schweig, "Untersuchungen über Differentiation der Magmen": *Neues Jahrbuch, Beil. Bd. xvii*, p. 563, 1903.

⁴ A. Harker, "Differentiation in Intercrustal Magma Basins": *Journ. Geol.*, vol. xxiv, p. 556, 1916.

foliation of the country. The younger igneous rocks of the Wardhouse district will not be considered here. That part of the Huntly Mass which occupies the district around Huntly has been described in detail by W. R. Watt,¹ but the whole of the area shown in the Sketch-map has been mapped by the present writer. The rocks of the Huntly Mass, with its isolated granite bosses of Aberchirder, Ord, and Longmanhill (4 miles E.S.E. of Banff), form a lengthy sequence, here appended in order of intrusion:—

1. Picrite-Norite Set (Picrite, Olivine-gabbro, Troctolite, Norite).
2. Diorite of Gibstone.
3. Monzonite and Diorite (Central Intrusion of W. R. Watt).
4. Granite.
5. Pegmatites with tourmaline.

The picrite-norite set are well seen around Huntly and extend thence northwards to within two miles of Portsoy. The picrite forms a narrow border on the western edge of the Huntly Mass in the Huntly district. It is a black rock with conspicuous lustre mottling and in thin slice is rather variable. Occasionally it approximates to a peridotite, but usually carries common ophitic pyroxene with relatively scarce basic plagioclase. Brown hornblende, biotite, and hypersthene occur in small amount. The olivines are slightly serpentinized. No trace of cataclastic structure is found. The olivine-gabbro occurs east of the picrite and forms a coarse very fresh rock with labradorite, olivine, and pyroxene, with subordinate brown hornblende and biotite. The troctolitic type occurs mainly east of the olivine gabbro and is a characteristic olivine-labradorite rock with beautiful fluxional arrangements of the feldspars and with banding of more basic types of peridotite, etc. These fluxion structures are parallel to the margin of the mass, as is usual amongst fluxional gabbros.² Such structures are best explained for the Huntly Mass as due to movement during the intrusion of a somewhat pasty and not strictly homogeneous magma. Troctolite also occurs at the western edge of the Huntly Mass west of Knock Station. Beautiful reaction rims of anthophyllite and actinolite are developed between the olivine and feldspar of the troctolitic and olivine gabbros.³ The predominant body of the picrite-norite set is, however, the norite. This type forms nine-tenths of the Huntly Mass. It is usually a fine-grained bluish rock, consisting of labradorite-bytownite and hypersthene with widespread augite, hornblende, biotite, and olivine. Structures are variable, being ophitic, granular, or granitic. Occasionally the norite lacks its hypersthene and then forms a very coarse gabbro.

The members of the series—picrite, olivine-gabbro, troctolite, norite—follow in order from west to east, and at first glance this arrangement seems to point to a direct gravitative differentiation of a gabbro magma in the position in which it is now found. But no

¹ W. R. Watt, "Geology of District around Huntly (Aberdeenshire)": Q.J.G.S., vol. lxx, pp. 266–93, 1914.

² F. F. Grout, "Internal Structures of Igneous Rocks": *Journ. Geol.*, vol. xxvi, p. 439, 1918.

³ W. R. Watt, loc. cit., pl. xxxviii, fig. 2.

gradual passage from one rock to another can be demonstrated and the individual rock types are well marked. Again, the west-east sequence in certain localities may be partly reversed. Moreover, there is no ultrabasic western border to the norite north of the Huntly district. It seems more probable that the differentiation of a gabbroic magma took place in a lower chamber and that the picrite was intruded as a small sill, followed by increasingly acid derivatives, each of which slid in roughly on the top of its forerunner. But most of the picrite-norite set were fluid at the time of intrusion of the whole series and so no marked contacts are seen; schlieren and banded types occur and mixed edges may have been formed locally. Finally, the phase of the picrite-norite set was ended by the widened sphere of sill-like intrusion, together with great cross-cutting, of the norite magma, and by the time of intrusion of this norite the more basic members were sufficiently solid to be cut by dyke-like apophyses of gabbro and norite. The areal relations of this set are: picrite .83 sq. mile, olivine-gabbro .39 sq. mile, troctolite 3.32 sq. miles, and norite 37.4 sq. miles.

After the composite intrusion of the picrite-norite set had finished, there were intruded a few small bosses of diorite (quartz, biotite, augite, and andesine). Of these bosses, that at Gibstone ($1\frac{1}{2}$ miles N.W. of Huntly) has a marked foliation which is, however, not of cataclastic origin. This Gibstone diorite is intermediate in composition between the earlier norite and the later monzonite, and probably owes its foliation to its soft and hot nature at the time of the movements which caused the monzonite to present a markedly intrusive character to the norite.

The picrite-norite set was solid at the time of intrusion of the large monzonite mass of the Bin Wood (Central Intrusion of Watt¹). This rock is a coarse garnetiferous monzonite which has produced great contact effects on the earlier norite.² It consists of orthoclase, plagioclase, augite, biotite, quartz, and garnet.

The next member of the Younger Series is of granitic nature and forms small masses, sometimes in the basic members and sometimes as isolated bosses, as shown on the Sketch-map. The rock is a grey granite composed of quartz, predominant microcline, orthoclase, scarce plagioclase, biotite, and scarce muscovite. It often shows a very rude fluxional structure. All the granites associated with the Huntly Mass are biotite-microcline granites.

Tourmaline pegmatites are common as the final stage in the intrusion of the Younger Series of the Huntly Mass.

The areal distribution of the whole Younger Series of this area is: ultrabasic .83 sq. mile, basic 41 sq. miles, intermediate 2.8 sq. miles, and acid rocks 3.2 sq. miles.

Continuous variation in place is not seen in the Huntly Mass, and there seems to be an individuality about the various closely related types which is not explained by a crystallization-differentiation hypothesis.

¹ W. R. Watt, loc. cit., p. 275.

² W. R. Watt, loc. cit., pp. 282 ff.

3. THE TWO SERIES.

On comparing the two series of igneous rocks outlined above, it will be seen that there is a well-marked similarity in sequence and characters, but this similarity does not extend to details. The Older Series forms two anchi-monomineralic differentiates, one a femic type consisting of predominant pyroxene with subordinate olivine, the other of a felspathic type provided by the small anorthosite of Portsoy. The Younger Series has only a locally developed monomineralic phase, and its ultrabasic member is provided by a predominant olivine type with subordinant pyroxene and plagioclase, intrusion occurring before the production of a non-felspathic femic magma had been possible. So, feldspar is common in the picrite of this series, but is never found in the pyroxene-olivine rocks of the Older Series. The basic members of the two series again present the same general types of gabbro, enstatite or hypersthene-gabbro, and diorite, but are different in the relative development of such types, in the predominance of certain species of pyroxene, and in the widespread occurrence of olivine in the Younger Series. The acid members are perfectly similar, both being biotite-microcline granites. The areal relations of the Older Series and of the Younger Series of the Huntly Mass show the same order of magnitude for the different differentiates of each series.

The distinction between the two series may be based upon the degree of alteration of the rocks, the character of this alteration among the Older Series, the characters of the predominant mineral in the ultrabasic facies, and the character of the pyroxenes in the two orthorhombic pyroxene-gabbros. In the field, the general greenish appearance due to the alteration into hornblende of the augite of the Older Series and the occurrence sooner or later of cataclastic foliation in them are of great value. Finally, a most important criterion is supplied by their metamorphic effects on the country rocks. The contact rocks produced by the Older Series are foliated by the later regional folding, whereas the effect of the intrusion of the Younger Series is to obliterate this foliation.

It may be stated, therefore, that in this district there are two petrogenic cycles separated by an epoch of great earth movement. Between Huntly and Portsoy the rocks of these two cycles have risen along almost the same belt of country and present great similarities in their main characteristics.

In conclusion, the author wishes to express his indebtedness to Dr. John Horne, F.R.S., and to Dr. J. S. Flett, F.R.S., for many helpful suggestions.

V.—BRACHIOPOD NOMENCLATURE: *SPIRIFER* AND *SYRINGOTHYRIS*.

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ACCORDING to a strict interpretation of the international rules of zoological nomenclature the generic name *Spirifer* is wrongly used for the group including *Anomites striatus*, Martin, and should be restricted to the group including *Anomites cuspidatus*, Martin,