Petrology of the Bodmin Moor granite (eastern part), Cornwall.

(With Plates VI and VII.)

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I. Introduction.

THIS paper presents the results of an investigation of the granite composing the eastern part of Bodmin Moor, Cornwall, as mapped on Sheet no. 337 of the Geological Survey. The work was undertaken on the suggestion of Dr. J. W. Evans, and comprised the field- and laboratory-work necessary for a detailed study of the petrology and tectonics of the area.

The boundary of the granite, as mapped by the Geological Survey, has been retained, and also the distribution of the two main granite types ('coarse' and 'fine') shown on the Survey map. The coarse granite, however, has been sub-divided into two varieties, and it has been found practicable to map the distribution of each (fig. 1).

The killas inclusions in this granite have not hitherto been studied, and these have received due attention. Similarly, the minor intrusions described include some that have not been previously recorded.

Bulk analyses of Bodmin Moor granites were lacking, and, as the investigation indicated the need of such analyses, representative types have been selected and analysed.

II. The Prevalent Rock-types.

(a) *The granite types and their distribution.*

The Survey map (Sheet no. 337) distinguishes between two different varieties of granite, namely (1) an earlier 'coarse-grained granite', and (2) a later 'fine-grained granite'.

The results of the author's investigation establish the composite character of the coarser granite, which presents two varieties differing in chemical composition and petrographical characters. One of these varieties corresponds in detail with the standard coarse-grained granite

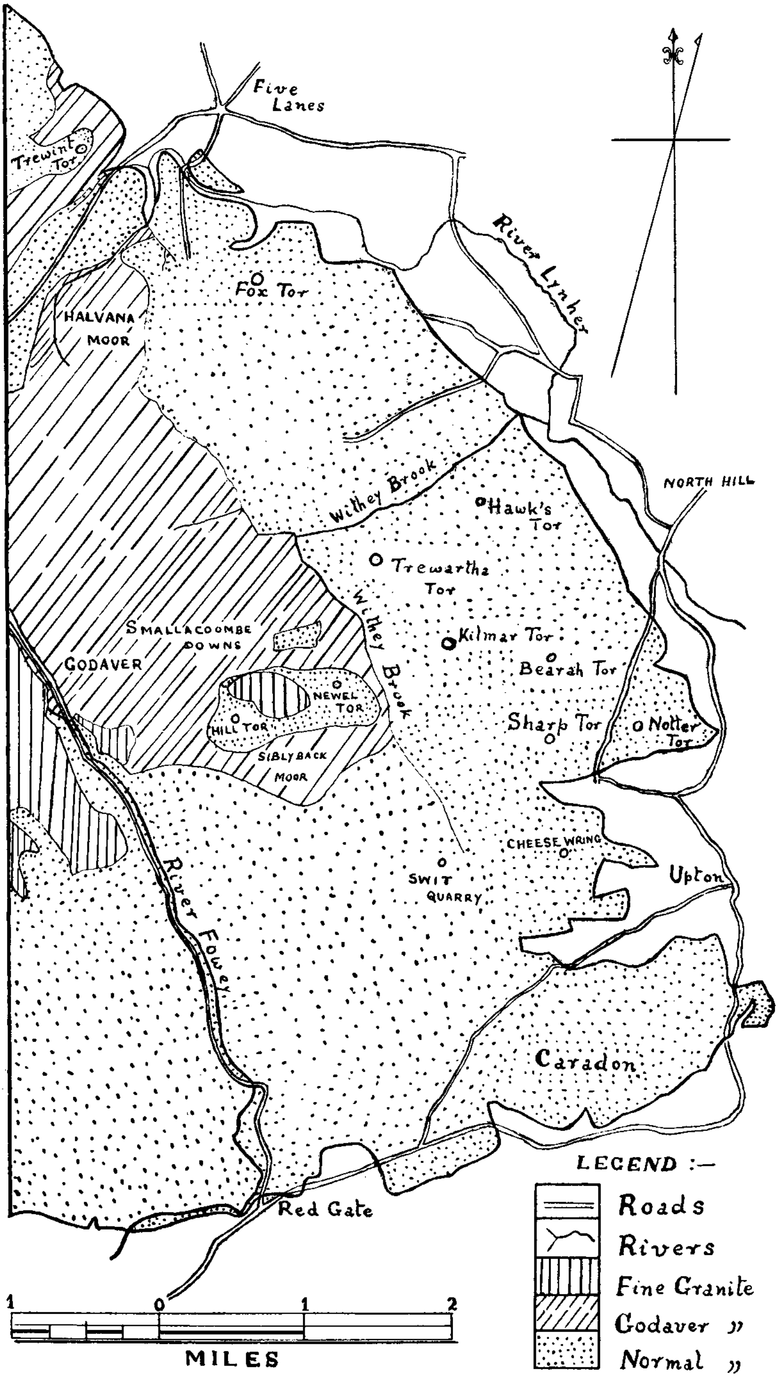


FIG. 1. Sketch-map of the Bodmin Moor granite (eastern part).

described in the Memoir, and will be referred to, herein, as the '*Normal type*'. The other variety, newer than the former, will be referred to as the '*Godaver type*'; the type-locality being in the region of the Godaver mines, just a little to the north of Harrow Bridge, east of the Fowey, where it was first noticed. The third type will be referred to as the '*fine type*', after the Geological Survey.

The distribution of the three types is shown on the map (fig. 1). The 'Normal type' predominates, forming the whole of the eastern and southern parts of the area and some portions on the north. It also forms some of the tor-caps,[1] resting on the 'Godaver type', in the region where that reaches its maximum development.

The 'Godaver type', with the exception of an occurrence west of the Fowey, bordering the east and north of the 'fine granite', is confined to the area between the Fowey and the Withey Brook and its northward extension. South of the typical area it appears on the flanks of the Smallcombe Tor, Newel Tor, and Hill Tor (all of which are capped by the 'Normal type'), and gradually falls in level towards the Siblyback Moor, where it eventually disappears. South of the main area it occurs again on the Craddoc Moor as dikes in the 'Normal' granite, e.g. in the Swit quarry.

North of the three tors named above, as far as the north side of Halvana Moor, the whole area is made up exclusively of the 'Godaver type'. On the north-east of Halvana Moor, the 'Godaver type' gradually dips beneath the Normal type, becoming finer-grained near the contact. On the slightly higher ground east of the small river, the Normal type is extensively injected by vein-like offshoots from the underground prolongations of the Godaver type beneath this area, and also by veins of quartz-tourmaline and quartz in large amounts. The Godaver type reappears again as a thin sill and vein injections in the Normal type in the region north of Fox Tor.

From the characters described above it would appear that the Godaver type was intruded almost horizontally below the Normal type. The contact-surface or 'roof' is practically horizontal towards the centre, e.g. Hill Tor, Trewint Tor, &c., but shows a gentle dip at the margins, e.g. Halvana Moor. Pseudo-bedding is parallel.

The character of the intrusive 'fine granite' has been described in Memoirs 336 and 337. It may be added that this also shows intrusive relations to the Godaver type at its eastern and northern margins, where

[1] Cf. the occurrence on Dartmoor described by Dr. A. Brammall, Proc. Geol. Assoc., 1926, vol. 37, pp. 262-264.

it sends vein-like offshoots and quartz-schorl veins into the Godaver type.

The Normal granite is laccolithic in relation to the country-rock, the pseudo-bedding showing a flat dip near the junction, while it is practically horizontal elsewhere.

Megascopic characters of the three types.—The Normal type is the coarsest in texture. Porphyritic orthoclase is abundant. Biotite and muscovite are present in almost equal proportions, and tourmaline also occurs. Quartz affords the most valuable guide to the identification of this type in the field; it occurs in large granular patches more or less interstitially.

The Godaver type is of medium grain and is also porphyritic, but its phenocrysts are less abundant than those of the Normal type. Pink orthoclase occasionally occurs in the groundmass. Biotite is less, and tourmaline more, abundant than in the Normal type. A little purple mica, lithionite, may be detected in hand-specimens. In contrast to the Normal type, quartz generally shows a porphyritic habit; it is more or less rounded, and does not appear granulated. The bleb-like character of the quartz is very characteristic. At its contact with the Normal type, the Godaver type has a finer texture, and may then resemble the 'fine granite'; but it never shows any great amount of chill-effects, and rapidly regains a medium coarseness at a short distance from the contact, where it is coarser than the 'fine granite' at its coarsest.

The 'fine granite', in addition to its fineness in grain, shows a few and very small porphyritic crystals of orthoclase, which sometimes vanish completely. 'The usual absence of the large quartz grains that are persistently present in the main intrusion . . .'[1] is also a remarkable feature. The amount of biotite is less and that of tourmaline more, than in the earlier types.

(*b*) *Minor intrusions and mineral veins.*

Each of these major igneous intrusions was followed by a suite of minor intrusions through fissures newly opened in them as they gradually cooled and consolidated. They occur in dikes, sills, and thin veins, and present many varieties, representative of an undifferentiated granite magma on the one hand, and its differentiated fractions, both leucocratic and melanocratic, on the other. In addition, there occur also mineral

[1] Geol. Survey Sheet Memoir, no. 337 (The geology of the country around Tavistock and Launceston), 1911, p. 70.

veins, e.g. quartz-tourmaline veins, and quartz-veins, joint-plane crusts of fluorite, and metalliferous lodes.

The intrusive history may be summarized thus:

1. Intrusion of the Normal granite, followed by quartz-tourmaline veins, and then by
   (a) Pegmatites and melanocratic veins,
   (b) Aplites,
   (c) Quartz-tourmaline veins, quartz veins.
2. Intrusion of the Godaver granite, followed by quartz-tourmaline and quartz veins.
3. Intrusion of the 'fine granite', followed by quartz-tourmaline and quartz veins.
4. Elvan dikes, followed by quartz-tourmaline and quartz veins.
5. Metalliferous lodes, followed by quartz-tourmaline and quartz veins.

(i) *Undifferentiated Type of Minor Intrusion.*—The rocks of the undifferentiated type, which are the commonest and occur chiefly as dikes, belong to the granite- and quartz-porphyry families, with the usual characters. They are locally known as 'elvans'. They follow the 'fine granite'. Their trend is roughly E.N.E. to E.-W., parallel with the mineral veins and lodes and to one of the major joints of the granite. A feature in connexion with many of these dikes is the large development of cubical crystals of pyrites, especially near the margins, embedded in the felsitic groundmass. Jointing is well-developed, often in three or more systems, which divide the rock into rhombohedral blocks.

(ii) *Differentiated Types.*—Turning to the differentiated types, we find pegmatites and highly felspathic veins (both of coarse texture), with aplites and melanocratic veins (both fine-grained), the latter very rich in biotite and plagioclase. The differentiated minor intrusions, with the exception of mineral veins and lodes, are associated with the Normal granite only and are pre-Godaver.

1. *Pegmatites and Felspathic veins.*

These occur generally as irregular and lenticular pocket-infillings of no great extent in the body of the main granite; the longest axis lies more or less on the horizontal plane. They are sometimes crossed by surfaces of the pseudo-bedding in continuity with those of the granite (e.g. at Notter Tor, upper quarry). They are very coarse-grained, with large felspars, quartz, muscovite flakes, and tourmaline crystals. They sometimes occur as horizontal, sill-like sheets, and as narrow, more or less vertical dikes along the roughly east and west joint-planes of the granite. The rock of the dike is medium-grained, but coarser than the granite, that of the sill is coarser still. In some cases, the enclosing granite becomes mineralized near the contact.

2. *Melanocratic Differentiates.*

The melanocratic differentiates sometimes occur associated with the lenticular pocket-infillings of the pegmatitic material as thin films forming, in part at least, the external boundary of the pocket and then passing into the granite itself as a narrow and very irregular vein.[1]

Similar differentiates may also be found in the granite without any apparent connexion with the pegmatitic material, and show the same irregular habit. Thus, from a horizontal position along the pseudo-bedding of the granite, the rock may suddenly pass upwards through the granite in a deviating fashion with repeated minor veinings at all levels.

Small lenticular patches of this material may be found in the near neighbourhood of the veins, sometimes connected with them by minor veins. This connexion is not apparent in other cases, and the patches in consequence appear as a sort of segregation product. These are fine-textured, with porphyritic plagioclase and quartz and a large amount of biotite embedded in a bluish, even-grained groundmass. The biotite usually shows a banded arrangement. Andalusite is abundant.

3. *Aplites.*

These have been observed mainly in the Kilmar, Hawk's, and Trewartha Tors along the southerly-dipping E.N.E. joint-planes. A smaller number also occur in the other set of main joints. These are never

[1] Here perhaps we have an instance of rock-differentiation on a small scale. As the consolidation of the main body of the rock continued, there continued to collect in these pockets the remaining 'liquor', which had a high content of fluxes promoting crystallization. The liquor was, however, contaminated: andalusite, collected below and marginally, by interaction with the residual liquor, precipitated a large amount of plagioclase and biotite (see p. 304), and gave rise to the melanocratic rock (which still contains a large amount of andalusite); while the body of the fluid, being freed from the ferromagnesian and a large amount of more basic plagioclase content in this way, crystallized out as a perfectly leucocratic rock with orthoclase and albite as its dominant felspathic constituents.

thick, varying generally from 2 to 9 inches in breadth. They are always fine-textured and even-grained; they are light greyish-white in hand-specimens, showing a certain amount of light-coloured schorl and occasionally small flakes of muscovite. The aplites do not show any chilling at the margin, but, on the contrary, have been seen to grow a little coarser in some cases, though this marginal facies never attains the coarseness of a pegmatite, as in the Dartmoor granite.[1]

4. *Mineral Veins and Lodes.*

The mineral veins, viz. quartz-tourmaline, quartz, and fluorite veins, occur along the joint-planes of the granite and elvans, and also as abundant offshoots at the contact regions of the various granite types. They followed every one of the major and minor intrusions. The lodes appear as the last phase of igneous activity, and are found to cut through all the granites and elvans. These were also followed by quartz-tourmaline and quartz veins.

III. General Microscopical Character.

(a) *The Normal Granite Type.*—This type is very coarse-grained, with a large development of porphyritic crystals of microcline and orthoclase. None of the constituent minerals, except accessories, present well-defined crystal outlines. Even the porphyritic microcline and orthoclase show a rugged and resorbed margin, and there is almost always a narrow and irregular growth of plagioclase along the margin partly or almost completely surrounding the crystals. These plagioclase strips (albite, albite-oligoclase) may be composed of several small crystals; sometimes, individual crystals of fairly large size are also met with. Orthoclase and microcline also occur in the groundmass in irregular plates. The plagioclase is a little more idiomorphic, the smaller ones still more so. Coarse patches of granulitic quartz are usual and the boundaries are the least defined. The individual patches are composed of a large number of smaller individuals with interlocking and sutured boundaries.[2]

Biotite and muscovite are present almost in equal amounts, and are very often intergrown. Pleochroic haloes are abundant, especially in the former. Tourmaline is invariably present. Cassiterite, iron-ores (titaniferous or not), apatite, are very usual accessories; andalusite is

[1] A. Brammall, loc. cit.
[2] Cf. W. A. Richardson, A micrometric study of the St. Austell granite. Quart. Journ. Geol. Soc., 1923, vol. 79, p. 553.

a very characteristic accessory; corundum and zircon are not uncommon. These three minerals occur generally as inclusions in micas and felspars; but andalusite also occurs as an independent mineral. Topaz and fluorite are rarely present except in pneumatolysed varieties.

Sharp Tor—Notter Tor Sub-Type.—While predominance of potash-felspars over the plagioclase, and coarseness of grain of the groundmass in the Normal granite type, hold as a general rule, an exception in both these respects has been noticed in the case of the rocks of the Sharp Tor and Notter Tor areas. The mineral character and the texture, presenting several departures from the standard type, are noted below.

The potash-felspars are heavily charged with perthitic intergrowths. They also contain small inclusions of plagioclase as usual. The cross-hatching of microcline is on a very delicate scale and may disappear from a part of the crystal altogether.[1] The boundary of these felspars is exceedingly irregular and corroded, with large marginal deposition of plagioclase (albite–oligoclase). Some of the phenocrysts are irregularly cracked, often giving rise to wide interspaces (due evidently to melting under conditions of disturbed equilibrium), the infilling of which is exclusively plagioclase in subhedral plates, and rather narrow and elongated tablets. A considerable amount of the potash-felspars seems to have been removed in this way to make room for so much plagioclase; sometimes, only a very narrow strip of the original microcline is left as a relic among the growths of later plagioclase.

The smaller crystals of microcline and orthoclase in the groundmass also show the border zone of plagioclase—a fact never observed except in this type. These phenomena are perhaps somewhat akin to albitization, and there is, on the whole, a preponderance of plagioclase over potash-felspars. The proportion of $K_2O : Na_2O$ (4·26 : 4·31) when compared with that of the usual types (5·5 : 3·5, on the average), is also marked with a striking variation. (Vide Chemical Analyses 1, 2, & 3, p. 307).

While the rock is coarse-grained on the whole, there has been noticed a very delicate lace-like structure, in places as a groundmass, sometimes as a fringe to the larger constituents, and somewhat resembling 'myrmekite structure'.[2] In this case it consists, however, of slender rods and grains of clear orthoclase intergrown with vermicular and wart-like grains of quartz. Some of the muscovite plates ophitically

[1] This implies a large content of soda: J. P. Iddings, Rock Minerals, 1911, p. 235.

[2] J. J. Sederholm, Bull. Comm. Géol. Finlande, 1916, no. 48, p. 63.

enclose slender orthoclase laths. Shreds of biotite are also present in the groundmass; they belong to a later stage than large flakes—the usual habit of the mineral.

The rock presents another peculiarity; it is crossed by thin veins of clear orthoclase resembling in purity that in the granophyric groundmass. These traverse earlier formed potash-felspars and plagioclase and consist of a sub-granular aggregate of clear orthoclase crystals, with twinning rarely developed. In places, these are crowded with needles of blue tourmaline. Apatite is very often associated with these veins.

These rocks have been considerably injected by tourmaline veins towards the later stages of consolidation, and in connexion with them there has been a development of small needles and grains of tourmaline in the granophyric groundmass. Some sections, cut perpendicular to the vein, show under the microscope the development of tourmaline on one side of the vein only, while the other half of the rock is quite unaffected.

(i) *Microscopical Characters of Individual Minerals.*

Microcline is generally fresh and clear as opposed to plagioclase. Carlsbad-twinning is often present in addition to the usual cross-hatching. The latter type of twinning is sometimes on a very delicate scale and may disappear from a part of the crystal altogether. The porphyritic felspars specially are largely perthitic. There are also, in addition, inclusions of twinned and zoned plagioclase crystals, generally of tabular habit with good crystal outlines; also of elongated narrow prisms, sometimes along the composition-plane of the twin itself. These may also exhibit a tendency to occur zonally; in a few observed cases, four or five alternate zones could be made out. Thus in one case, the core is formed of a Carlsbad-twin of microcline, followed and surrounded on all sides by a narrow zone of small crystals of plagioclase; then follows another wider zone of microcline in reversed orientation relative to the core. This is again followed by a less definite zone of plagioclase, and then by microcline in reversed orientation relative to the nearest zone (Plate VI. fig. 1). The later zones are very much interrupted by the intergrowth of plagioclase with irregular boundaries and large flakes of mica (muscovite), some of the latter with inclusions of microcline in optical continuity with the phenocryst of microcline itself. Some of the included plagioclases may show neither zoning nor twinning, but are marked by undulatory extinction (?anorthoclase). The included plagioclases themselves may carry inclusions of idiomorphic biotite.

Inclusions of quartz are also present. They may be quite irregular in shape, occurring throughout the whole mass of the crystal; or they may occur as numerous rounded grains at the border zone and optically continuous among themselves.

Phenocrysts are often cracked and filled with later minerals. There is often a zone of spongy and fibrous muscovite fringing the contact of the phenocrysts with plates of muscovite (Plate VI, fig. 1).

Orthoclase is present in far greater abundance than microcline and also presents the above characters.

Plagioclase is generally turbid with decomposition products. When zoned, the centre is always more decomposed than the exterior. Even when present as inclusions in the porphyritic potash-felspars, these characters seldom fail. The results of the cleavage fragment tests, supplemented by the extinction-angle method are recorded below :

Relative *n* of felspar fragments.	Medium used.	Orientation.	Ext. angle.	Composition.	Remarks.
(i) *n*	>Clove oil	(010)	$-9°$	$Ab_{59}An_{41}$	Not very frequent.
(ii) *n*.	Clove Oil >Chlor-benzene	(010) and (001)	0°	$Ab_{70}An_{30}$	Frequent.
(iii) *n*	<Clove Oil >Chlor-benzene	(010)	$+(12–15)°$	Albite-Oligoclase	Very frequent.

Thus among the plagioclases, there is a preponderance of oligoclase over albite, the latter occurring generally as a marginal zone to the more basic species, oligoclase-medium andesine ($Ab_{59}An_{41}$). The preponderance of oligoclase has been noted by Flett as one of the special and distinguishing features of the Bodmin Moor granites, the felspars of other Cornish granites being generally of a more acid type.[1]

Plagioclase may carry inclusions of other early minerals in addition to quartz grains. The latter sometimes occur as innumerable rounded blebs at the periphery, and these blebs are in optical continuity among themselves.

Micas and Tourmaline. What has already been noted about muscovite and tourmaline in the St. Austell granite by Flett[2] and Richardson[3], regarding their long continued period of crystallization, applies very largely to biotite also in this part of Bodmin Moor. This phenomenon has been referred to the action of gases such as hydrogen, fluorine, and boric acid.[2]

Thus as inclusions, biotite may carry not only the earlier minerals (ores, apatite, and secondary rutile in altered varieties) but also felspar and quartz. Sometimes, a single grain of apatite may serve as a nucleus for both mica and plagioclase, being partially enclosed in both ; also when micas segregate, crystals of plagioclase may serve as nuclei. Small but idiomorphic crystals of biotite occur as inclusions in plagioclase. These facts suggest that biotite started to crystallize before the plagioclase, but that its crystallization-period covered that of plagioclase and orthoclase and overlapped that of quartz.

Quartz generally occurs in patches of rather large size, and being as a rule the last product of crystallization, idiomorphism is practically wanting. These large patches, however (as noted by Richardson in some varieties of St. Austell granites), are resolved microscopically into aggregates of smaller crystals interlocked with one another along sutured boundaries. Undulose extinction and cataclastic structures are a general feature. There is often a development of two systems of cracks roughly at right angles to each other, noted also by Richardson and referred by him to imperfect rhombohedral cleavage of the

[1] J. S. Flett, Geol. Survey Sheet Memoirs, 335 ; 336, p. 54.

[2] J. S. Flett, Geol. Survey Sheet Memoir, 347, pp. 58, 59.

[3] W. A. Richardson, Quart. Journ. Geol. Soc., 1923, vol. 79, p. 565.

mineral. Sometimes one set only may be developed; when viewed under crossed nicols, extremely fine twin-like striations may sometimes be observed. This feature has been noticed also by Franchi[1] in the Ligurian granites, Italy. According to Rosenbusch[2] these may perhaps be twin-lamellae produced by strain.

Accessory minerals will be referred to in a later section (p. 307).

(ii) *Order of Crystallization.*—With slight variations, the sequence described by Flett in the case of the minerals of the St. Austell granite holds good for this area also. Here apatite seems to be distinctly later than zircon and ores, as the latter are found to be included in the former either partially or completely. Biotite in the St. Austell granite had a more or less definite period of crystallization, but here it falls in the same category as tourmaline and muscovite: the two latter exhibit the same tendencies in both places regarding their overlapping periods of crystallization. Felspars and quartz belong very largely to the normal order of appearance. Summarizing, the sequence of crystallization appears to have been as follows:—Ores and Zircon; Apatite; Andalusite; Biotite and Tourmaline; Muscovite; Plagioclase; Orthoclase and Microcline; Quartz.

(*b*) *The 'Godaver Granite' Type.*—While the mineral assemblage in this type is practically the same as in the 'Normal' type, and in a general way reproduces the same features under the microscope, there are a few distinguishing features worth noting:

(1) The proportion of biotite is decidedly smaller, and

(2) A little lithionite mica, purple-brown to light purple in colour, is present.

(3) There is a larger development of tourmaline.

(4) The plagioclase is more acid, not exceeding oligoclase in basicity. The oligoclase occurs as small cores, often cloudy in appearance, surrounded by a clear zone of albite.

(5) Quartz presents the most important variation. It has all the aspects of a porphyritic crystal. It forms large crystals more or less rounded at the margin and scarcely presents the appearance of the large, ill-defined, patches of granular quartz of the Normal type. The quartz of the second generation is not idiomorphic. It may occur as an idiomorphic inclusion in felspars.

(6) The rock is also finer in grain than the Normal granite.

In addition to the usual type, there are certain sill-like intrusions into the Normal type, which have been regarded as offshoots of the Godaver granite. These may be conveniently dealt with in this connexion.

They are granite-porphyries, much finer in texture than the typical Godaver granite, but they never show a chilled or felsitic selvage even at the contact, as the elvans and dikes of later ages so often do. At the

[1] S. Franchi, Boll. R. Com. Geol. Italia, 1893, no. 43.

[2] H. Rosenbusch, Mikroskopische Physiographie, 1907, vol. 2, p. 41.

actual contact, they are a little finer but regain their medium texture within a very short distance.

They contain porphyritic microcline, orthoclase, and quartz as in the main mass; and muscovite and biotite showing the usual characters. Tourmaline of usual habit is present; in addition, a large development of tourmaline occurs as grains and needles in the groundmass. They show a fair development of topaz, an unusual mineral in their plutonic representatives. This is perhaps connected with 'auto-pneumatolysis'.

(c) *The 'Fine Granite'.*—In this type, the amount of porphyritic orthoclase has markedly diminished, and microcline is very rare. The texture is much finer. The general groundmass is hypidiomorphic and more or less equigranular—excepting small local developments of slender quartz and orthoclase in fine granophyric intergrowths. A few peculiarities are noted below:

Orthoclase. The phenocrysts show perthitic intergrowths, which, however, vary considerably in thickness from place to place. Groundmass orthoclase is not perthitic.

Plagioclase diminishes in basicity. Oligoclase is much smaller in amount, the average extinction on (010) cleavage fragments varies from $+11°$ to $+14°$; the composition is between $Ab_{85}An_{15}$–$Ab_{90}An_{10}$. The plagioclase tablets are often notched by numerous irregular growths of quartz of elongated and bulging shape. These may be confined to a small part of the border zone only, or may penetrate far towards the interior of the crystal, leaving only a small core unattacked. These quartz grains are optically continuous and resemble a granophyric intergrowth.

Quartz. Crystals are never large, as in the first two types of granite. It may nevertheless show cataclastic structures and compose a rough mosaic.

Tourmaline is much larger in amount than in the earlier types; in common with that of other constituents, its coarseness also diminishes. In contrast with tourmaline of the earlier types, it tends to be idiomorphic, and is earlier than biotite, being found as idiomorphic inclusions in the latter and in muscovite. It may also occur as an inclusion in felspars, and partially in topaz also.

Biotite and Muscovite. The former is smaller in amount than in the earlier types. The two minerals present the same features as in the main intrusions. In the case of biotite, the overlap in the period of crystallization is even more emphasized than before. Flakes of biotite may occur as a sort of matrix in the interspaces between crystals of quartz and felspar. It may carry inclusions of quartz. In muscovite, both quartz and orthoclase occur as inclusions.

Topaz has not been found as a normal constituent in the earlier types. Here, however, its occurrence is very common. It occurs as flat, rectangular tablets, partially or almost completely enclosing idiomorphic tourmaline and presenting quite a sharp boundary to felspar and quartz. Prism-faces are well-developed; cleavage is not very sharp.

Andalusite is very small in amount and occurs as an inclusion only. It had hitherto been regarded as absent from this particular rock. Heavy residues, however, yield the mineral. This marked diminution of andalusite is a departure from the usual character of the rocks of Bodmin Moor.

In connexion with the diminution of andalusite and the corresponding frequency of topaz with a consequent higher fluorine-content, as borne out by chemical analysis as well, it is interesting to recall Flett's contention regarding the relationship of the two minerals.[1]

(*d*) *Aplite Vein.*—Typically intergranular in texture, and composed of rectangular plagioclase tablets, often meeting at an angle, the angular interspaces being composed of granular quartz, irregularly formed felspars, and other constituents. Orthoclase is also present and may carry inclusions of quartz. Quartz is irregular in outline and often shows cataclastic structures, specially marginally. Both biotite and muscovite are present, usually as an intergrowth of very small flakes. They are very subordinate. Tourmaline, in subordinate amount, occurs as grains and slender rods. When included in quartz and felspar, it is greenish; in felspars, such inclusions are often arranged parallel to their elongation. When not an inclusion, the tourmaline forms yellow-brown crystals, with or without blue cores, the crystals being stouter and idiomorphism less marked.

(*e*) *Melanocratic Differentiate.*—The texture is porphyritic, the porphyritic constituents being:

Quartz. Outline rounded; often cracked or broken up; inclusions of biotite present.

Plagioclase. Large, zoned crystals with altered cores and inclusions of quartz, biotite, &c. Twinning and cleavage ill-developed. The groundmass plagioclase may be twinned; zoning is not well-developed, but cleavage is usually distinct. The crystals are smaller in size but more numerous than those of orthoclase. The latter is very fresh, and untwinned; cleavage is distinct.

Biotite. In large jagged flakes showing numerous pleochroic haloes. It may tend to form aggregates, or may be intergrown with muscovite. It never shows rectilinear outlines, and it encloses quartz grains, felspar, &c., partly or completely. The biotite is more abundant than in the granites.

Muscovite. Small in amount but forming large flakes intergrown with biotite. When ending against orthoclase, the flakes are fringed.

Predominating accessory minerals are:

Andalusite. Plentiful; as grains or laths, marginally altering to white mica. Marginal zones are colourless; central zones violet or colourless.

Iron-ores.

IV. Altered Facies of the Granites.

(*a*) *Hydrothermal and Pneumatolytic alteration of the Granites.*—Altered facies of the granites have been observed chiefly with mineralization and with the intrusion of later into earlier granite-types. Three main phases are distinguished:

1. *Hydrothermal*—generally connected with the formation of tin-bearing veins.

[1] Geol. Survey Sheet Memoir, 347, p. 58.

2. *Fluoritization and Topasization*—with the development of secondary mica, fluorite, and topaz.

3. *Tourmalinization.*

The three phases generally occur together, the different pneumatolytic agents having apparently acted through the same channels. Thus cassiterite, fluorite, topaz, and tourmaline may be associated together in the altered granite—the first being, however, of somewhat restricted occurrence.

A few cases have been observed in which alteration, though referred to one or other of these alteration-processes, has yielded the products of the other processes in very small smounts. Such cases serve to indicate the sequence of the processes listed above.

Hydrothermal Phases.—Slide 179 shows the characteristic features: Slight development of secondary tourmaline and quartz; the clouding of felspars with opaque decomposition products—plagioclase being much more affected than orthoclase and often stained with chloritic matter. Biotite passes into radiating fan-shaped aggregates of green chlorite, often zoned, the centre being brownish, intimately associated with cassiterite. Cassiterite may be granular and brownish-red, or may show a rectangular habit, and may be zoned. Long prisms of steel-grey colour have also been noticed. It may also occur as small needles included in secondary quartz and arranged parallel to the dihexahedral prism faces. Apatite is often associated with the chlorite. Secondary tourmaline may surround cassiterite and may 'eat' its way into biotite.

Fluoritization and Topasization. In connexion with the development of topaz, felspar is highly sericitized, and biotite is bleached. Topaz may be attended by a little cassiterite and fan-shaped aggregates of bleached biotite. Tourmaline may be present, surrounding grains of topaz and cassiterite. During fluoritization, biotite does not seem to be affected, nor is felspar. When topaz develops in addition to fluorite, both biotite and felspars are altered. It is possible that this mode of alteration of biotite during topasization may be due to the action of fluorine in the presence of the (—OH) radicle, and that fluorine has no such potency when acting alone, as in the development of fluorite.

Tourmalinization does not alter either the form or colour of biotite, but often eats into it as well as into the plagioclase-felspars. Secondary quartz is almost always associated with this type of change, and carries abundant needles and grains of tourmaline. This type of alteration is generally confined to very narrow zones of the granite alongside the tourmaline-vein itself. The first two modes of alteration usually penetrate a little farther into the interior of the granite, as in similar occurrences in Scilly, where '. . . peach-veins are often seen to be fringed with a thin band of granite altered to greisen.'[1]

(*b*) *Pneumatolysis—a contact phenomenon associated with the later intrusive members of the sequence.*—An earlier granite at its contact with either of the later types shows fan-shaped bleached biotite-aggregates,

[1] Geol. Survey Sheet Mem. 335, 336, p. 57.

and large crystals of secondary topaz associated with sericitized felspar. The later granite shows these peculiarities and, in addition, a large development of idiomorphic groundmass-tourmaline, forming a matrix surrounding the phenocrysts of quartz and felspar. The amount of tourmaline is much larger near the contact.

Though the earlier rock has been affected by fluorine (with topasization as a result) it is quite unaffected by tourmalinization: it shows no fresh development of tourmaline. The later granite near the junction is traversed by thin veins of quartz, sometimes containing small schorl needles. These veins cut through all the earlier crystals and are more or less at right angles to the contact-surface of the two granites. These phenomena are very well seen in thin sections across the actual junctions of the two rocks.

(*c*) *Superficial Alteration.*—Agencies of weathering have acted on the granite producing wide-spread decomposition and kaolinization, superficially. The deep and workable deposits of china-clay, which are of limited occurrence in this area, are probably attributable to the action of carbonic acid and water emitted during the paulo-post stage of consolidation of the granite.

In this connexion, may be mentioned the alteration of granite beneath the high-level peat on the uplands. Under the peat occurs a thin layer of white soil about an inch in thickness, passing downwards into slightly disintegrated granite and thence into the solid rock. Analysis of a sample of this disintegrated granite taken beneath its soil-cover under 9 inches of peat, shows that the Fe_2O_3-content is reduced to an equivalent of FeO, with a little gain in moisture, a trace of CO_2 also being detected (vide chemical analysis, p. 307). This may be a distinct kind of alteration, having nothing to do with the production of extensive kaolin-deposits, for Blanck and Rieser[1] have shown that kaolin does not result from the decomposition of granite under peat.

V. Inclusions.

The following table shows the various types of inclusions, classified according to their modes of origin and present distribution:

A. *Sedimentary*:

1. *Hornfelses* in Normal and Godaver granites; plentiful in the Normal granite.

[1] E. Blanck and A. Rieser, Chemie der Erde, 1925, vol. 2, 15. [Min. Abstr., vol. 3, p. 41.]

B. *Igneous* :

2. Melanocratic differentiates in the Normal granite.
3. Leucocratic differentiates, highly felspathic, in the Normal granite.
4. Micaceous segregations, in ovoid spots, around apatite and corundum grains.
5. Xenocrysts (pegmatitic felspars only) of Normal granite in dikes of Godaver granite.
6. Blocks of Normal in Godaver and Fine granites.
7. Fragments of No. 2 (above) in Godaver granite.

Although all the above types have been studied, the sedimentary xenoliths (no. 1, above) alone will be dealt with in detail in the following pages, as they present the most interesting features.

Hornfelsed (sedimentary) Inclusions.

(*a*) *Megascopic Character.*—Hornfelses occur throughout the granites, specially in the Normal type. In general, they are dark-brown in colour, and are of finer texture than the granite. The usual colour is of course due to the preponderance of biotite. In hand-specimens they may present a schistose appearance—alternate bands being made up of biotite on the one hand, and quartz and felspars on the other. Purple andalusite, though subordinate in amount, is also recognizable in the common types.

In addition to the prevalent type (biotite-hornfels) other varieties also occur, e.g., inclusions which are purple in colour and are made up chiefly of andalusite; and greenish-blue aggregates of sillimanite and corundum. Such types are, however, very scarce.

Bridging the gap between these extreme types, occur inclusions of hornfelsed killas, rich in biotite enclosing porphyroblastic sillimanite and corundum or andalusite in a lenticular fashion. With a gradual increase in the amount of biotite and a decrease in other constituents, these pass into the normal biotite-hornfelses—the predominant types.

Inclusions of the normal biotite-hornfelses are ovoid and variable in size, though usually small (2 to 2·25 cm. along the greatest diameter). Exceptionally large ones are of rare occurrence: the largest yet found has a diameter of 12 cm. In the granite, immediately margining these inclusions, are distributed still smaller fragments of the same material, which point to the shattering and dispersal of relatively large masses by the magma. Microscopical examination of the granite samples taken at, and near, the junction of granite with inclusions always reveals such fragments in all stages of disruption, till finally only a microscopic fragment is left intact.

These inclusions end abruptly against the granite, and anything like an intermediate or transitional zone is rarely seen. An interesting variation, however, occurs in connexion with a specially large inclusion of biotite-hornfels: a rim of potash-felspar, about 1 cm. thick, is moulded on to the inclusion itself, ending abruptly against the granite; the rim only partially surrounds the inclusion; the ferromagnesian minerals of the granite, at the junction with the rim, are crowded together and arranged parallel to the contact; in no case does the granite show any 'chill-effect' or difference in texture at contact with the inclusion.

As regards distribution, the different types of inclusions show no preference for any particular depth-zone or peripheral zone. All the varieties may be found closely associated in one and the same sheet of granite.

(*b*) *Microscopical Character.*—For convenience of description and discussion of their microscopical character, the hornfelses are grouped as follows:

1. Biotite-hornfels type.
2. Andalusite-spinel-cordierite type (with subordinate corundum and biotite).
3. Sillimanite + andalusite-corundum-spinel type (with much biotite).
4. Sillimanite + andalusite-spinel-quartz type (with much biotite).
5. Andalusite-quartz-felspar type.

1. *Biotite hornfelses.*—These are generally schistose, specially near the contact with the granite (Plate VI, fig. 2). Far in the interior, the texture becomes more open, and is sub-ophitic to intergranular, with lath-shaped biotite embedded in a groundmass of granular quartz and plagioclase.

At the schistose margin, the planes of schistosity are constituted by alternating bands of dark-brown biotite and light-coloured minerals, chiefly felspars. In these bands biotite, specially, shows very close packing; individual crystals may be distributed at all angles to one another, but generally display a subparallel arrangement.

A large amount of magnetite often occurs in the biotite zone. Other minerals associated with biotite are, a little brown tourmaline (derived from the biotite itself), very little muscovite (larger in size than biotite and sometimes intergrown with it), grains of colourless to bluish corundum (which may show pseudo-cleavage), apatite, and a little quartz. Biotite contains pleochroic haloes around inclusions of zircon, and shows well-developed crystal outlines. Farther inward, however, schistosity is less definite and there is a large influx of felspar and quartz, and the biotite shows a jagged appearance (fig. 6). It may sometimes be found altering to titaniferous minerals, the latter associated with violet fluorite.

In the colourless bands, the chief mineral is plagioclase as small grains and tablets, ranging from albite-oligoclase to medium andesine; it is zoned, the centre being of higher refractive index and turbid; it shows scarcely any twinning. A few sporadic large crystals have also been noticed, surrounded by biotite in a lenticular fashion.

Other minerals are very subordinate: orthoclase (generally untwinned and fresh, sometimes with inclusions of quartz) and quartz, as small granules, sometimes with inclusions of biotite and tourmaline.

Injection veins of quartz also occur, cutting the planes of schistosity of the inclusion at an angle (Slide 172). The component grains of quartz are larger than those first described, and are often fractured. The veins represent injections from the magma.

More remote from the granite, schistosity disappears, and felspars, especially orthoclase, tend to become smaller in size. This is evidently connected with a larger supply of the requisite components near the granite-contact. The marginal schistosity may also be due to the pressure from the granite, probably the pressure set up at the time of crystallization of the surrounding magma.

As has been already noted, the texture becomes intergranular to sub-ophitic in the interior of the inclusion. Another remarkable feature is that, andalusite, often in very large flakes, occurs only in the interior of the inclusion, while the portion of the inclusion near the granite is perfectly free from it. The crystals of andalusite in the interior are surrounded by a zone of clear and colourless secondary muscovite, followed by zones of biotite and plagioclase (fig. 6).

All the constituents, except andalusite, are very much smaller in size than those in the granite. But the xenolithic andalusite is much larger in size than that in the granite, and resembles the porphyroblastic mineral of typically contact-altered aluminous rocks of this area.

In its mineral assemblage and texture, this type of inclusion most nearly approaches an igneous rock.

Rim of potash-felspar round an inclusion (Slide 172).—This consists of a multiple aggregate of potash-felspars (showing faint cross-hatching, perthitic structures and Carlsbad-twinning), growing radially outwards from the contact of the inclusion towards the granite. These felspars contain inclusions of small rounded blebs of quartz and small crystals of plagioclase; the former increase in amount as the inclusion is approached, and at the contact they are innumerable, and the microcline in consequence has a very jagged appearance; the plagioclase crystals, on the other hand, are scanty and may almost disappear near the contact with the inclusion, though steadily rising in amount towards the granite contact. Biotite, of a slender habit and in scanty amount, may also be included in this rim of microcline (figs. 4 and 5).

The granite at the contact with this outgrowing felspar-rim shows biotite crystals arranged with their long axes parallel to the contact (fig. 4). This has evidently been brought about by the growing pressure of the felspar itself as it crystallized outwards towards the granite magma.

(i) *Origin of the Biotite-hornfelses.*—Although texture and mineral assemblages (apart from andalusite and corundum) are those of an igneous rock, a possible igneous origin may be at once dismissed on the basis of chemical analysis alone (vide analyses, nos. 7 and 8, p. 307). The parent-rock was evidently shaly, and highly aluminous, as is indicated by the high percentage of Al_2O_3, and the presence of andalusite, corundum, &c. The aureole of sedimentary rocks is made up of shales of various kinds.

Regarding the way in which this alteration of the shales was brought about, the idea of melting and re-crystallization can at once be dispensed with: according to Bowen, any change that could be brought about would be only by 'reaction-precipitation'.[1]

Attention will be confined to the alumina content only (as being the most important constituent of the parent-rock), its behaviour under conditions of metamorphism being well understood.

Dr. Evans[2] suggested that in the case of a magma reacting on aluminous sediments, anorthite and rhombic pyroxene are precipitated, e. g. the charnockite series in southern India. Bowen accepts this view in its entirety in the case of basic magmas, and thinks that in the case of acid magmas we should rather get micas than pyroxenes.[3] When a magma is particularly rich in volatile fluxes, as this granite magma was, we should perhaps expect the formation of micas in place of pyroxene.

In these Bodmin Moor inclusions, the aluminous matter re-acting with the granite magma precipitated a very large amount of plagioclase and biotite (and incidentally a little orthoclase and muscovite). The formation of andalusite and other minerals characteristic of contact-metamorphic rocks may be regarded as 'intermediate steps' in the process of alteration of the original shale. In these inclusions, andalusite is characteristically absent near the granite contact, the reaction evidently having proceeded to completion there, while its sporadic presence in the interior suggests its survival because of the exhaustion of the liquid magma.

(ii) *Formation of the felspathic rim.*—In the process of precipitation of plagioclase and biotite, the magma, in the immediate neighbourhood of these inclusions, became more or less depleted of ferromagnesian-, lime-, and soda-content, relatively to potash. The rim of potash-felspar may thus represent the material left over by the reaction. In this connexion the dearth, in this rim, of plagioclase inclusions but abundance of quartz near the contact with the hornfels, and the exactly opposite phenomena near the contact with the granite, is suggestive. The felspathic liquid, now represented by the rim, under favourable circumstances started crystallizing at the very place of its origin, i.e. just along the margin of the inclusion and grew outwards towards the granite, and during its growth outward, naturally pushed the biotite crystals of the granite magma in a line perpendicular to the direction of its growth. This may explain the 'packing' of the biotite, parallel to the line of contact with the inclusion.

The two analyses of inclusions of this type (nos. 7 and 8, p. 307) are, possibly by chance, remarkably uniform. The two samples were collected from different localties and from different situations; one was an inclusion in the Normal granite, the other an inclusion in a dike-modification of the Godaver granite. The original rocks were evidently of the same type, and their modification by granite had gone on almost to the same extent.

[1] N. L. Bowen, The behaviour of inclusions in igneous magmas. Journ. Geol., 1922, vol. 30, pp. 513–570.

[2] J. W. Evans, Quart. Journ. Geol. Soc., 1921, vol. 77, p. 133 (discussion on Tilley's paper).

[3] N. L. Bowen, loc. cit.

2. *Andalusite-spinel-cordierite type* (with a little corundum and some biotite).—Slide 44 a shows large plates of purple-coloured andalusite, with films and narrow elongated flakes of biotite intergrown along the prismatic cleavages, containing numerous inclusions of dark, opaque grains (graphite ?), and irregular grains of green spinel, sometimes decomposing marginally into fibrolite. These are enclosed as lenticules in an outer zone of small biotite crystals (fig. 8). Cordierite, as large crystals of tabular and rectangular habit, often pinitized, is arranged more or less parallel to the andalusite, with a partially intervening zone of quartz (fig. 7). Well-shaped corundum crystals occur in small amount in association with biotite and andalusite. A little muscovite and quartz are present interstitially, and a small amount of felspar occurs near the granite contact. Here appear four phases in a three-component system—a departure from the 'mineralogical phase rule' established by V. M. Goldschmidt, e. g. andalusite, corundum, cordierite, and spinel. This does not necessarily indicate 'a failure of equilibrium' as Tilley appears to consider[1]; according to Bowen, 'they could occur throughout a range of conditions rather than merely at a point, and there is no reason why these conditions might not be met with in nature.[2]

3. *Andalusite + sillimanite-corundum-spinel type* (with much biotite).—Slide 185 shows large stout plates of sillimanite, often in parallel intergrowth with acicular and platy andalusite. Large crystals of corundum with three rhombohedral pseudo-cleavages well developed, and partially filled with decomposition-products; the mineral often shows graphic intergrowth with biotite at the contact, and also penetration by needles of sillimanite. Its intergrowth with a sillimanite plate is also noted (figs. 9 and 10). Quartz and magnetite may be present as inclusions. Green spinel grains associated with sillimanite and corundum. The porphyroblastic constituents are surrounded by a matrix of biotite mainly, and a little quartz. Tourmalinization of biotite is usual. Corundum and andalusite also show tourmalinization, many relics of these altering minerals having been found in all stages of attack—some occurring at the centre of the tourmaline crystal.

4. *Sillimanite + andalusite-spinel·quartz type* (with much biotite).—Slide 178 shows a plexus of biotite with pleochoic haloes, surrounding, and very often intergrown longitudinally with sillimanite, the latter often in divergent needles with a little quartz in the interspaces. Sillimanite is often decomposing to fibrolite. Andalusite, very often in longitudinal tablets, and grains, altering to micaceous substances. It may sometimes show parallel intergrowth with needles of sillimanite. It also occurs as inclusions in micas. A little green spinel, embedded in andalusite and sillimanite. Tourmalinized biotite, with the original sillimanite-intergrowth still preserved (fig. 11).

Groups 2, 3, and 4 of the hornfelsed inclusions include types which have the mineral-assemblages produced in contact-metamorphism of the system $MgO-Al_2O_3-SiO_2$.[3] These have been modified very slightly, or not at all, by the

[1] C. E. Tilley, Quart. Journ. Geol. Soc., 1924, vol. 80, pp. 68, 69.

[2] N. L. Bowen, Journ. Washington Acad. Sci., 1925, vol. 15, p. 280. [Min. Abstr., vol. 3, p. 88.]

[3] C. E. Tilley, Paragenesis of the minerals of the three component system $MgO-Al_2O_3-SiO_2$ in thermal metamorphism. Geol. Mag., 1923, vol. 60, pp. 101–107.

granitic magma (with which equilibrium was not attained) and may be regarded as 'intermediate products', surviving only because of the exhaustion of the liquid.

These present a marked contrast in texture to the biotite-hornfelses. The habit of the constituent minerals is truly porphyroblastic, generally with an insignificant matrix of biotite and quartz enclosing the large crystals of andalusite, sillimanite, and corundum in a lenticular manner.

A certain peculiarity of behaviour of cordierite is also noticeable in these types. Cordierite arises when there is a very slight or no development of biotite (type 2); but it is absent in types which are very largely biotitic (types 3 and 4). This is also more or less the case in contact-altered shales, the presence of cordierite being connected with a limiting value of FeO-content in relation to MgO. To quote Tilley (loc. cit.):

'With a high FeO-content it is possible that cordierite may disappear, and it is of interest to note that available analyses of rock-forming cordierites show a limiting value of FeO-content.'

Thus in types 3 and 4, the FeO-content having perhaps exceeded the limit, as is suggested by the large amount of biotite, cordierite has been entirely suppressed.

5. *Andalusite-quartz-felspar type.*—Andalusite, as large, tabular plates of purple colour, sometimes zoned (purple centrally, colourless at the margin); or as anhedral grains and elongated, lenticular forms, as well as lozenge-shaped rhombic sections and cruciform aggregates, the latter embedded in large, ophitic or sub-ophitic quartz which may also enclose small tablets of plagioclase. Plagioclase may also enclose andalusite. Quartz shows undulatory extinction and is often fractured. The plagioclase is albite-oligoclase to oligoclase, and more or less turbid. There are also wedge-shaped injection-veins of later quartz cutting through some of the rock-minerals. Near the granite-contact, quartz and felspar tend to become larger in size. No orthoclase and no mica occurs (fig. 12).

This type is quite different from the others already described in having no mica. In texture, it closely resembles an igneous rock, and hence is quite unlike types 2, 3, and 4. This has evidently been affected by the granite magma, more or less like type 1, which it most resembles in texture. But the absence of micas is a striking contrast, and hence its allocation to a different class is justified.

VI. Chemical Analyses.

(Analysed by P. K. Ghosh.)

1. Normal granite from Cheesewring quarry.
2. Normal granite from Fox Tor (top).
3. Normal granite (? albitized) from Notter Tor (lower quarry).
4. Godaver granite, underlying peat, from north flank of Hill Tor.
5. Godaver granite (fresh) from the Godaver region, just south of the foot-bridge.
6. Fine granite, 300 yards north of Dozmary farmhouse.
7. Killas inclusion (biotite-hornfels type) in a dike-modification of Godaver granite from Swit quarry, Craddock Moor.
8. Killas inclusion (biotite-hornfels type) in Normal granite, Notter Tor.

	1.	2.	3.	4.	5.	6.	7.	8.
SiO_2 ...	70·96	71·25	71·66	72·99	73·01	74·16	54·82	53·63
TiO_2 ...	0·36	0·20	0·32	0·13	0·11	trace	1·60	1·97
Al_2O_3 ...	15·92	15·72	15·31	15·33	15·26	14·68	16·75	17·03
Fe_2O_3 ...	0·20	0·16	0·19	nil	0·29	0·26	1·06	1·10
FeO ...	0·84	0·86	0·84	1·09	0·73	0·65	9·53	9·91
MnO ...	0·30	0·21	0·28	0·06	0·07	0·07	0·34	0·33
MgO ...	0·49	0·32	0·25	0·28	0·06	0·18	1·60	1·77
CaO	1·11	1·42	1·21	0·64	0·68	1·01	1·54	1·75
BaO ...	trace	trace	n.d.	n.d.	0·02	nil	n.d.	n.d.
Na_2O ...	3·53	3·56	4·31	2·96	3·18	2·51	3·84	3·75
K_2O	5·60	5·51	4·26	5·59	5·47	5·15	6·54	6·55
F	0·08	0·05	0·06	n.d.	0·03	0·11	n.d.	n.d.
$H_2O\pm$ ...	0·80	0·71	0·83	1·18	0·63	0·53	1·73	1·84
B_2O_3 ...	0·28	0·29	0·25	n.d.	0·73	0·82	n.d.	n.d.
P_2O_5 ...	0·03	0·32	0·32	0·18	0·21	0·27	0·71	0·82
V_2O_5 ...	trace	n.d.	n.d.	n.d.	trace	n.d.	n.d.	n.d.
CO_2	n.d.	n.d.	n.d.	trace	n.d.	n.d.	n.d.	n.d.
Total ...	100·50	100·58	100·09	100·43	100·48	100·40	100·06	100·45
Sp. gr. ...	2·64	2·63	2·65	2·59	2·62	2·59	—	—

The analyses of the granites show the progressive enrichment in silica-content in the younger types. As shown by Brammall, the same feature is displayed by Dartmoor granites. Analysis no. 3 shows a marked departure from the usual ratio of $K_2O : Na_2O$. The higher Na_2O-content is probably due to causes somewhat akin to secondary albitization (see p. 293).

VII. Results of 'Heavy Residue' Determination.

(Accessory Minerals.)

	'Normal'.	'Godaver'.	'Fine'.	Elvan.
Percentage by weight of minerals heavier than bromoform (sp. gr. = 2·9)	8·5–5·5	5–4·4	3	1·1–2·4
Number of rocks crushed ...	(5)	(3)	(3)	(3)

These results are in agreement with facts established by Brammall for the Dartmoor granite, viz. the younger types contain a progressively lower percentage of accessories.

The accessories of the two main granite types are enumerated below:

In the Normal granite.—Magnetite, ilmenite, pyrrhotine, cassiterite, rutile, brookite, anatase, tourmaline, biotite, muscovite, andalusite (purple and colourless), corundum (yellow, colourless, bluish), zircon, fluorite, beryl (very limited), apatite.

In the Godaver granite.—All the species named above, except beryl, with the additional species lithionite. Yellow corundum and colourless andalusite have not been observed.

Large amounts of wolframite have been found in river-sands. This mineral is probably derived from lodes and is not a primary constituent of the granite.

My very best thanks are due to Professor W. W. Watts and Dr. J. W. Evans for their never-failing help and advice throughout the period of my work. I also gratefully acknowledge my indebtedness to Mr. J. G. C. Leech, Dr. H. F. Harwood, Dr. A. Brammall, Dr. S. K. Chatterjee, Mr. M. Chatterjee, Mr. G. S. Sweeting, and Mr. E. J. Tallin.

Explanation of Plates VI and VII.

[Photomicrographs in ordinary light.]

Fig. 1. A porphyritic crystal of microcline in Normal granite. The core is formed of a Carlsbad-twin (M_1 and m_1) followed by a narrow zone of small crystals and narrow strips of plagioclase (P) ; then follows another zone of microcline (m_2 and M_2) in reversed orientation relative to the core ; the third zone of microcline is just represented in the figure (right-hand, top) by m_3. The potash-felspar has a frilled margin (right of the figure, bottom), and is intergrown with plates of muscovite growing out into networks and spongy masses at the contact with the felspar. (×21.) [p. 294.]

Fig. 2. Biotite-hornfels (banded type). It shows the alternate bands of biotite (dark) and granular plagioclase (light). (×26.) [p. 302.]

Fig. 3. Biotite-hornfels with a sub-ophitic texture. It shows biotite (b), set in a granular groundmass of quartz (Q), and plagioclase (P). (×17.) [p. 303.]

Fig. 4. The junction of granite with the microcline rim of a biotite-hornfels. The junction is towards the top where the biotite (b) appears. The biotite belongs to the granite and is arranged with its long axis parallel to the surface of contact with the rim (M) ; it contains inclusions of apatite (a). The rim contains inclusions of small crystals of plagioclase (P) with decomposed cores and hence appearing dark in the figure. Plagioclase decreases in amount farther from the contact. (×17.) [p. 303.]

Fig. 5. The same slide showing the junction of the microcline rim with the hornfels (the dark zone at the bottom). Note the abundant inclusions of quartz grains (Q) in the rim. (×17.) [p. 303.]

Fig. 6. The same slide (showing the hornfels only) farther removed from the granite contact. Note the advent of andalusite (A) as the view recedes from the contact. Compared with fig. 5, the texture is more open, and biotite is decidedly smaller in size as well as less idiomorphic. Andalusite is surrounded by a zone of muscovite (m) which is followed by plagioclase and biotite. (×17.) [p. 304.]

FIG. 7. Hornfels inclusion, showing porphyroblasts of pinitized cordierite (C) and andalusite (A), in a matrix of quartz (Q) and a little biotite (b). (×21.) [p. 305.]

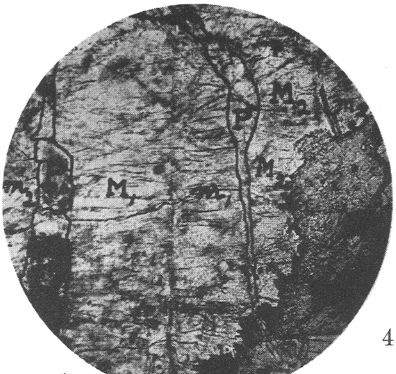
FIG. 8. Hornfels inclusion, showing andalusite (A) with inclusions of spinel (S). Andalusite crystals are enmeshed in a tangle of biotite fibres. (×21.) [p. 305.]

FIG. 9. Hornfels inclusion showing porphyroblastic corundum (C) intergrown with sillimanite (S). The rest is biotite. (×21.) [p. 305.]

FIG. 10. The same showing large corundum (C) with well-developed pseudo-cleavage. There is also a band of biotite and quartz on the right of the figure. Small shreds of biotite occur along the partings of the corundum. (×21.) [p. 305.]

FIG. 11. Hornfels inclusion showing sheaf-like aggregates of sillimanite and shreds of biotite intergrown with one another; biotite appears dark in the figure. (×21.) [p. 305.]

FIG. 12. Hornfels inclusion showing plates of quartz (Q) ophitically enclosing andalusite (A) and plagioclase: the plagioclase is centrally decomposed and appears dark in the figure. (×21.) [p. 306.]



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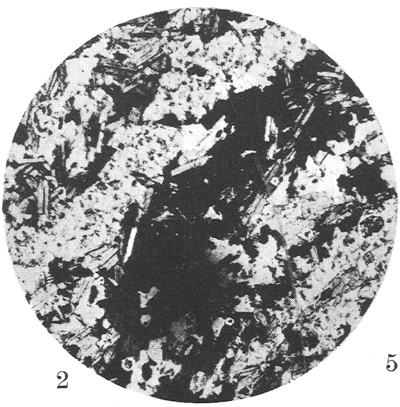

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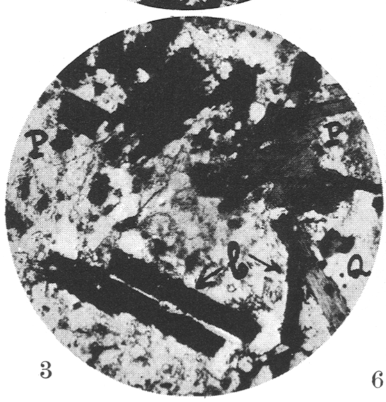

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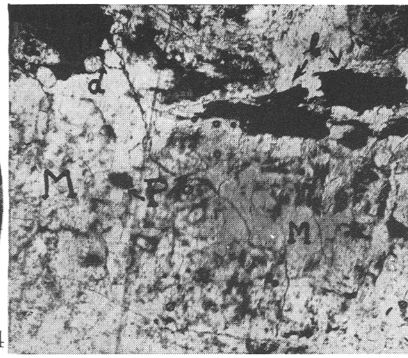

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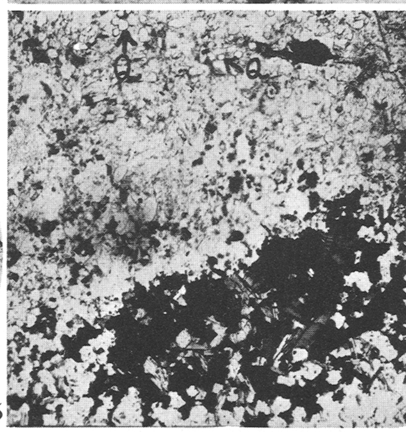

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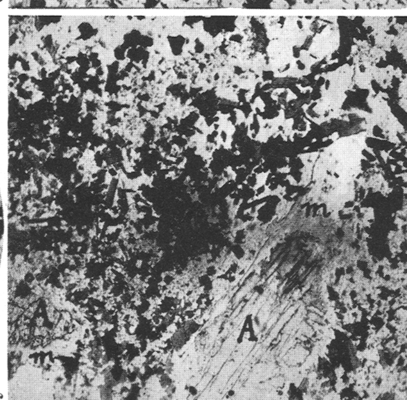

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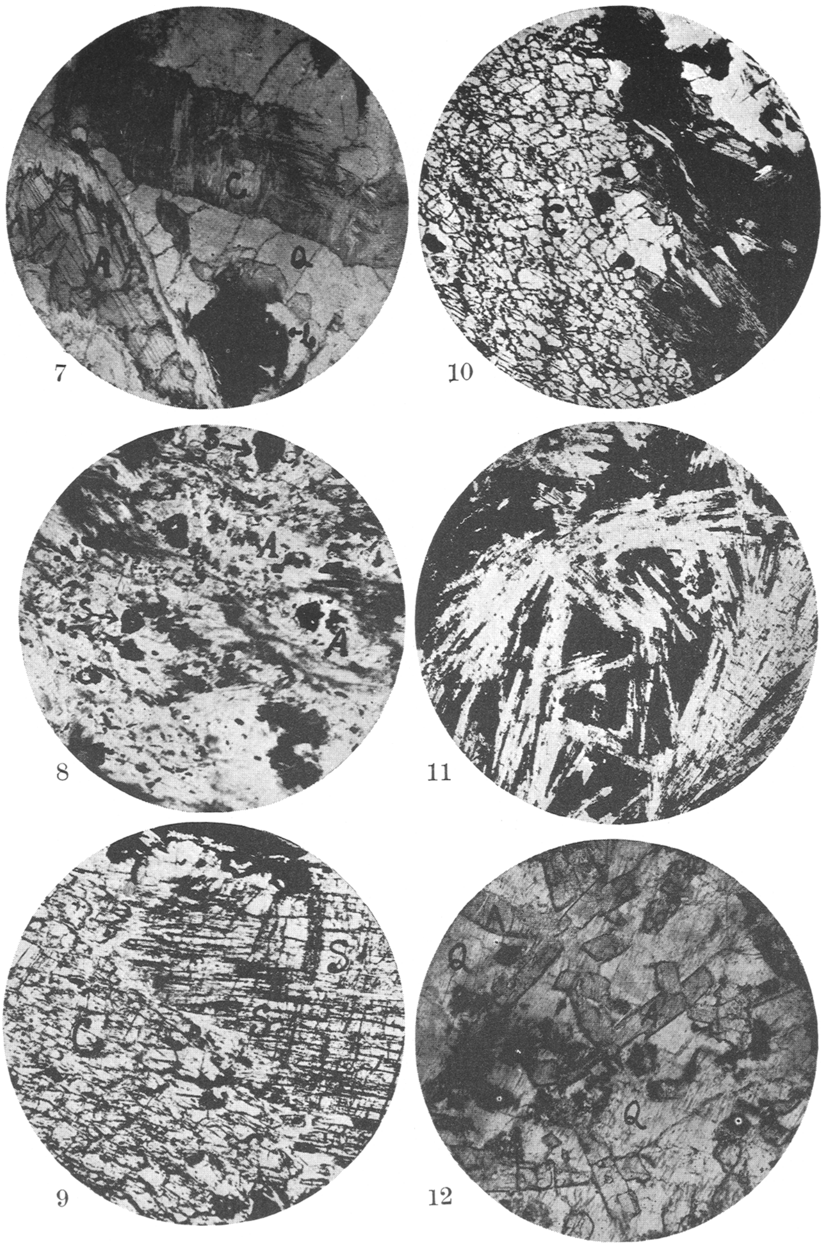

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