Chapter 10 Petrology of basalt and mugearite lavas

Introduction

A general introduction to the basalt and mugearite lavas of Mull is furnished in Chapter 5. It is there pointed out that certain types of basalt-lava, Plateau Types, are particularly characteristic of the earlier part of the lava-sequence still preserved from erosion; that other types, Central Types, are equally characteristic of the later part of this sequence; that mugearite-lavas are interbedded among the Plateau Basalts, more especially on a comparatively high horizon, well-displayed in Ben More; and that early representatives of Central Types are also found associated with Plateau Types—these early Central Types include basalts of Staffa Type, occurring at the base of the Plateau Group in south-west Mull, and also big-felspar basalts, roughly synchronous with the Ben More Mugearites.

The chemistry of these different lavas is represented by eleven analyses, quoted and discussed in Chapter 1 (pp. 15, 17, 24).

The differences, which in Ben More allow of a separation of the Plateau Basalts into a dark group below and a pale group above, have been dealt with in Chapter 8.

The pneumatolytic changes and contact-alteration, by which both Plateau and Central Lavas have often been affected, have been discussed to some extent in Chapters 5 and 8, but are further considered in the following pages.

With the help of these preliminary remarks the reader will readily understand the grouping of the petrological material adopted in the sequel.

Plateau types of basalt

(Anals. I.-III.; (Table 1), p. 15)

The lavas of the Plateau-region of Mull are, with relatively few exceptions, normal olivine-rich basalts (S14913), (S19071) [NM 6633 4446], (S17781) [NM 5187 3118] or basaltic dolerites (S15749) [NM 5654 4573], (S16044) [NM 5074 2169], (S14983) [NM 6774 4700], (S18506) [NM 4804 2910]. The latter lie in the debatable zone, where some authors employ the term basalt, others dolerite. As will be shown presently, the differences of texture do not necessarily correspond with the degree of development of ophitic structure. The majority of these rocks, whether basaltic or doleritic, are not conspicuously porphyritic. Abundant olivine is in many cases the only micro-porphyritic constituent. At the same time, there is a fairly well-marked tendency for both olivine and plagioclase-felspar to recur in two somewhat ill-defined generations (S14976) [NM 6898 4328], (S15777) [NM 5383 4703], as noted in Scottish Carboniferous basalts of Jedburgh Type. The analysed rock (S19070) [NM 6786 4463], Anal. II. p. 15) is a basalt closely allied to the Jedburgh Type so far as structure is concerned, though in chemical composition it shows a characteristic relative deficency in alkalis. In some eases, there is a tendency towards a glomero-porphyritic grouping of the felspars either alone or with olivine (S17779) [NM 5188 3109]. The augite of the Plateau Basalts is generally of a purplish tint of varying intensity and sensibl.y pleochroic (S15995) [NM 5412 2210], Anal. I., p. 15). The purple colour is apt to be particularly marked towards the margins of crystals and presumably bespeaks titanium. When not purple, the augite is pale-brown. In its structural relation to the felspar (labradorite), the augite varies from thoroughly ophitic (S15686) [NM 6482 4254], (S15995) [NM 5412 2210], to hypidiomorphic (S18505) [NM 4824 3262]. Where hypidiomorphic, the augite may occur either in long crystals, or equidimentional grains. In the latter case it determines a hypidiomorphic granular structure. In another type of granular structure, the augite granules are ophitic (S15741) [NM 5602 4699]. The analysed specimen (S19071) [NM 6633 4446], Anal. III., p. 15) is an ophitic type where the augite-individuals approach dimensions characterizing granular types. Granular structure of either type is subordinate to ophitic structure among the Plateau Basalts as a group. The word granular is here substituted for Judd's term granulitic, as applied to the structure of basalt-lavas that have not suffered contact-alteration.

The tendency to hypidiomorphism of the augite is found both in the coarse (doleritic) rocks (S14983) [NM 6774 4700], (S18505) [NM 4824 3262], (S18506) [NM 4804 2910] and in the definitely fine-grained basalts. Among the latter there are a few slides (S17779) [NM 5188 3109], (S17781) [NM 5187 3118], (S18975) [NM 6878 2844] in which the hypidiomorphic granular augite occurs in minute and very abundant individuals that lack the purple tint of titaniferous augite. Such a granular base is highly characteristic of the Central Types, but is aberrant among the Plateau Lavas. Further points of similarity to the Central Types as exemplified by these slides are the tendency of the felspars to form definite phenocrysts, sharply separated by reason of their size from the rest of the felspars of the rocks, and also the occasional occurrence of small phenocrysts of augite. There is, it will be remembered, a conspicuous absence of augite-phenocrysts in the true Plateau Type of Mull lava (p. 16). Moreover the hypidiomorphism, noted above as a minor feature of the augite in the ground mass of the Plateau Types, never develops to such idiomorphism as is shown by the beautiful little prisms so well known in. the Carboniferous basalts of Britain and the Tertiary basalts of the Continent. An approximation to a variolitic structure assumed by felspar and augite (S15545) [NM 6920 3896], (S15853) [NM 6804 2270], (S18829) [NM 7074 3316] has been noted 'as a very occasional feature of the Plateau Lavas (p. 121), and is interesting as an indication that this structure may develop in rocks relatively rich in olivine. Probably, instances of this could be multiplied if more attention were given to the petrology of the scoriaceous tops of flows.

Before leaving the subject of the Plateau Basalts, a word must be said concerning the ophitic structure presented by a great number of the doleritic and basaltic lavas. In the doleritic rocks, the ophitic structure is moderately coarse and quite normal in character, though varied by an occasional tendency for the augite to assume idiomorphism. In the ophitic basalts, the augite most frequently takes the form of small irregularly bounded clots, that behave ophitically towards the narrow labradorite-crystals, and are separated from each other by a matrix consisting almost entirely of labradorite, olivine, magnetite, and interstital matter (now largely converted into serpentine). To the resultant structure the term ophimottling may be applied. Generally, olivine is distributed more or less evenly without regard to the ophitic patches (S16041) [NM 4988 2299], (S16051) [NM 5122 2247], (S18503) [NM 4901 3100]; but in some instances there is a marked concentration of small crystals of the olivine in the interspaces beyond the limits of the ophitic augite (S16042) [NM 4871 2186], (S16049) [NM 5002 2363], (S17789) [NM 5189 3152], (S17813) [NM 5254 3245], (S18151) [NM 7380 2927]. This relative exclusion of olivine is due to an early crystallization of augite and felspar, followed without a break by felspar and olivine<ref>This explanation of ophimottled structure was arrived at during a discussion of the evidence with Mr. A. F. Hallimond, and contributed largely in leading me to accept a crystallization-basis for the gravitational differentiation dealt with in Chapter 30.</ref> (see also pp. 232, 240).

A certain amount of ground-mass, represented by zeolites and serpentine, is commonly present among the Plateau Basalts, and its failure to resist atmospheric erosion is probably responsible for the pimply-weathering of many of the basalt-flows outside the Limit of Pneumatolysis ((Plate 3), p. 91).

Segregation veins

A few of the Plateau Basalts show a somewhat remarkable tendency to segregate contemporaneous veins consisting mainly of augite, felspar, and analcite, without olivine. These veins differ in texture and composition from the parent-lava, and afford interesting evidence as to the manner of differentiation of the normal basalt-magma. They have an acicular crystallization, and are often associated with lines of amygdales, in which case there is generally an ingrowth of acicular crystals forming a first lining to the vesicles. The subject of their mode of occurrence has been dealt with more or less fully in Chapter 7, where it has been pointed out that the lavas affected by such veining are no less fresh than their unveined neighbours of similar composition and that they often retain their olivine in an undecomposed condition. The best examples of this phenomenon occur, beyond the limits of pneumatolytic action ((Plate 3), p. 91), in Sheet 43 of the one-inch Map; and from them a small series of slides has been prepared.

A good instance is afforded by a lava (S20782) [NM 4217 2623] in the cliff of Dùn Bhuirg on Loch Scridain. This lava is a normal ophitic olivine-basalt of Plateau Type with a violet titaniferous augite. Its olivine is mostly fresh, but there is some marginal serpentinization of the individual crystals. The felspars are short, twinned, crystals of labradorite. The rock, however, is traversed by minute veins of slightly turbid analcite, and this mineral, together with radiate zeolites, mostly lime- and soda-bearing varieties, occupies drusy cavities. The more definite segregation-veins (S20783) [NM 4217 2623] traversing the lava are moderately coarse in texture. Their chief characters are a tendency towards panidiomorphism exhibited by their augite and felspar, and the presence of an analcitic and zeolitic matrix. The augite builds elongated crystals that are highly coloured and usually of a deeper tint towards their margins. The felspars are labradorite, and are often unduly elongated and zoned with varieties-that rapidly increase in alkalinity. They are frequently analcitized either by strings or in patches. Both felspars and augite are sharply idiomorphic against the base, which consists of turbid analcite, chlorite, and a little alkali-felspar. Iron-ore, presumably ilmenite, is moderately abundant as thin plates and skeletal growths of triangular form. The alkalinity of the matrix is emphasized by the frequent presence of a green augite, either as a fringe to the large titaniferous augite-crystals, or as independent prisms in the matrix. Vesicular cavities are numerous, and these are filled by analcite, or by radiate growths of natrolite.

Veins from a similar lava (S20865) [NM 4194 3832], from the shore of Ulva,<ref>Additional slides from Ulva are (S21260) [NM 4 4]-61</ref> southeast of Ormaig Farm, are again of a. relatively coarse rock. The augite is a deep-lilac coloured pleochroie variety with a zonal or hour-glass arrangement of the colouration ((Figure 19)B, p. 137). It occurs in stout columns rudely ophitic towards the felspar, but elsewhere sharply idiomorphic with a good development of terminal faces and a border of pale green aegerine-augite. The felspars are narrow, zoned, laths of labradorite, strung and fringed with analcite. Ilmenite is abundant in large irregular crystals, more particularly in association with the augite, which latter is moulded upon it. There is a little interstitial base, now composed in large measure of chlorite and analcite. It contains mierolites of alkali-felspar, a little aegerine-augite, and needles of apatite, and also small clear seemingly isotropic hexagonal crystals that sometimes appear to have hollow centres. These small six-sided crystals occur with others of similar dimension but rectangular outline, which in some instances show a low birefringence in their unaltered portions. Their form, refractive index, and manner of alteration, makes us inclined to regard them as either nepheline or pseudomorphs after that mineral; but it has not proved possible to apply such microchemical tests as would place the matter beyond doubt. The proportion of six-sided sections is certainly rather larger than would be expected in the case of nepheline, and it is possible that the crystals referred to may be in part analcite and in part alkali-felspar. At the same time, the probability of nepheline in rocks of this character must not be lost sight of; and undoubted occurrences may at any time be met with as further research on these segregation-veins is carried out. In the heart of the definitely igneous material of the rock described above, we encounter numerous amygdaloidal cavities lined with chlorite and filled either with analcite alone, or with chlorite, analcite, thomsonite, and natrolite.

Other examples may be drawn from the lavas of Tòn Dubh-sgairt (S20784) [NM 416 301], just north of the Wilderness in the Gribun Peninsula, and from the shore east of the house on Little Colonsay (S21258) [NM 3818 3699]–(S21259) [NM 3818 3699]. Specimens from the last-mentioned locality are almost identical with those from Ulva, but are in a more intensely zeolitized condition.

It will be seen from the above description that these segregation-veins, which cannot be otherwise regarded than as normal differentiation-products of a basalt-magma, are in a general way mineral-logically and structurally related to the lamprophyres. They distinctly recall the ocelli of the camptonites (Chapter 35), a fact that must be reckoned with in discussing the age of the captonitic dykes of the Mull region (p. 380).

Another point of interest is the modification of the segregation-veins within the Limit of Pneumatolysis ((Plate 3), p. 91). This subject will be considered as soon as a brief statement has been given regarding the amygdales of the Plateau Region outside the same limit.

Amygdales outside limit of pneumatolysis

(Anals.; (Table 9), p. 34).—Previous workers have collected considerable information concerning the amygdale-assemblages of the lavas (Plateau and Staffa Types) lying outside the Limit of Pneumatolysis of (Plate 3) (p. 91), It will suffice here to reproduce with verbal modification what Dr. Heddle says regarding the occurrence of analcite in the Mull archipelago (*Mineralogy of Scotland, vol. ii.,* p. 98).

- Mull (Sheet 44): inland of the farmhouse of Carsaig (Compton); west side of Carsaig Arches; sea-cliffs below Beinn Chreagach, between Carsaig Arches and Carsaig Bay, associated with stilbite, mesolite, and scolecite (Goodchild); Loch Scridain, near Killinichen, on quartz (Mrs. Currie).
- Mull (Sheet 43): Dearg Sgeir, with gyrolite, mesolite, and scolecite (Heddle and Goodchild).

- Mull (Sheet 51): Calgary Bay (Currie).
- Mull (Sheets 51 or 52): Northern division of island with stilbite, mesolite, and prehnite (Macculloch).
- Staffa (Sheet 43): north end, on scolcite.
- Ulva (Sheet 43): (Macculloch).
- Treshnish Isles (Sheet 43): Bac Mòr, on stilbite and covered with natrolite; Lunga, with faröelite<ref>In British Museum Students' Index, faröelite is listed as a variety of thomsonite.</ref> and scolecite; Sgeir a' Chaisteil; Fladda, on scolecite and covered with natrolite.

From its mode of occurrence in the segregation-veins just described, it is safe to regard much of the analcite of Mull as an auto-pneumatolytic product of the containing lavas.

General pneumatolysis

(Anals. XI. and XII.; (Table 9), p. 34). It has been pointed out in some detail in Chapter 5 that within a line, termed the Limit of Pneumatolysis ((Plate 3), p. 91), all the lavas, and many of the intrusions, of Mull have undergone a characteristic type of alteration. The olivine of the lavas inside this pneumatolytic area has been entirely decomposed with a development of serpentine, chlorite, and magnetite. Analcite has also been completely replaced. Felspar has proved less susceptible, but all stages leading to total decomposition are common (S17751) [NM 5193 2973], (S18122) [NM 7408 2917], (S18139) [NM 7395 2922]. The slides just cited show a remarkable relative stability of augite. In the vicinity of amygdales, however, augite is replaced by chlorite. Occasionally augite is pseudomorphed by hornblende, or serves as a nucleus for horblendic outgrowths; but in such cases, the change may perhaps more fitly be ascribed to low-grade contact-alteration (S14814) [NM 5342 3887], (S17365) [NM 6043 2156].

Albite and epidote have resulted from the decomposition of the original felspar, and with - chlorite are the characteristic amygdale-minerals within the Limit of Pneumatolysis (S2112) [NM 525 331], (S17752) [NM 5193 2980], (S17778) [NM 5189 3104], (S17779) [NM 5188 3109]. Generally speaking, they are disposed in circumferential zones; but in two exceptional slides (S17814) [NM 5257 3247] from Ben More, and (S17829) [NM 5326 2906] from Loch Beg), it is clear that the bottom portion of vesicles had been filled with a fine deposit before the albite-epidote crystalline assemblage formed in the remaining spaces.<ref>Compare, M. F. Heddle, Mineralogy of Scotland, 1901, vol. i., p. 60.</ref>

Epidotic veins are highly characteristic of the more altered areas (S14815) [NM 5380 3893], (S18129) [NM 7402 2922], (S18133) [NM 7399 2921].

It is particularly interesting to try and trace the fate of the segregation-veins, described above, within the Limit of Pneumatolysis. Dr. M'Lintock<ref>W. E. P. M'Lintoch, On the Zeolites and Associated Minerals from the Tertiary Lavas around Ben More, Mull. Trans. Roy. Soc. Edin., vol. li., 1915, p. 1.</ref> has made a special study of certain amygdaloidal lavas of the Ben More Massif ((Figure 20), p. 142); and among them he has encountered segregation-veins, with associated outgrowths into vesicles (cf. (S2109) [NM 523 334], (S2629) [NM 726 331], (S17753) [NM 5192 2984], (S18122) [NM 7408 2917] from various localities), which so strongly recall the phenomena since investigated in the outer districts, that we venture to correlate them (*op. cit.,* pp. 17, 18, 21, and Pl. 1). They have the same purple augite, and the same acicular structure; but their felspar-laths, instead of being partially analcitized labradorite, are albite. Analcite is nowhere to be seen; while chlorite has become an important associate. The interpretation we suggest is that the albite of the laths has replaced partially analcitized labradorite as a result of the general pneumatolysis of the district. Dr. M'Lintock, in his account, treats the original composition of the felspar-laths as an open question (*op. cit.,* p. 22); but he thought that any albitization that might have taken place was completed during the cooling of the containing lava.

We have stated above that analcite is altogether replaced within the Limit of Pneumatolysis, so far as the Mull lavas are concerned. The chief support for this claim is the complete absence of analcite inside the Limit, whether we look for it in segregation-veins, or in amygdales, or in the general base of the lavas affected. In addition, Dr. M'Lintock has in one case found albite pseudomorphing icositetrahedra of analcite<ref>Dr. Heddle had previously recorded albite-pseudomorphs after heulandite, laumontite and analcite in Carboniferous lavas of Central Scotland, *Mineralogy of*

Scotland, 1901, vol. ii. p. 13.</ref> (*op. cit.,* pp. 10 and 19); but it must be admitted that he regarded the phenomenon as abnormal in the district he examined; and he did not think that analcite had ever been a common mineral in his lava-group. As already mentioned (pp. 50, 128), Dr. M'Lintock assigns the alteration of the particularly vesicular zone of Ben More to auto-pneumatolysis; whereas we are disposed to follow Mr: Currie in referring it to the general pneumatolysis of the central region.

The outstanding feature of the vesicular zone of Ben More is its richness in scolecite, first described by Mr. Currie (p. 49). Some of the fibrous agregates reach 10 cms. in length. Leaving out of consideration the segregation, or pegmatitic, minerals, Dr. M'Lintock arrives at the conclusion that the main sequence of amygdale-infilling has been: chlorite, followed in turn by albite, epidote, prehnite, and scolecite; and he connects this time-scale with a gradual fall of temperature allowing of the deposition of increasingly hydrous minerals (except for the chlorite—op. *cit.,* p. 24).

Dr. M'Lintock's further work in elucidating the thermal metamorphism of the amygdale-assemblage in proximity with the granophyre of (Figure 20) is dealt with later (p. 152).

Mugearites associated with plateau basalts

(Anal. I.; (Table 7), p. 27).

Mugearites are represented amongst the lavas of Mull, more particularly in association with those of Plateau Type. Except for the main mugearitic horizon of Ben More and the plateau-region to the south and west, their occurrence is somewhat fitful. Petrographically, there are many examples which conform closely to the type as described from Skye; but, as has been found in other districts where rocks of this nature are developed, there is a tendency for them to pass, by an increase in the basicity of the felspars, and by a greater proportion of ferromagnesian minerals, into rocks with more definitely basaltic characteristics, which must be described either as basaltic mugearites or mugearitie basalts. In the other direction, with an increase in alkalinity, and a falling off in the ferromagnesian constituents, the mugearites grade into oligoclase-trachytes.

That the relative alkalinity of the mugearites when compared with the basalts is an original specific character there can be no doubt; but it is well to point out, that rocks similar to mugearites in many respects can be, and are, produced by the more or less complete albitization of some of the finer textured basalts.

In their mode of weathering and their platy fracture, due in a large measure to the fluxional arrangement of the microscopic felspars, they are, as a, rule, easily distinguishable from the basaltic rocks with which they are associated.

They are fine-grained holocrystalline dark-grey rocks, usually without phenocrysts. In some instances, however, small and infrequent phenocrysts of plagioclase may be detected with the unaided eye; while in one case among the mugearites of Ben More distinctly porphyritic crystals have been observed (S17797) [NM 5191 3172].

Microscopically, these rocks in their typical development consist of minute elongated crystals of an acid plagioclase, approximating to oligoclase in composition. The microlites are arranged with varying degrees of parallelism (trachytic structure) indicating that the rock retained considerable fluidity up to the final stages of its consolidation. Next in abundance is iron-ore, which is generally widely distributed throughout th rock as minute crystals of magnetite lying between the felspars or, less frequently, segregated into irregularly bounded patches. Olivine and, less abundantly, augite are the only original ferromagnesian minerals that occur in quantity; but in the case of the Mull examples olivine has not as yet been detected in an unaltered condition. It usually exists as rounded grains or minute elongated phenocrysts arranged parallel to the direction of flow as indicated by the felspar-microlites. In the majority of cases, it has been converted into highly birefringent chloritic pseudomorphs of deep-green colour (S17796) [NM 5191 3170]; but in other cases the pseudomorphs are of iddingsite (S17840) [NM 5214 3386], or normal serpertine (S14858) [NM 5296 2670]. Chlorite and attendant finely divided iron-ore occur interstitially between the felspar-microlites and may conceivably represent in some instances a chloritized glassy residuum (S16747) [NM 5565 2852]. Small vesicular cavities are the rule, and these may be variously filled with chlorite (S18111) [NM 6266 4139] or, less frequently, with secondary quartz. A specimen of the iron-stained vesicular top of the Ben More flow, as exposed two-thirds of a mile south of Kinlochscridain Hotel, shows fragments having varying grades of crystallization and containing a considerable proportion of what was once a glassy residue (S20771) [NM 5355 2713].

Orthoclase has not been definitely recognized in the Mull rocks, nor have the pale-brown hornblende and biotite that occur in the Skye and Central Valley mugearites.<ref>J. S. Flett, On the Mugearites, Summary of Progress for 1907, Mem. Geol. Survey, 1908, p. 122.</ref>

Dr. Harker allows himself a certain amount of latitude in the interpretation of his type, and it appears quite clearly that slight departure of the dominant felspar from the composition of oligoclase, an increase or decrease in the percentages of olivine and augite, and the presence of micro-porphyritic crystals are, within limits, features of varietal significance only.

The Ben More mugearite at Kinloch (S20582) [NM 5364 2832] is representative of the main mugearitic horizon of Mull, and is closely related to the Skye examples; but the analysis (p. 27) shows a decided difference in the somewhat higher percentages of silica and alkalis, and indicates an approximation to the composition of certain of the trachytes. The characters of the rock as a whole, however, link it with the mugearites, and Dr. Harker, who has seen the rock in question, is prepared to accept it as falling within the limits of his type. It is quite possible, as Dr. Harker points out, that many of the rocks which have been described as mugearites from other areas, particularly from the Scottish Carboniferous lavas, would, on analysis, show slightly greater alkalinity than the typical mugearite, although resembling it in general characters.

Certain specimens of basaltic mugearite from Ben More (S17795) [NM 5190 3168], (S17799) [NM 5192 3177] show their departure from the type mainly in the increased proportion of augite, which, when sufficiently abundant, assumes the micro-ophitic mottled texture of many of the finer-grained olivine-basalts. The felspars, too, although in most cases more acid than those of the basalts, are often more basic than oligoclase. Texturally, these basaltic mugearites are similar to the typical rocks and exhibit good fluxion-structure.

In the more acid direction again, a rock south-west of Cruach Inagairt (S17328) [NM 5600 2282] is composed entirely of small narrow crystals of oligoclase, arranged fluxionally, with a green augite occuring between the felspars in irregular granules and prisms. The amount of iron-ore is somewhat smaller than is typical of the mugearitcs. The colour of the augite and the general character of the rock recalls the soda-trachytes, and its analysis would probably indicate a higher percentage of alkalis than usual.

The mugearite of the mapped outcrop, north-west of the head of Loch na Kcal, is almost typical (S17991) [NM 5212 4226]. It consists of the usual elongated oligoclase-microliths, moderately abundant small green pseudomorphs after olivine, a fair quantity of yellowish green augite which has suffered some chloritization, a moderate amount of magnetite in small crystals and patches, and a small proportion of chloritized material that probably represents residual glass. The rock has perfect fluxion-structure, beautifully shown by a parallel arrangement of the felspars and an orientation of the olivines and augites with their long axes in the direction of flow.

Another mugearite, not mapped but easily located, crops out from the raised-beach deposits at Ardchoirk (east of Lochdonhead). In some respects this rock approaches the soda-trachytes. The fetspars are andesine zoned with oligoclase. The augite is pale green, slightly pleochroic, and has a tendency towards a micro-ophitic habit. Olivine is represented by minute, well-shaped, dark-green, highly birefringent, pseudomorphs; and magnetite is moderately abundant. The section (S15555) [NM 7445 3341] is of special interest as it is crossed by a segregation, filling an elongated fissure or cavity, and composed of relatively large crystals of oligoclase, green augite, apatite, and an indeterminate zeolite. Probably this segregation is comparable as regards origin with those already described in connexion with the Plateau Basalts.

Central types of basalt associated with the plateau basalts

(1). Staffa Type

(Anals. II. & III.; (Table 2) p. 17).

The columnar lavas of the south-west of Mull are mainly of the Staffa Type, and are moderately compact fine-grained basalts, poor in olivine, that approach somewhat closely to the olivine-poor or olivine-free basalts of the central region. On the other hand, columnar structure reveals itself occasionally in olivine-rich rocks of normal Plateau Type which occur at a low geological position in the same south-western district.

As representative of the Staffa Type, we may cite: the Fingal's Cave lava of Staffa (S20874) [NM 3260 3513], (S20875) [NM 3256 3513]; the lava that surrounds Macculloch's tree (S20581) [NM 4025 2793], Analysis, p. 17), and others in the same district (S20774) [NM 4054 2847]; the lavas from above and below the Ardtun Leaf-bed (S20750) [NM 3774 2482], (S20751) [NM 3774 2482]; that exposed at the river-mouth at Tavool (S20775) [NM 4412 2723]; and the lowest lava seen at a point 4400 ft. west-north-west of Fionna Mhàm (S20776) [NM 4323 3109].

All these rocks are distinguished in the field by fine-texture combined with columnar structure, generally of the double-tier type; and their microscopic appearance is equally characteristic.

Their constituent minerals are augite, olivine, labradorite, and magnetite or titano-magnetite. The augite is typically non-titaniferous, and the felspars, for the most part, are microlithic in habit. The rocks consist of a felted mass of labradorite microlites, usually without good terminations, which include within their meshes small granules of augite, olivine, and magnetite. Augite is particularly abundant, but olivine is a minor constituent. There is usually no semblance of fluidal structure, but residual material in the form of a chloritized base representing glass is a constant feature. Infrequent microporphyritic crystals of olivine, augite, or felspar may be represented, and, in keeping with the position of these rocks beyond the limit of the central Mull pneumatolysis, olivine is in a more or less undecomposed condition.

Augite is the dominant ferromagnesian mineral, in fact, the dominant mineral. It has a granular habit, and shows a tendency to segregate into aggregates that may, or may not, behave ophitically towards the felspar. The structure is highly characteristic, and occasionally becomes almost intersertal (p. 280). The Staffa Type of basalt is essentially a fine-grained olivine-tholeiite, and, if it were more coarsely crystalline, it would agree closely with the Salen Type of tholeiite (p. 285). This relationship is clearly shown by the agreement of the analyses (p. 17). It is interesting to note that the Staffa Type includes the columnar basalt of the Giant's Causeway (I. 440).

The tendency to display columnar structure, generally in two tiers, is so marked a feature of the Staffa Type that it is necessary to emphasize the fact that all the conspicuous columnar basalts and dolerites of the Hebrides, or even of south-west Mull, do not belong to one petrological category.

The best known columnar sheet of Skye, that of Preshal More and Preshal Beg, approaches the Staffa Type in its preponderance of augite with which is associated felspar, olivine, and iron-ore; but the structure in the only Survey slide (S9249) [NG 326 280] is of the ophimottled variety (p. 138). It will be remembered that Dr. Harker<ref>A. Harker, The Geology of the Small Isles of Inverness-shire, Mem. Geol. Survey, 1908, p. 119.</ref> considers this sheet a sill with, probably, a double-tier arrangement of jointing.

In four slices of columnar basalts from the south-western district of Mull, the rocks prove to be of Plateau Type (S20746) [NM 2442 2625], (S20748) [NM 4544 1942], (S20749) [NM 4527 1943], (S20777) [NM 4326 3105], with purple augite and with more abundant olivine than is characteristic of Staffa; but it is doubtful whether, in any of these four instances, double-tier jointing is developed. Three of them, it may be added, are certainly lavas, while the fourth is the columnar doleritic basalt of Réidh Eilean, outside Iona (Sheet 43), where exposures are too restricted by the sea to furnish decisive evidence of field-relations.

(2). Big-felspar basalt type

Basalts with conspicuously porphyritic felspars are only occasionally met with amongst the Plateau Lavas. The most striking examples belong to the Big-Felspar Basalt Type and their outcrops are indicated on the one-inch Map (Sheet 44) and (Plate 3) (p. 91). They occur towards the top of the Plateau Group, and may be regarded as the forerunners of the lavas of the Central Group. They are themselves definitely of Central Type, though their felspar-phenocrysts are distinctly larger than those of the porphyritic basalts of the central outcrops. The felspar-phenocrysts range up to 10 inches in length (p. 125), but this is very exceptional. An inch, or an inch and a hall, is a more common measurement.

The chief porphyritic constituent is a basic labradorite approaching bytownite in composition, similar to, but showing more signs of zoning than, the smaller porphyritic felspars that characterize a large proportion of the later Central Lavas. These basic crystals are often edged with a more acid felspar (oligoclase), and in almost every case are albitized to a considerable extent.

Olivine in moderately large porphyritic crystals, often with good outlines, is a constant constituent, represented by frequent pseudomorphs in chlorite, calcite, and serpentine. It is always quite subordinate in amount to felspar.

These two porphyritic constituents make up by far the greater portion of the rock. In certain cases (S19068) [NM 733 294], the olivine crystallized, in part, before the porphyritic felspars, but in the majority of rocks of this type e.g. (S18161) [NM 7375 2992] the whole of the olivine is of later separation.

In its content of a considerable proportion of olivine, the Big-Felspar Type approaches the Plateau Lavas, and comformably with this its augite assumes a definitely purple tint.

There is often no marked difference between the groundmass, in which the big felspar-phenocrysts are embedded, and that, of an ordinary Plateau Basalt. Ophitic structure is frequently well developed (S18839) [NM 681 345], (S18840) [NM 680 346], (S19068) [NM 733 294]. On the other hand, there seems to be a marked tendency to variolitic structure, for, from a comparatively small collection, three slides exhibit it (S14226) [NM 7032 3583], (S18161) [NM 7375 2992], (S18162) [NM 7375 2992].

In agreement with their position inside the Pneumatolysis Limit of (Plate 3), all specimens have their olivine completely decomposed. In one slide, chlorite, epidote, and calcite may be seen in crush-lines crossing porphyritic felspar and matrix alike.

Central Types of basalt occurring in the Central Group

The Central Types of basalt are poorer in olivine than the Plateau Types; in fact, so far as one can judge from specimens, all of necessity collected within the Pneumatolysis Limit of (Plate 3), they are often destitute of that mineral. Chemically, as has been shown (p 25), this poverty in olivine corresponds with a poverty in magnesia. Two main types are recognizable, the one rich in porphyritic felspar and correspondingly rich in alumina and lime, the other essentially non-porphyritic.

An unusual proportion of the rocks show variolitic structure, a circumstance in keeping with the assumption that many of the Central Lavas were erupted into water. A description of these 148 interesting variolites will be furnished after the more normal porphyritic and non-porphyritic types have been dealt with.

All specimens show pneumatolytic affects such as have been described above (pp. 95, 141). These include a universal decomposition of olivine, a certain variable amount of albitization of basic felspars, and also the production of abundant epidote. It is interesting to note that quartz occurs more commonly in the veins and vesicles of Central Lavas (S15598) [NM 5737 2805], (S16721) [NM 5785 2613], (S18656) [NM 6336 3289] than among the Plateau Types. In two slices, it appears as if the infilling of vesicles had been commenced by a sedimentary accumulation of chloritic waste at the bottom of the cavities. In one instance (S16721) [NM 5785 2613], this early 'sediment' occupies the bottom of several adjacent vesicles and has been followed by crystallized quartz, epidote, etc. In (S18960) [NM 5794 2542], bedded 'sediment' has choked the vesicles, and has developed a spotted structure probably due to subsequent thermal metamorphism.

(1). Non-variolitic porphyritic basalts of Central Type

(Anals. III. & V.; (Table 6), p. 21).

The chief characteristic of this type is an abundance of small phenocrysts of basic plagioclase, about 5 mm. across, and ranging in composition from basic labradorite to anorthite. A minor feature is the occasional occurrence of porphyritic augite (S18049) [NM 6237 2299], (S18889) [NM 6573 3444].

Where olivine pseudomorphs are recognizable, there is a tendency for the augite to have a somewhat purple tint and to occur with frankly ophitic structure in a ground of doleritic texture (S16740) [NM 5904 2404], (S17184) [NM 5932 2982], (S18897) [NM 6541 3430], (S18961) [NM 5793 2554], thus recalling the structure of the Plateau and Big-Felspar Basalt Types already described. In such cases, the relative scarcity of olivine (as compared with Plateau Types) depends upon the large part played by felspar-phenocrysts. The analysis of the Cruach Choireadail pillow-lava (Anal.. 4; (Table 6)) may be taken as representing this variety, for although the specimen analysed was a porphyritic variolite, others from the interior portions of the pillows are porphyritic dolerite ((Figure 21), p. 151). The analysis illustrates very clearly the large part that felspar-phenocrysts play in the constitution of the rock as a whole.

With further reduction in olivine, the augite of the ground-mass loses its purple tint, and becomes granular (S18899) [NM 6535 3428], while the texture is moderately fine. Many of the lavas from Beinn Bhearnach, east of the head of Glen Forsa, are of this type, but have a very poor development of porphyritic felspar (S18877) [NM 6604 3471], (S18878) [NM 6600 3468], (S18877) [NM 6604 3471]9). These lavas have been referred to in Chapter 9 as intermediate in character between the Plateau and Central Types.

With the disappearance of olivine, augite is almost universally granular and the texture of the base is very fine indeed. The analysed rocks from Derrynaculen (S18469) [NM 5640 2847], p. 24), and from Cruach Doire nan Guilean (S18471) [NM 5757 2907] are typical of this variety which is widespread (S16487) [NM 5904 3075], (S18050) [NM 6293 2306]. They consist of abundant porphyritic and somewhat zoned crystals of basic labradorite, which show signs of albitization, in a fine-grained ground-mass that is made up of minute granules of augite, microliter of labradorite, and microscopic crystals of magnetite.

(2). Non-variolitic non-porphyritic basalts of Central Types

(Anals. IV. & V.; (Table 2), p. 17).

The Non-Porphyritic Central Types, here considered, reproduce the structures and composition of those Porphyritic Types in which olivine is very scarce or absent. They are very closely allied to the Staffa Type (p. 145), but are generally poorer in olivine and finer in texture. An extremely compact type is prevalent (S16441) [NM 6341 3884], (S18921) [NM 6646 2438], of which the two analysed specimens (S14824) [NM 5819 3928], and (S18474) [NM 6309 3205], p. 17) are thoroughly typical. Small porphyritic crystals, a millimetre or so across, are occasionally met with. These are usually labradorite, but to a very minor extent augite (S16441) [NM 6341 3884], (S17242) [NM 5942 3088].

The matrix is microlithic, and consists of minute elongated microlites of labradorite, often altered, and microscopic granules of augite. Magnetite in a finely divided state is an abundant constituent and is largely responsible for the dark colour characteristic of these rocks in hand-specimens. Fluxion-structures are rare; more frequently the microlites are felted together without definite orientation.

(3). Variolites

(Porphyritic variolite: Anal. IV.; (Table 6), p. 24).

Variolites are common among such minor intrusions of Mull as correspond in composition with the Central Types of lavas (pp. 18, 24). In keeping with this, where the Central Type of magma has assumed the pillow-lava habit, that is, where it has been extruded as small masses into water, it has developed a distinctly variolitic facies—though not comparable in perfection with what is common among the minor intrusions. Instances of variolitic structure in Mull lavas which have not the pillow-habit have been already noted as rarities (pp. 121, 138). It has also been suggested that if scoriaceous tops *were* specially selected for examination further instances might be found in considerable number. The significant fact remains, however, that, among the Pillow-Lavas of Central Type, variolites arc sufficiently abundant to require no special search to bring them to light.

Some of the variolotic pillow-lavas belong to the porphyritic class (S18472) [NM 5960 3011], (S18641) [NM 6538 3414], (S18644) [NM 6544 3414], (S18647) [NM 6344 3442], (S18880) [NM 6596 3465]; others are non-porphyritic (S17859) [NM 6114 2914], (S17900) [NM 6091 2815], (S18032) [NM 6354 3026], (S18039) [NM 6437 2936].

There are three main reasons why the Mull pillow-lavas are particularly interesting, as compared with other occurrences:

1. In their association of variolitic structure, on the microscopic scale, with pillow-structure on the large scale, they agree with what has been found in certain other parts of the world.<ref>G. A. J. Cole and J. W. Gregory, The Variolitic Rocks of Mount Genevre, Quart. Journ. Geol. Soc., vol. xlvi., 1890, p. 311. F. L. Ransome, The Eruptive Rocks of Point Bonita, Univ. of California, Bull. Dept. Geol. vol. i., 1896, p. 99. H. Dewey and J. S Flett, On Some British Pillow Lavas and the rocks associated with them, Geol. Mag., 1911, p. 203.</ref>

2. In their froth-invaded vesicles, to be described immediately, they reproduce another microscopic peculiarity which has already been found in pillow-lavas elsewhere.

3. In their low soda-content (Anal. IV., p. 24), they contrast with what has been noted in other cases, more especially by Teall,<ref>J. J. H. Teall in Silurian Rocks of Britain, vol. 1, Scotland, Mem. Geol. Surv., 1899, p. 86.</ref> Dewey, and Flett.<ref>Op. cit., p. 205.</ref>

The phenomenon briefly styled 'froth-invaded vesicles' is quite a feature of many of the Mull pillow-lavas. It results from an invasion of vesicles by magma which after entry has frothed up in *situ* (Figure 21)D. The mere invasion of a vesicle by residual glassy magma is, of course, common, more especially among tholeiitic intrusions. What renders the phenomenon peculiar in the present instance is the subsequent frothing of the invading magma, which has led to a development of vesicles within vesicles (S17859) [NM 6114 2914], (S17897) [NM 6104 2810], (S18032) [NM 6354 3026], (S18039) [NM 6437 2936], (S18646) [NM 629 347]. Sir Jethro Teall<ref>Op. cit., Pl. XVIII.; instances of completely filled early vesicles are probably shown, Pl. XIX., Fig. 1.</ref> has figured vesicular complexes of this character from pillow-lavas of Arenig Age from the South of Scotland, so it appears likely that the phenomenon is of common occurrence. It is probably influenced by the chilled crust of the pillows resisting the external escape of vapours.

The variolitic structure of the Mull pillow-lavas is occasionally discernible under the microscope in a subradiate grouping of the felspar microliths (S17900) [NM 6091 2815]; but is only at all pronounced where augite takes a prominent share in the form of skeletal growths and bundles (S17185) [NM 5940 3000], (S18641) [NM 6538 3414], (S18893) [NM 6557 3435]. A particularly interesting suite was collected by Dr. Clough from the pillows of a porphyritic flow on the slopes of Cruach Choireadail (Figure 21). The actual chilled edge of a pillow (S17186) [NM 5924 3011]; (Figure 21)c) belonging to this suite is a dark grey, almost aphanitic, rock with small unzoned phenocrysts of basic plagioclase in a glassy base, which latter is crowded with irresolvable growths of augite accompanied locally by minute felspar-microlites sometimes radially arranged. Olivine is represented, if at all, by minute pseudomorphs. A neighbouring pillow has given a specimen of the marginal zone, just a little inside the extreme chilled edge. The augite and groundmass-felspar are much more clearly individualized. The former occurs for the most part in groups of narrow rods. The slide may be taken as typical of many of the rather ill-defined variolites found among Mull pillow-lavas (S17185) [NM 5940 3000]; (Figure 21)B. The same pillow in its interior is porphyritic ophitic dolerite with augite in large crystals (S17184) [NM 5932 2982]; (Figure 21)A. The felspar-phenocrysts of this interior dolerite are enlarged by marginal zoning, and pseudomorphs after olivine are well-developed.

A similar transition from variolite to dolerite is traceable in another porphyritic flow occurring on Sren Dubh. Here the chilled base of a flow is found to be a variolite (S17898) [NM 6104 2810], while three feet up the rock develops into a dolerite (S17899) [NM 6104 2810], (S17901) [NM 6091 2815]. Once again, pseudomorphs after olivine are relatively very small in the variolitic portion. It may also be remarked, as a general feature of these rocks in Mull, that iron-ore is poorly represented.

The pneumatolytic changes in the pillow-lavas seem to be of the same kind and degree as are met with in other Central Types. As might be expected, there is generally a certain amount of albitization of the basic felspars.

Contact-metamorphism of the basalt-lavas

Lavas of both Plateau and Central Types have come within the influence of many later intrusions of considerable magnitude which have been able to produce in them marked thermal effects. Sometimes the sphere of influence is but a narrow contact-zone, in other cases it embraces a wide and much less definite area.

As was found by Dr. Harker in Skye, and by Sir Archibald Geikie and other workers on the Tertiary volcanic rocks of Scotland in general, it is the low-temperature decomposition-products of the lavas themselves, and the minerals which fill amygdaloidal cavities, that first show the effects of contact-alteration. In extreme cases, however, every constituent of the rocks, whether original or secondary, may be recrystallized, and entirely new structures may be produced. In the field, an increasing toughness of the lavas is noticeable as an intrusive mass is approached, long before any actual signs of contact-metamorphism can be detected by the microscope.

In the majority of cases, the lavas that show the effects of contact-alteration most clearly had previously had impressed upon them low-temperature hydrothermal changes in common with the other lavas within the Central Area, and thus contact-alteration has given rise to obvious and interesting mineralogical features.

Contact-alteration of lavas of the Plateau Group can best be studied in relation to the Knock and Beinn a' Ghràig Granophyres; that of the lavas of the Central Types is especially well exhibited above the flat-topped Loch Uisg Granophyre, and in proximity to the gabbros of Corra-bheinn and Ben Buie.

Plateau Basalts within the Contact-Zone of the Knock Granophyre

The Knock Granophyre has produced interesting metamorphic effects on the Plateau basalt-lavas of its neighbourhood. In some cases (S14816) [NM 539 389], augite has been replaced by pale-brown hornblende, and there has been a development of biotite from chlorite, and a crystallization of secondary felspar. In another instance (S14817) [NM 540 388], the body of the rock has suffered partial granulitization with production of biotite in proximity to iron-ores; while vesicular cavities, presumably once filled with epidote and chlorite, have given rise to aggregates of biotite and fayalite in all respects similar to those which will presently be described in connection with the Loch Uisg Granophyre (p. 154).

Certain more coarsely crystalline rocks of doleritic characters (S14818) [NM 541 388] have had their ophitic crystals of titaniferous augite partly converted into a brown, slightly pleochroic, hornblende. Occasionally this change has occurred throughout the augite-crystals, but at other times it is restricted to the external portions.

Amygdales of Plateau Basalts within Contact-Zone of Beinn a' Ghràig Granophyre

(Anals. XIII. and XIV.; (Table 9), p. 34).

We have already drawn upon an account which Dr. M'Lintock<ref>W. F. P. M'Lintock, 'On the Zeolites and Associated Minerals from the Tertiary Lavas around Ben More, Mull,' *Trans. Roy. Soc. Edin., vol.* li., 1915, p. 1.</ref> has given of the amygdales of a particular group of zeolite-bearing lavas exposed on the slopes of Maol nan Damh, An Gearna, and Beinn Fbada. The lavas concerned are olivine-basalts of Plateau Type. On the Map (p. 142), it is seen that one of the main localities studied, Maol nan Damh, is situated two miles from the Beinn a' Ghràig Granophyre, while An Gearna, and still more Beinn Fhada, are much closer. The thermal metamorphism of the amygdales corresponds with their nearness to the granophyre; and Dr. M'Lintock's main observations and inferences in respect to its distribution and character may be summarized as follows:

Even in the field, obvious differences are apparent on comparison of the amygdales of Maol nan Damh with those of An Gearna. The dark marginal chloritic layers of the amygdales on Maol nan Damh lose much of their definiteness on An Gearna, and are largely replaced by confused zones of yellow epidote, sometimes with tufts of green hornblende. Moreover, the colour of epidote found in the two localities is generally different: deep bottle-green on Maol nan Damh, and pale yellow, brown, or pink on An Gearna. Finally, garnet is extremely rare on Maol nan Damh, and fairly frequent on An Gearna; its tint varies, but is usually a pale wine-yellow.

On Beinn Fhada, the modification of the original amygdales is carried a step farther. Prehnite-tufts are in some cases found as pseudomorphs after scolecite. Beautiful specimens also occur where scolecite is sprinkled with groups of epidote and garnet, pale-pink, yellow, or even red, in colour. In other cases, nearer the granophyre, the amygdales merge at their margins into the containing rock: often prehnite is found veined and riddled with a pale yellow epidote and a garnet, pale-yellow to almost black in colour; elsewhere amygdales are represented by pale-pink massive material consisting largely of garnet and epidote.

Microscopic investigation shows that the following minerals have arisen during the thermal metamorphism of amygdales: prehnite, epidote, pyroxene, hornblende, garnet, sphene, albite.

The pyroxene and hornblende have been developed from the reaction of chlorite with scolecite or prehnite.

The sphene owes its origin to the titanium which in the original rock was contained in the augite and iron-oxides, and thence made its way into the epidote, and probably the chlorite, of the vesicles.

The prehnite, epidote, garnet, and albite have been derived from such minerals as scolecite and thomsonite. It is very interesting to note that their order of development, as revealed by the microscope, is the reverse of that which regulated the filling of the amygdales. Thus one finds: scolecite replaced by prehnite, followed in turn by epidote and garnet; or thomsonite converted to prehnite and albite, followed as before by epidote and garnet.

The order of alteration just cited bespeaks, in Dr. M'Lintock's judgment, a rising temperature; just as the order of their infilling corresponds with a falling temperature (p. 143). H.H.T., E.B.B.

Amygdales, etc., of Central Basalts in the roof of the Loch Uisg Granophyre

The crags above the Loch Uisg Granophyre are particularly well-suited for the collection of Central Types of lavas in all stages of alteration. The simplest and most prevalent metamorphism is practically that of dehydration of those secondary hydrous minerals which existed in the volcanic rocks at the time of their metamorphism. As such it takes the form of a simple molecular rearrangement of a more or less isolated character and finds expression in the reconversion of soda-lime zeolites to soda-lime felspars, chlorite to biotite, etc. The anhydrous and pyro-genetic minerals such as the pyroxenes and felspars are as a rule unaffected.

In the body of the lavas, low-grade thermal metamorphism is made evident by the formation of minute crystals and patches of red-brown biotite, more particularly in the neighbourhood of particles of iron-ore.

Many of the basalts, whether porphyritic or non-porphyritic, had already undergone some silicification, with a development of quartz in their vesicles and cracks. During metamorphism, the quartz behaved in a manner similar to quartz-xenocrysts caught up in a molten basalt. The interaction of quartz and basalt has, in such cases, given rise to secondary minerals and structures identical with those described in connexion with quartz-xenocrysts by Lacroix in his *Enclaves des roches volcaniques.* Partial assimilation of the secondary quartz of the vesicles has resulted in the residual quartz being surrounded by a reaction-border of augite, rhombic pyroxene, or both. Where assimilation has been complete, the place of the quartz is taken by clots and strings of pyroxene, which, but for the evidence of the less extremely altered rocks, might be taken for cognate pyroxenic nodules.

Partial assimilation of quartz and its envelopment by a reaction-border is exemplified by several sections (e.g. (S18048) [NM 6234 2306], (S18936) [NM 6610 2494], (S18941) [NM 6600 2511]. The reaction-border is of variable width and is composed of glass, usually turbid and coloured by iron, in which are abundant short well-formed prisms of augite and small patches of magnetite. The glass apparently had the composition of an acid plagioclase for such is the usual product of its devitrification. A more or less complete granulitization of the rock as a whole is a usual accompanying feature of the metamorphism. Elsewhere, enstatite-quartz areas represent amygdales and are contained in a granulitic matrix (S18940) [NM 6606 2506].

Complete assimilation of quartz may be inferred where clots of granular augite occur in association with secondary felspar and chlorite (S19085) [NM 6513 2589]. In the larger patches, the augite has an acicular habit, radiating inwards from numerous points on the periphery of the vesicular cavity. A chlorite-nucleus is sometimes preserved. From the outline of such patches it would appear that they result from the metamorphism of amygdales composed of quartz and chlorite.

In other cases of complete assimilation of quartz, the original quartz-chlorite-filled vesicles and fissures are represented by zoned areas of biotite and rhombic pyroxene (S18939) [NM 6606 2502]. Generally, the outer portion of an amygdale is now composed of small prisms and slightly radiating crystals of rhombic pyroxene followed towards the interior by an aggregate of bright-brown biotite, pyroxene, and a little secondary felspar. Occasionally, secondary felspar alone occupies the central position. The containing fine-grained basaltic rock is more or less completely granulitized with a recrystallization of all its constituents other than the comparatively large porphyritic crystals of basic plagioclase.

The development of rhombic pyroxene in the two rocks quoted above (S18939) [NM 6606 2502], (S18940) [NM 6606 2506] presumably denotes a relatively intense phase of metamorphism.

Of all the metamorphosed amygdales, the most interesting occur in a compact porphyritic lava (S18933) [NM 6616 2493]. Here, circular or ellipsoidal areas that represent amygdales are occupied by a fine-grained aggregate of red-brown biotite into which elongated crystals of iron-olivine (fayalite) project from the periphery. The olivine is colourless in thin section but is usually partly decomposed with the separation of abundant magnetite. It is interesting to note that, contrary to custom, the crystals of fayalite are elongated parallel to the zone-axis (001) (100) and slightly flattened parallel to (100). Traces of the good cleavage parallel to (010) cross the crystals at right angles to their long axes. Usually in fayalite the elongation is parallel to the zone-axis (100) (010), but (100) generally shows a tabular development. It is suggested, though proof is lacking, that such a mineral-assemblage results from the metamorphism of vesicles filled with an iron-epidote and chlorite.

Granulitized basalts in the contact-zone of the Corra-bheinn Gabbro

Many additional examples from other aureoles might be cited, but it is enough here to draw attention to three fine-grained granulites which represent lavas baked by the Corra-bheinn Gabbro. In such extreme cases, it is impossible to say whether the originals were of Plateau or Central Type. The specimens were collected in an area that is, for the most part, occupied by Central Types but it is quite possible that they really belong to sharply up-folded lavas of the Plateau Group.

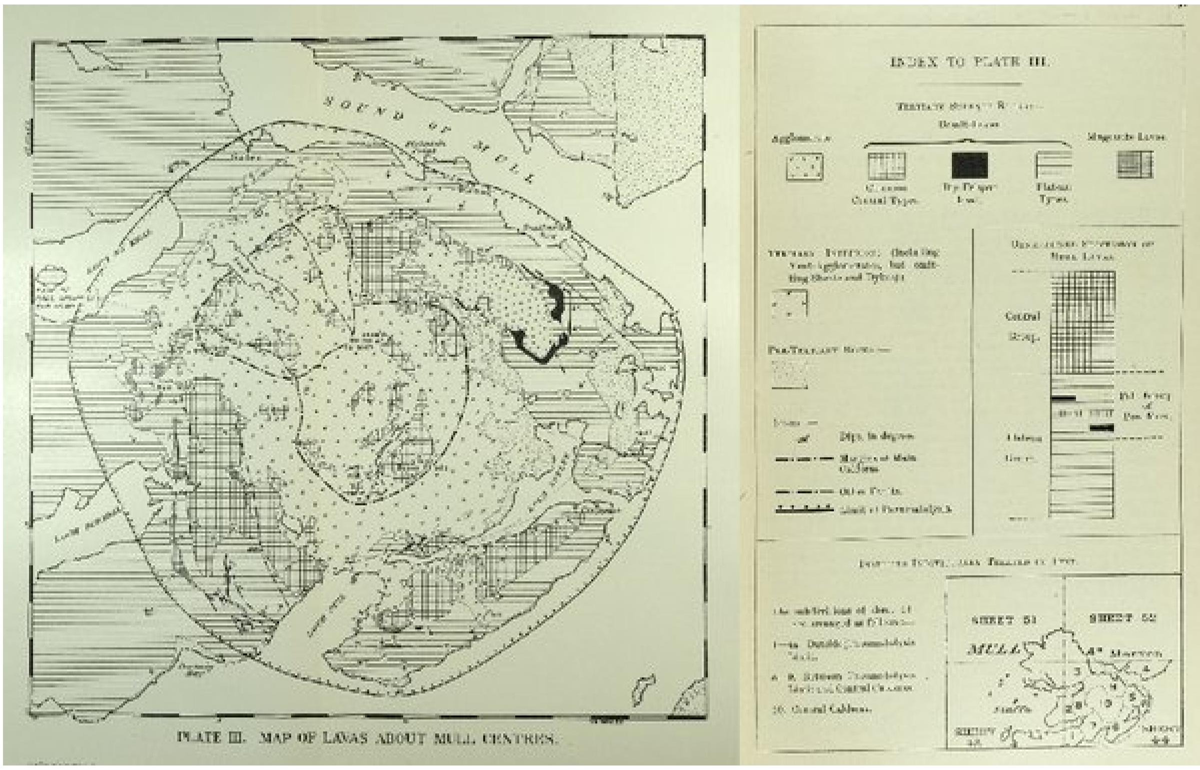
One example (S16494) [NM 5677 3130] consists of granular augite and hypersthene, recrystallized labradorite and magnetite, and, locally, brown hornblende. Patches of clear recrystallized labradorite enclosing biotite and strung with granules of pyroxene represent the partially chioritized original porphyritic felspars. The structure of the rock is typically granulitic. Another (S16493) [NM 5686 3132] is similar but with the granulitic structure coarser and still more pronounced. The rock consists of a mozaic of hypersthene, augite, biotite, magnetite and plagioclase. Its vesicular cavities are filled with a crystalline mass of secondary felspar, near to bytownite in composition, and produced, in all probability, by the dehydration of some zeolitie mineral such as scolecite or laumontite. Such granulites are well-known products of the metamorphism of basaltic rocks and are identical with those described and figured by Dr. Harker<ref>A. Harker, Tertiary Igneous Rocks of Skye, Mem. geol. Surv., 1904, p. 62.</ref> from amongst the Tertiary rocks of Skye.

The remaining specimen was presumably a lava of Plateau Type (S16496) [NM 5829 3184] before its metamorphosis by the Corra-bheinn gabbro. It consists now of a granulitic mass of augite and labradorite veined with actinolitic hornblende. In addition, however, it has developed relatively large areas of clear secondary felspar and brown hornblende, the hornblende being in ophitic or poecilitic relationship to the felspar. H.H.T.

TABLE I. : PLATEAU MAGMA-TYPE OF FIG. 2.

	A	B	I.	II.	III.	C	D	E	
SiO_2	43·94	45·24	45·37	45·48	45·52	46·46	46·61	47·64	SiO_2
TiO_2	2·45	2·26	2·87	3·48	2·85	2·07	1·81	1.27	TiO_2
Al_2O_3	14·03	15·63	15·16	15·66	14·30	15·48	15·32	14·15	Al_2O_3
Cr_2O_3	tr.	tr.	...	...	...	0·02	tr.	0·01	Cr_2O_3
V_2O_3	...	...	...	...	...	0·05	...	0·06	V_2O_3
Fe_2O_3	1·95	5·56	3·38	3·64	3·43	3·63	3·49	5·18	Fe_2O_3
FeO	11·65	7·19	11·58	10·56	9·00	10·23	7·71	7·96	FeO
MnO	0·32	0·23	0·31	0·20	0·19	0·48	0·13	0 33	MnO
(Co,Ni)O	nt. fd.	tr.	nt. fd.	...	...	0·02	tr.	tr.	(Co,Ni)O
MgO	10·46	7·82	6·72	6·99	10·65	6·80	8·66	7·38	MgO
CaO	8·99	9·38	8·11	8·24	9·54	9·05	10·08	11·71	CaO
(Ba,Sr)O	nt. fd.	...	nt. fd.	..	...	0·02	...	nt. fd.	(Ba,Sr)O
Na_2O	2·68	2·01	2·90	2·68	2·21	3·01	2·43	2·38	Na_2O
K_2O	0·33	0 72	0.44	0·49	0·42	0·68	0·67	0·71	K_2O
Li_2O	nt. fd.	...	nt. fd.	nt. fd.	nt. fd.	? tr.	...	...	Li_2O
$H_2O + 105°$	2·31	2·21	1·96	1·52	1·53	1·43	2·07	1.44	$H_2O + 105°$
H_2O at 105°	0·85	1·12	1·18	0·93	0·70	0·89	1·10	0·19	H_2O at 105°
P_2O_5	0·20	0·20	0·29	0·26	0·23	0·30	tr.	0·09	P_2O_5
CO_2	0·16	0·49	...	0·21	0·15	nt. fd.	tr.	...	CO_2
FeS_2	0·04	...	...	...	...	...	...	...	FeS_2
Fe_7S_8	0·06	...	...	...	...	...	...	...	Fe_7S_8
½S	...	...	...	...	...	0·08	...	...	½S
S	...	...	...	nt. fd.	nt. fd.	...	...	0·03	S
	100·42	100 06	100·27	100·34	100·72	100·70	100·08	100·53	...
Spec. grav.	...	2·85	2·95	2·93	2·99	...	2·87	...	...

(Table 1) Plateau Magma-Type of Figure 2



(Plate 3) Map showing the distribution of lava-types and the limit of pneumatolysis

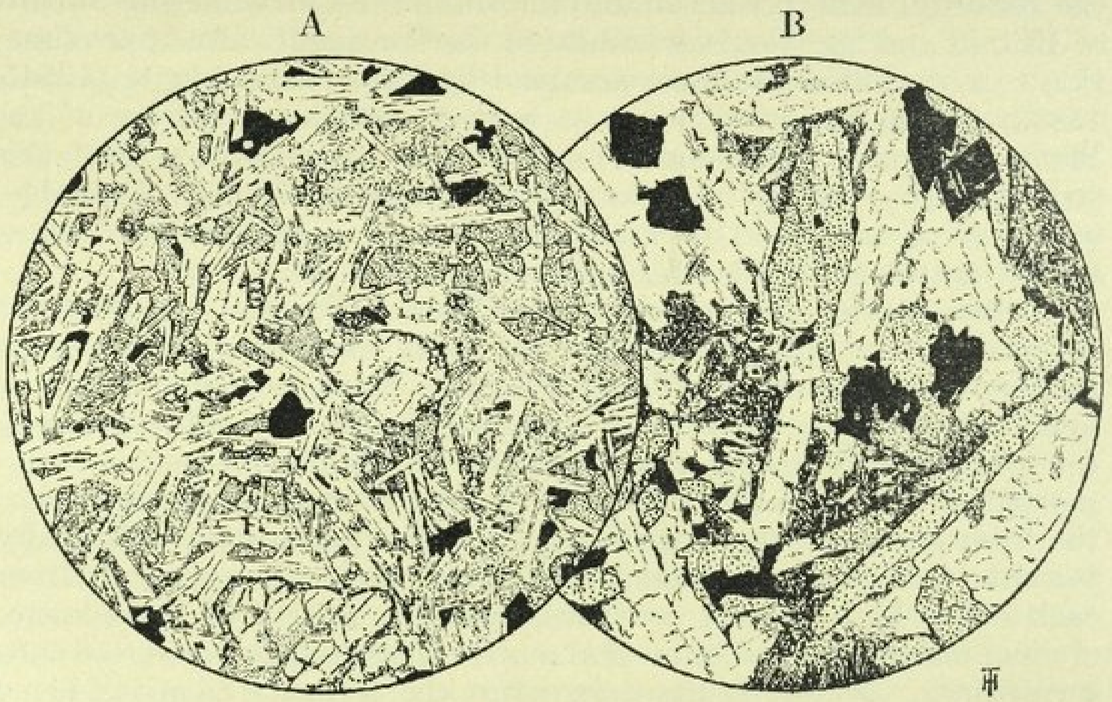


Fig. 19.—Lavas of Plateau Basalt Type.

(Figure 19) Lavas of Plateau Basalt Type. A. [(S15686) [NM 6482 4254]] x 17. Porphyritic Olivine-basalt. The olivine is practically unaltered and occurs as porphyritic crystals (centre and bottom). The augite is titaniferous, having a lilac tinge, and is subophitic in its development with respect to the felspar. The felspar occurs as narrow elongated crystals of labradorite. B. [(S20865) [NM 4194 3832]] x 28. Segregation-vein in basalt-lava of Plateau Type. Titaniferous augite in large crystals that exhibit hour-glass structure and are zoned with aegerine-augite; partially analcitized labradorite; and conspicuous ilmenite. The residuum consists of microlithic alkali-felspar, aegerine-augite, and chlorite.

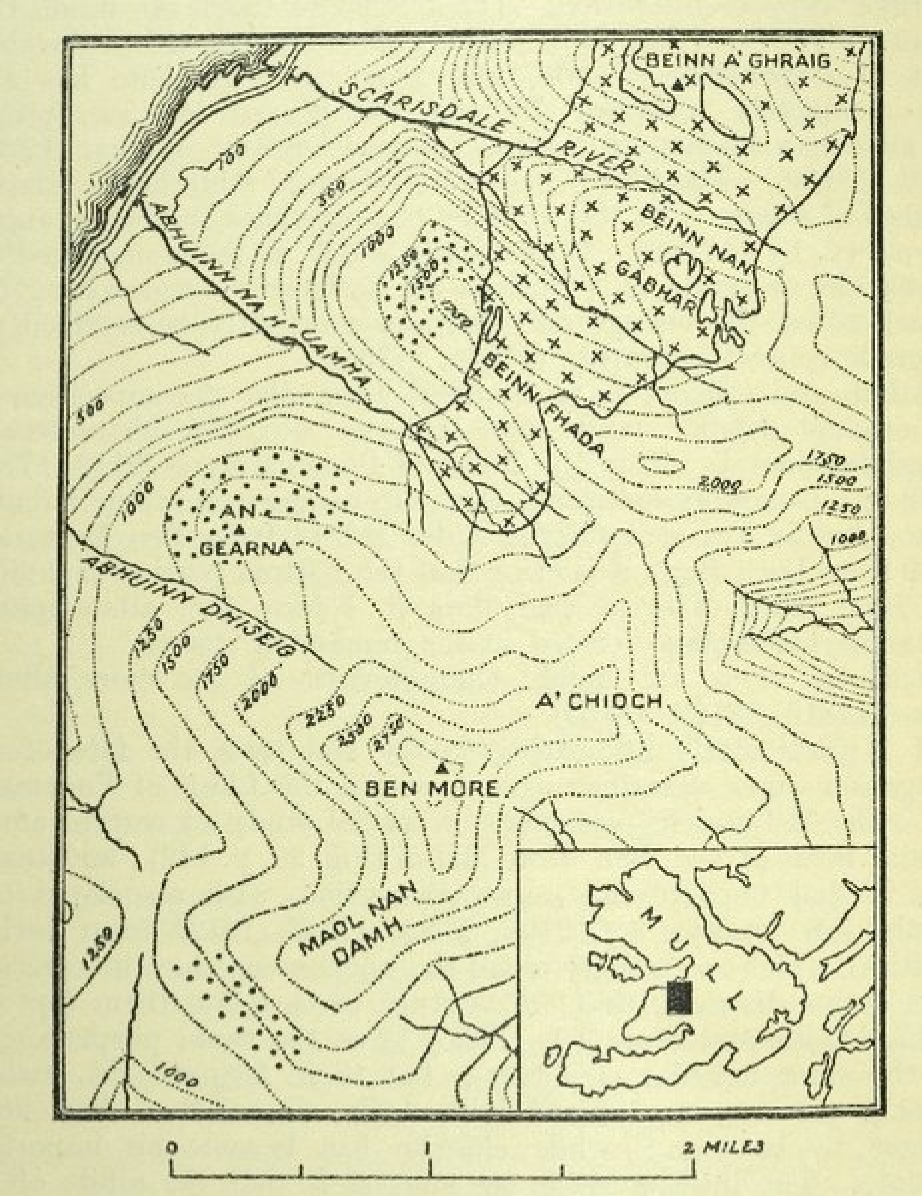
TABLE IX.

	Phenocrysts		Amygdale—Minerals												Mud-Stone	Xenoliths and enclosed Spinel			
			Outside Pneumatolysis Limit								Inside Pneumatolysis Limit			Inside Contact-Zone						
	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X	XI.	XII.	XIIa.	XIII.	XIV.	XV.	XVI.	XVII.	XVIII.	
SiO_2	49·72	53·80	53·74	53·41	52·36	53·29	45·91	46·51	46·62	46·75	46·21	46·10	45·9	38·60	37·66	30·26	49·74	38·67	0·77	SiO_2
TiO_2	0·85	—	—	—	—	—	—	—	—	—	—	nt. fd.	—	0·12	0·12	1·32	1·19	0·90	0·50	TiO_2
Al_2O_3	0·90	31·04	0·62	1·76	1·71	—	5·11	2·40	3·90	24·32	27·00	25·65	26·0	23·34	21·24	27·34	31·99	37·27	67·81	Al_2O_3
Fe_2O_3	1·72	—	—	—	—	—	—	1·34	0·60	—	—	—	—	0·97	1·67	1·57	1·53	2·78	4·25	Fe_2O_3
FeO	27·77	—	—	—	—	—	2·07	1·85	1·08	—	—	0·25	—	0·22	0·34	17·18	4·34	5·07	24·02	FeO
MnO	0·08	—	—	—	—	—	2·27	—	—	—	—	nt. fd.	—	0·29	0·53	0·13	0·13	0·17	0·15	MnO
(Co, Ni)O	nt. fd.	—	—	—	—	—	—	—	—	—	—	nt. fd.	—	nt. fd.	nt. fd.	0·04	nt. fd.	nt. fd.	nt. fd.	(Co, Ni)O
MgO	12·69	—	—	—	—	—	0·56	0·47	—	—	—	0·32	—	0·49	0·45	0·34	0·66	2·35	0·57	MgO
CaO	3·89	12·83	31·19	31·60	31·48	33·41	40·39	33·40	33·08	13·90	13·43	14·17	14·8	22·79	33·36	0·74	0·88	4·85	0·36	CaO
BaO	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	nt. fd.	nt. fd.	—	—	BaO
Na_2O	0·23	3·56	9·34	8·11	8·04	8·80	0·32	0·36	0·80	0·89	—	tr.	—	tr.	1·17	1·08	2·76	3·63	—	Na_2O
K_2O	0·12	tr.	nt. fd.	2·43	2·47	—	1·16	1·15	0·37	—	—	0·03	—	0·03	0·73	2·05	1·72	3·01	—	K_2O
Li_2O	tr.	—	—	—	—	—	—	—	—	—	—	nt. fd.	—	tr.	nt. fd.	nt. fd.	tr.	nt. fd.	—	Li_2O
H_2O -105°	1·37	0·52	2·38	2·66	4·07	4·16	4·17	12·91	12·11	13·64	13·78	13·78	13·8	0·89	0·29	7·20	3·44	1·05	0·14	H_2O+105°
H_2O at 105°	0·08	—	0·6	—	—	—	—	—	—	—	—	0·13	—	0·09	nt. fd.	1·44	0·61	0·22	nt. fd.	H_2O at 105°
P_2O_5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0·24	0·36	—	—	P_2O_5
CO_2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0·04	—	—	CO_2
FeS_2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	nt. fd.	nt. fd.	—	—	FeS_2
	100·13	99·65	99·67	101·05	100·67	100·06	100·76	100·10	99·81	99·80	100·44	100·13	100·0	100·21	100·19	100·04	100·21	100·35	100·39	
Spec. grav.	3·44	2·78	—	—	—	—	2·605	—	2·423	—		2·285		3·488	3·61		2·65	2·21	3·867	

I. Uniaxial Augite. II. Labradorite. III.–VI. Pectolite. VII. Xenotlite. VIII, IX. Tobermorite.[1]
X.–XII. Scolecite. XIII. Pink Epidote. XIV. Garnet. XV. Basal Mudstone (altered).
XVI. Uncontaminated argillaceous xenolith. XVII. Contaminated argillaceous xenolith.
XVIII. Dark-green Spinel.

[1] In British Museum Students' Index Tobermorite is listed as a synonym of Gyrolite.

(Table 9) Analyses other than bulk anayses of igneous rocks, made from material collected collected in the Mull District.



(Figure 20) Map showing zeolite-localities (dotted) and granophyre (crossed). Quoted from Trans. Roy. Soc. Edin., vol. li., 1915, p. 3.

TABLE VII.—ALKALINE MAGMA-SERIES OF FIG. 4.

	Mugearite				Syenite	Trachyte		
	A	B	C	I.	II.	III.	IV.	
SiO_2 .	49·24	49·92	50·70	55·76	58·81	60·13	63·12	SiO_2
TiO_2 .	1·84	2·04	1·89	1·78	0·76	0·73	0·51	TiO_2
Al_2O_3 .	15·84	12·83	14·60	16·55	14·81	16·53	15·44	Al_2O_3
Cr_2O_3 .	tr.	tr.	..	...	...	...	...	Cr_2O_3
V_2O_3 .	...	0·04	...	...	...	...	...	V_2O_3
Fe_2O_3 .	6·09	6·96	5·23	3·10	4·58	2·86	1·73	Fe_2O_3
FeO .	7·18	6·21	7·68	6·02	4·21	2·55	3·53	FeO
MnO .	0·29	0·52	0·42	0·22	0·27	0·46	0·27	MnO
(Co,Ni)O	tr.	0·03	tr.	nt. fd.	nt. fd.	nt. fd.	nt. fd.	(Co,Ni)O
MgO .	3·02	3·78	4·15	1·08	0·80	1·20	0·62	MgO
CaO .	5·26	7·25	7·20	3·23	2·33	1·61	1·31	CaO
BaO .	0·09	0·09	0·08	0·07	0·03	0·11	nt. fd.	BaO
SrO .	tr.	tr.	tr.	...	...	...	...	SrO
Na_2O .	5·21	3·72	3·71	6·28	5·60	8·06	5·81	Na_2O
K_2O .	2·10	1·73	1·33	3·87	4·96	3·99	5·36	K_2O
Li_2O .	...	tr.	? tr.	tr.	nt. fd.	tr.	nt. fd.	Li_2O
$H_2O + 105°$	1·61	1·05	1·15	0·95	0·82	0·97	0·44	$H_2O + 105°$
H_2O at 105°	1·08	3·58	2·08	0·80	2·00	0·55	0·14	H_2O at 105°
P_2O_5 .	1·47	0·45	0·49	0·40	0·20	0·57	0·25·	P_2O_5
CO_2 .	...	nt. fd.	nt. fd.	0·03	...	...	1·89	CO_2
FeS_2 .	...	...	...	nt. fd.	nt. fd.	nt. fd.	nt. fd.	FeS_2
S . .	0·03	? tr.	nt. fd.	...	...	...	...	S
F . .	0·18	...	...	...	...	...	...	F
	100·46*	100·20	100·71	100·14	100·18	100·32	100·42	
Spec. grav	2·79	...	...	2·67	2·64	2·51	2·89	

(Table 7) Alkaline Magma-Series of Figure 4

TABLE II.—NON-PORPHYRITIC CENTRAL MAGMA-TYPE OF FIG. 2.

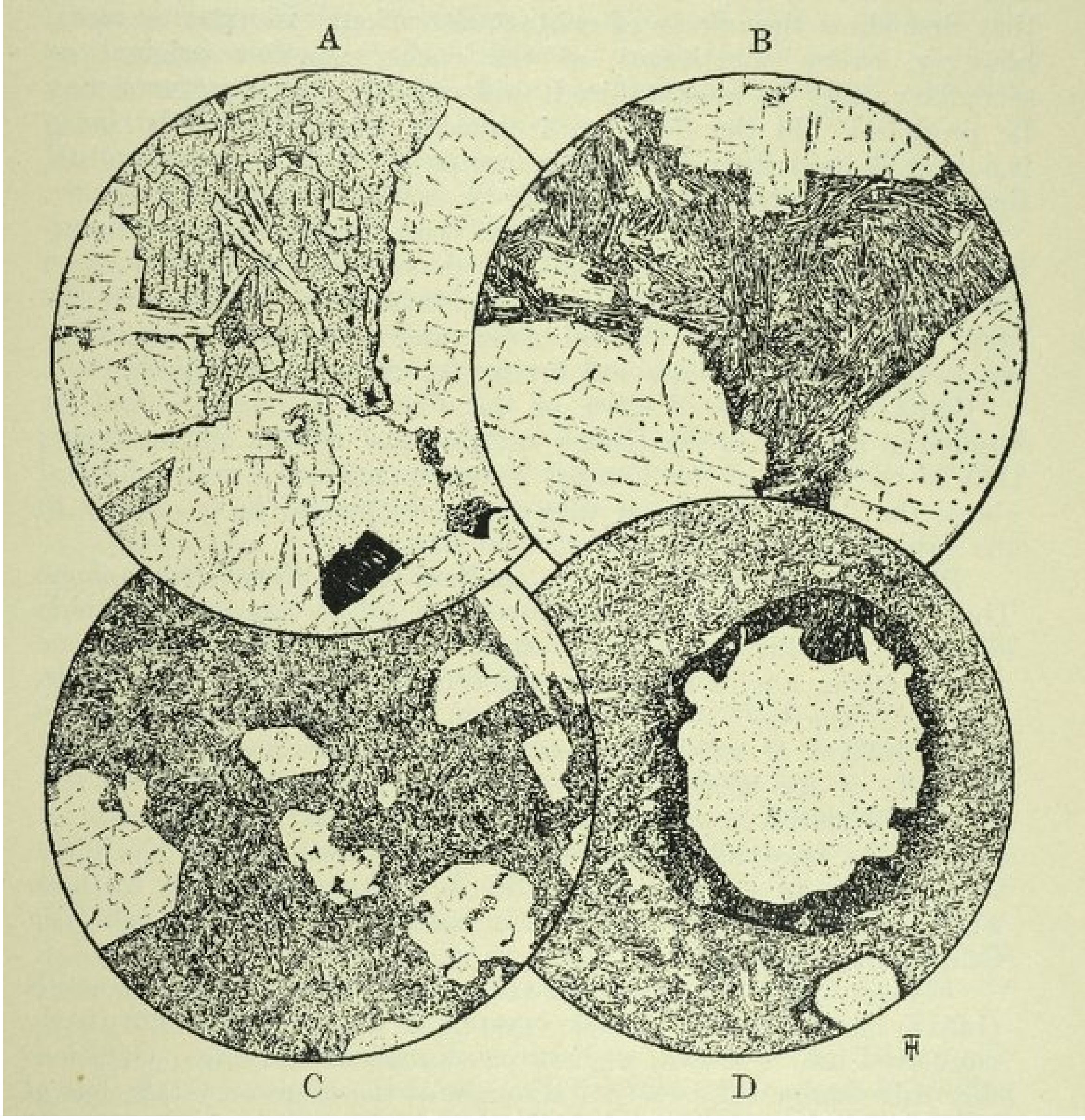
	Tho-leiite Salen Type	Basalt Staffa Type			Basalt Compact Central Type		Tholeiite Brunton Type		Quartz-Dolerite and Tholeiite Talaidh Type		
	I.	II.	III.	A	IV.	V.	VI.	VII.	VIII.	IX.	
SiO_2 . . .	47·35	47·80	49·76	52·13	50·54	53·78	51·53	51·63	52·16	53·97	SiO_2
TiO_2 . . .	1·75	....	0·94	....	2·80	2·28	1·57	2·00	3·25	1·24	TiO_2
Al_2O_3 . .	13·90	14·80	14·42	14·87	12·86	12·69	11·05	11·77	11·95	14·65	Al_2O_3
Fe_2O_3 . .	5·87	....	3·95	....	4·13	3·44	2·73	3·23	4·86	3·62	Fe_2O_3
FeO . .	8·96	13·08	7·77	11·40	8·75	8·94	10·98	10·47	9·92	6·32	FeO
MnO . .	0·23	0·09	0·20	0·32	0·32	0·53	0·45	0·35	0·18	0·30	MnO
(Co, Ni)O .	nt. fd.	....	nt. fd.	....	0·06	nt. fd.	nt. fd.	0·04	....	nt. fd.	(Co, Ni)O
MgO . .	5·97	6·84	5·30	6·46	4·63	2·58	5·21	5·02	3·77	4·49	MgO
CaO . .	10·65	12·89	10·22	10·56	8·74	6·36	9·68	9·34	7·14	7·98	CaO
BaO . .	....	....	0·04	....	nt. fd.	0·09	nt. fd.	0·03	....	0·04	BaO
Na_2O . .	2·73	2·48	2·49	2·60	2·89	2·74	3·48	2·90	2·36	2·51	Na_2O
K_2O . .	0·54	0·86	1·83	0·69	1·43	2·27	0·86	0·91	1·74	1·52	K_2O
Li_2O . .	....	....	tr.	....	nt. fd.	nt. fd.	tr.	nt. fd.	....	tr.	Li_2O
$H_2O - 105°$	1·16	1·41	1·03	1·19	2·25	2·19	1·26	1·40	1·95	0·94	$H_2O + 105°$
H_2O at 105°	1·04		2·04		0·17	1·19	0·71	0·68	0·56	1·92	H_2O at 105°
P_2O_5 . .	0·24	....	0·21	....	0·34	0·55	0·22	0·29	0·24	0·27	P_2O_5
CO_2 . .	0·32	....	0·06	....	0·33	0·08	0·08	0·11	0·18	0·51	CO_2
FeS_2 . .	....	....	0·04	....	nt. fd.	0·42	0·26	0·08	....	0·09	FeS_2
S . . .	0·23	....	....	....	....	....	....	....	0·18	....	S
	100·94	100·25	100·30	100,22	100·24	100·13	100·07	100·27	100·44	100·40	
Spec. grav.	2·96	....	2·72	....	2·90	2·68	2·93	2·95	2·91	2·83	

(Table 2) Non-Porphyritic Central Magma-Type of Figure 2

TABLE VI.—Porphyritic Central Magma-Type of Fig. 3.

	Dolerite	Gabbro			Basalt			
	I.	A	B	II.	III.	IV.	V.	
SiO_2	45·54	46·39	47·28	48·34	47·24	47·49	48·51	SiO_2
TiO_2	1·06	0·26	0·28	0·95	1·46	0·93	1·46	TiO_2
Al_2O_3	23·39	26·34	21·11	20·10	18·55	21·46	19·44	Al_2O_3
Cr_2O_3	...	tr.	...	...	...	...	...	Cr_2O_3
Fe_2O_3	1·98	2·02	3·52	1·97	6·02	1·72	5·66	Fe_2O_3
FeO	6·98	3·15	3·91	6·62	4·06	4·80	4·00	FeO
MnO	0·27	0·14	0·15	0·32	0·31	0·15	0·23	MnO
(Co,Ni)O	...	...	...	nt. fd.	0·05	0·04	0·04	(Co,Ni)O
MgO	4·60	4·82	8·06	5·49	5·24	4·59	5·12	MgO
CaO	11·82	15·29	13·42	13·16	11·72	13·24	12·03	CaO
BaO	...	...	...	0·10	nt. fd	nt. fd.	nt. fd.	BaO
Na_2O	2·50	1·63	1·52	1·66	2·42	2·17	2·53	Na_2O
K_2O	0·44	0·20	0·29	0·98	0·15	0·42	0·25	K_2O
Li_2O	...	...	...	nt. fd.	nt. fd.	nt. fd.	nt. fd.	Li_2O
$H_2O+105°$	0·72	0·48	0·53	0·44	2·24	2·54	0·48	$H_2O+105°$
H_2O at 105°	0·62	0·10	0·13	0·02	0·21	0·17	0·04	H_2O at 105°
P_2O_5	0·13	tr.	tr.	0·04	0·26	0·43	0·16	P_2O_5
CO_2	...	...	...	0·11	0·19	0·08	0·09	CO_2
FeS_2	...	...	...	nt. fd.	nt. fd.	nt. fd.	nt. fd.	FeS_2
	100·05	100·82	100·20	100·30	100·12	100·23	100·04	
Spec. grav.	2·85	2·85	2·90	2·93	2·85	2·82	2·93	

(Table 6) Porphyritic Central Magma-Type of Figure 3



(Figure 21) A -C Pillow-Lava, Cruach Choireadail. D Beinn Fhada. A. (S17184) [NM 5932 2982] x 17. Interior of Pillow. Moderately coarse doleritic rock with the augite and felspar in ophitic relationship. B. (S17185) [NM 5940 3000] x 17. Exterior of Pillow. The felspar occurs in two generations as porphyritic crystals of bytownite-anorthite, and as slender laths, which, with elongated crystals of augite, impart a variolitic structure to the matrix (compare with (Figure 23a, p. 163). C. (S17186) [NM 5924 3011] x 17. Chilled Margin of Pillow. Porphyritic basic plagioclase, near anorthite in composition, in a fine-textured matrix. The ground-mass is composed of small, elongated crystals of felspar, augite and iron-ore, with a chloritized residuum probably representing glass (compare with Fig 23A, p. 163). D. (S18039) [NM 6437 2936] x 17. Beinn Fhada. Portion of the exterior of a pillow showing the characteristic invasion of vesicular cavities by mesostatic residual material which has subsequently frothed up in situ.