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The Dartmoor granite: its mineralogy, structure, and petrology.[1]

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THIS paper continues the study of the constituent minerals of the Dartmoor granite. The district to which it mainly refers comprises the tor-area around Widecombe and a part of the aureole adjoining. No detailed reference will be made at this stage to aureole phenomena. The results to be recorded necessitate a brief description of the two main granite types and of their field relationships. Abundant varieties and modifications of both types occur,[2] but for the purposes of the present paper they are of subordinate importance.

[1] Previous papers of this series (this vol., pp. 20 and 27) dealt with the minerals rutile, brookite, anatase, and zircon.

[2] For a general description of the granite and of its varieties, see 'The Geology of Dartmoor' (Mem. Geol. Survey), 1912, pp. 27–43.

The Main Types of Granite.

Most of the tor-masses and high-level exposures of granite in the area consist in the main of the type known locally as the 'giant granite'—a very coarse-grained, strongly porphyritic rock rich in biotite, and consistently garnetiferous; it has an index-figure[1] ranging from 7·5 to 12. Muscovite is never completely absent, though it ranks as a very minor accessory. The chief tor exposures of this type occur at the following localities:

Haytor Rocks.	Rowden Down.	Honeybag Tor.
Bag Tor.	Wind Tor.	Chinkwell Tor.
Saddle Tor.	Hamel Down.	Bell Tor.
Rippon Tor.	Hamel Down Tor.	Bonehill Rocks.
Buckland Beacon.	Hookney Tor.	Hedge Down.
Bel Tor.	Corndon Tor.	Pil Tor.
Mel Tor.	Birch Tor.	Tunhill Rocks.
Sharp Tor.	Bellever Tor.	Hollow Tor.
		Pudsham Down.

Other exposures of this granite are not numerous. The type is not quarried in the area, and low-level exposures are comparatively few. The type locality for this granite is Saddle Tor (analysis 5, p. 41).

Direct and indirect field evidence shows that the 'giant granite' is a thick, sheet-like mass overlying another, and later, granite which was intruded before the former had cooled to complete rigidity. This lower sheet is known locally as the 'blue granite', the type locality for which is the Haytor (east) quarry (analyses 8 and 9, p. 41).

The structural relationship between the two types is clearly seen in the Haytor area. At the Haytor Rocks, where a contact between the two is well exposed, the contact facies of the lower granite is of fine grain; it is non-porphyritic, and almost free from biotite, though muscovite is occasionally macroscopic; its index-figure is less than 1. The contact facies shows strong vertical jointing which, seen from a distance, is strikingly similar to the columnar jointing displayed by many basalts. With descent in the lower sheet, via a series of quarries, the rock is observed to become more coarsely crystalline; the content of biotite increases, the index-figure rises, and the rock ultimately passes into

[1] The term 'index-figure' is used to express the average percentage by weight of mineral grains of sp. gr. > 2·86 obtainable from crushed rock material which has been washed free from rock-flour. The raw material passes a sieve with 40 wires to the linear inch.

a coarse-grained, porphyritic granite of excellent building-stone quality. In the latter respect this type is in contrast with the 'giant granite', from which it differs also in chemical composition, being more acid, and in certain details of mineral composition: its garnet, for example, is negligible in amount and of peculiar habit; and its accessory minerals include fluorite, which occurs also in the rare drusy cavities and occasionally along joint-planes. Other mineralogical contrasts between the two granite types are detailed in a later section of this paper.

Rock Analyses (by H. F. Harwood).

	Granites.									Killas.	
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
SiO_2	63·40	68·09	70·23	70·50	71·69	71·97	73·16	73·66	75·09	71·40	85·98
Al_2O_3	15·12	14·34	13·95	14·40	14·03	13·99	13·95	13·81	13·46	14·44	6·75
Fe_2O_3	1·37	0·87	0·76	0·45	0·57	0·68	0·03	0·21	0·74	0·81	0·35
FeO	4·80	2·79	2·66	2·62	1·93	1·45	0·47	1·51	1·05	1·32	0·99
MgO	2·16	1·18	0·73	0·70	0·66	0·57	trace	0·45	0·74	1·08	0·50
CaO	3·42	2·58	0·89	1·48	1·49	1·56	0·43	0·67	0·66	0·13	0·18
Na_2O	3·15	3·10	2·97	3·00	3·03	3·22	2·57	2·89	3·10	0·65	0·39
K_2O	2·92	4·33	5·38	5·12	4·59	4·80	8·16	5·02	3·78	5·62	2·40
H_2O +	1·52	1·35	1·15	0·93	1.29	0·83	0·31	1·25	0·77	2.39	1·46
H_2O −	0·55	0·42	0·55	0·22	0·47	0·43	0·33	0·41	0·14	0·49	0·44
CO_2	nil	nil	nil	nil	nil	nil	nil	nil	0·02	nil	nil
TiO_2	1·11	0·62	0·53	0·35	0·33	0·32	0·04	0·16	0·25	0·60	0·29
ZrO_2	nil	nil	nil	nil	nil	0·01	nil	trace	—	nil	nil
P_2O_5	0·32	0·22	0·21	0·23	0·23	0·21	0·16	0·24	0·19	0·06	0·04
Cl	trace	0·03	trace	0·03	trace	0·07	trace	0·01	nil	trace	trace
F	—	—	—	—	—	—	—	—	nil	—	—
S	trace	nil	trace	0·04	nil	0·03	trace	nil	—	trace	nil
C	—	—	—	—	—	—	—	—	—	0.73	0.37
MnO	0·12	0·07	0·08	0·07	0·06	0·04	0·01	0·06	0·14	0·05	0·04
BaO	trace	0·01	nil	0·02	trace	trace	trace	trace	nil	0·06	0·02
SrO	nil	nil	nil	nil	nil	nil	nil	nil	nil	—	—
Li_2O	trace	trace	trace	trace	trace	trace	trace	trace	nil	—	—
	99·96	100·00	100·09	100·16	100.37	100·18	99·62	100.35	100.13	99·83	100·20

Brief description of the rocks analysed:

1. Nodular inclusion in the normal granite capping Birch Tor. A dark-grey rock of fine grain, containing only a few small phenocrysts, which are usually orthoclase. The groundmass consists of large irregular plates of clear quartz and much less abundant orthoclase, enclosing the following minerals, in ophitic fashion: laths and stouter prisms of plagioclase, which are strongly zoned and present irregular and often embayed outlines; laths and irregular flakes of biotite, in which pleochroic haloes are rare; and long slender needles of apatite.

2. Dark rock in situ at the base of the Birch Tor mass (see p. 46). Both in hand-specimens and in thin section this rock resembles no. 1 very closely. It differs from the latter in being of slightly coarser grain and in containing rather more abundant groundmass plates of orthoclase.

3. Non-porphyritic biotite-granite of medium grain. Wittabarrow. This type is widely distributed.

4. Coarse-grained porphyritic biotite-granite. Prison quarry, Princetown.

5. Typical 'giant granite'. Saddle Tor. (See p. 40.)

6. Coarse-grained, porphyritic biotite-granite. Greator Rocks. (See p. 50.)

7. A cream-coloured, coarsely-crystalline rock without phenocrysts, and composed essentially of felspar and quartz. Wittabarrow. This rock represents an extreme type. Similar rock occurs at several other localities, e.g. Pudsham Down, Hollow Tor, Cockingford, Bellever Tor, Chinkwell Tor, Bell Tor, &c.

8. Typical coarse-grained non-porphyritic 'blue granite'. Haytor east quarry. (See p. 40.)

9. Ditto. Analysis by E. G. Radley, 'The Geology of Dartmoor' (Mem. Geol. Survey), 1912, p. 42.

10. Banded killas, unweathered. From the outer zone of the aureole, Yarner, near Haytor.

11. Feebly spotted killas. Yarner. Samples 10 and 11 were taken from one large block which was brought to the surface during the sinking of a well.

Analyses 1–9, and supplementary analyses, will be discussed in later papers dealing specially with the petrology of the granite.

The sequence of types observed at Haytor is revealed elsewhere only partially, for departures from the simple structural relationship described are numerous. The upper sheet especially is traversed by minor granitic intrusions in the form of veins and narrow dikes (e.g. at Pil Tor, on Bonehill Down, at Greator Rocks, Bellever Tor, &c.), and by sill-like injections, also granitic, which may be of considerable thickness. The latter introduce some complexity, for they may split the upper sheet into two or more zones (e.g. on Pudsham Down and the slopes of Wind Tor, on Hamel Down, &c.). Moreover, these minor intrusions include rock types which record an unexpected degree of differentiation from the normal granite (see analysis 7, p. 41). Contacts between the upper and lower main sheets, or between intercalates of the lower granite in the upper sheet, are well seen at most of the localities given on p. 40.

As a consequence of (*a*) faulting and (*b*) the composite character of the granite intrusion as a whole, rock of 'giant granite' type is occasionally missing from the crest of a ridge on the slopes of which it may be exposed. The highest topographic levels are then occupied by rocks closely related to the 'blue granite' or its differentiates (e.g. at Wittabarrow, on Pudsham Down, Hamel Down, &c.). Samples of these rocks occasionally show feeble foliation.

The Felspars.

These are described in some detail by Flett and Dewey,[1] whose description may be summarized as follows:

The *phenocrysts* range from an inch to over seven inches in length. Idiomorphic crystals are common; they are of the Carlsbad habit, and usually twinned; they are commonly intergrown with albite to form a coarse microperthite. In them occur as inclusions small crystals of any or all of the other minerals of the granite. Quartz may be in micrographic intergrowth with phenocryst felspar as well as with the felspar in the groundmass. The most usual inclusion is biotite, the flakes of which may be centrally or zonally arranged, or may be irregularly distributed.

The *groundmass felspars* include anidiomorphic orthoclase (often pronouncedly microperthitic), and plagioclase ranging from albite to oligoclase; crystals of the latter often show a marginal zone of albite, and may show also good rectangular outlines.

Flett and Dewey discuss the mode of origin of the phenocrysts, and conclude that they are not a true first generation of crystals preceding all the others, but that they record the effect of certain conditions which, though of limited duration, were specially favourable to the production of large, well-formed crystals of one special mineral contemporaneously with the rest.

But the interpretation of these phenocrysts appears to involve also questions of differentiation and mechanism of intrusion. Phenocrysts are absent from many granitic sheets above which porphyritic granite is in place, as, for example, at Haytor Rocks, Saddle Tor, Pudsham Down, Bonehill Rocks, Hamel Down, &c., and in the Princetown district. Porphyritic granite may also occur beneath such sheets, as at Wind Tor, Pudsham Down, &c. At Haytor non-porphyritic granite passes downwards without a break into granite containing a few small phenocrysts and then somewhat rapidly into normal porphyritic granite. Moreover, phenocrysts from contrasted granite types show appreciable differences in chemical composition, and these differences are in some way related to the features in contrast, such as groundmass texture, content of phenocrysts and of biotite, &c.

Samples of phenocrysts from nine localities have been analysed. At each locality, sampling was restricted to a zone a few feet in thickness, and felspar fragments, representing a score or more of phenocrysts and totalling about 1 lb. in weight, were chiselled out of the freshest rock available. After crushing, the sample was freed from biotite, &c., as completely as possible by means of bromoform and the electromagnet, and by subsequent hand-picking. The analyses of these nine samples

[1] 'The Geology of Dartmoor' (Mem. Geol. Survey), 1912, pp. 31, 39-40.

are given below. The biotite included in the Haytor (E.) sample could not be completely eliminated, and the amount present in the material analysed was, in this case only, rather more than a trace. But if the whole of the magnesia and iron present in this sample be attributed to biotite, the correction to be made for potash is insignificant, that for soda is negligible, and the corrections for lime and baryta vanish.

Analyses of Felspar Phenocrysts (by H. F. Harwood).

	1. Princetown.	2. Chinkwell Tor.	3. Hedge Down.	4. Rippon Tor.	5. Saddle Tor.	6. Tunhill Rocks.	7. Haytor (W.) Qy.	8. Haytor (E.) Qy.	9. Greator Rocks.
SiO_2	65·59	65·94	65·88	65·33	65·37	65·50	64·87	65·16	65·53
Al_2O_3	19·12	18·67	18·60	19·05	19·22	18·81	19·18	19·17	18·81
Fe_2O_3	0·11	0·24	0·17	0·08	0·11	0·14	0·16	0·06	0·12
MgO	0·05	0·06	0·04	0·06	0·06	0·06	0·17	0·14	trace
CaO	0·81	0·71	0·71	0·51	0·51	0·65	0·50	0·46	0·58
BaO	0·06	0·07	0·05	0·13	0·15	0·10	0·14	0·18	0·12
Na_2O	3·72	3·42	3·34	3·30	3·26	3·12	2·95	3·07	2·70
K_2O	10·37	10·58	10·76	10·82	10·84	11·24	11·67	11·68	12·03
H_2O +	0·61	0·36	0·29	0·30	0·57	0·65	0·41	0·33	0·44
H_2O −	0·17	0·16	0·19	0·21	0·18	0·21	0·29	0·10	0·20
TiO_2	nil	0·01	0·02	trace	trace	trace	0·01	trace	0·03
	100·61	100·22	100·05	99·79	100·27	100·48	100·35	100·35	100·56
Index-fig. (av.) for rock (see p. 40).	7·9	10·3	8·1	8·5	8·7	8·9	6·5	6·7	8·0

The analyses are plotted, on a molecular-proportion basis, in fig. 1, silica and water being omitted. It will be observed that

Soda varies against potash.

Lime does not vary consistently with either soda or potash.

Baryta (in celsian) varies antipathetically to lime.

As these felspar phenocrysts are not homogeneous, refractive indices, specific gravities, &c., have not been determined.

Considering now the analyses of these felspars in relation to the rock analyses given on p. 41. Of the phenocrysts taken from granites in the Widecombe area, nos. 2–6 are the less potassic and are representative of phenocrysts in the 'giant granite', which has an index-figure 7·5–12 and is the less acid of the two main granite types. Nos. 7 and 8 are more potassic and are representative of the typical 'blue granite', which has an index-figure 0·5–7·0 and is the more acid of the two main types. The Greator Rocks felspar (no. 9) occupies an apparently anomalous position in the series (see p. 50).

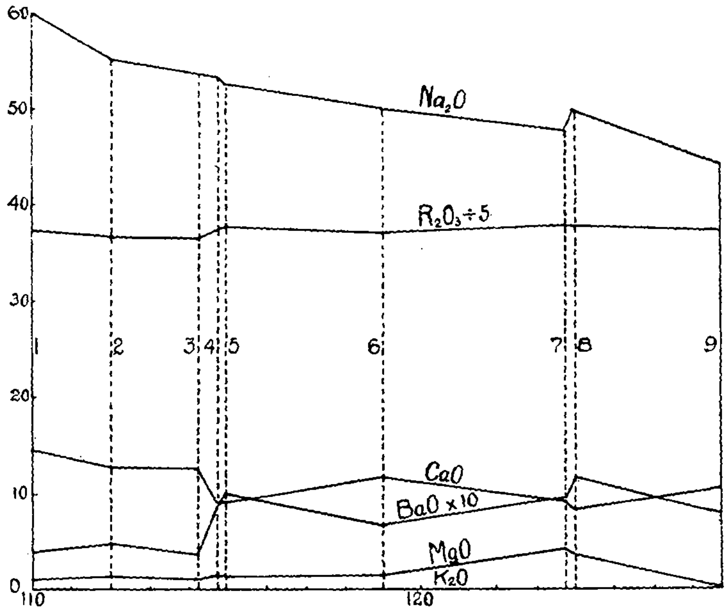


FIG. 1. Diagram showing the variable composition of felspar phenocrysts from the Dartmoor granite. Oxides are plotted on a molecular-proportion basis: potash as abscissae, other oxides as ordinates. (See analyses, p. 44.)

Inclusions in the Granite.

Those observed comprise the following:

(1) Coarse quartz-felspar-tourmaline-pegmatite, in masses up to 14 inches in diameter. These may be either 'acid' segregations or cognate inclusions. A distinction is drawn between inclusions of this type and smaller patches which are merely agglomerates of felspar phenocrysts.

(2) Highly altered 'greenstone', in spheroidal masses up to 10 inches in diameter. Reference may be made here to the discovery of fragments of schalstein (up to 6 inches in length) in granite debris below Hollow Tor, in a rubble pit at Venton, and in the bed of the West Webburn at Cockingford. The fragments are spotted rocks of pronounced amygdaloidal-basalt type, and may be related to the Devonian and Culm schalstein

of the West of England. Their occurrence is extremely interesting; but whether they represent xenoliths is as yet uncertain.

(3) Nodular masses of normal granitic rocks, of coarse or medium grain, and up to 9 inches in diameter. These are certainly cognate inclusions. Specimens taken from Tunhill Rocks show marked spheroidal weathering.

(4) Spheroidal masses of dark, fine-grained or medium-grained granitic rocks, some of which are almost certainly xenoliths; others may be basic segregations.[1]

Flett and Dewey observe[2] that 'it is difficult to make certain whether they [the basic segregations] represent broken fragments of early basic masses of granite that were disrupted . . . by later intrusions, but no large area of rocks of this type has ever been encountered, and hence the theory that they are basic segregations . . . is perhaps the most probable that can be advanced'.

The granites in situ, or dominant in boulder-belts, include somewhat specialized types of dark rock which are essentially identical with certain varieties of these 'dark segregations'. One variety of the latter displays certain peculiarities of microstructure (ophitic) and mineral composition observed also in a rock of apparently identical type underlying the main Birch Tor mass (see p. 41). Other varieties are closely comparable to dark rocks occurring at other localities: e.g. Bellever Tor, Pudsham Down, Wittabarrow, Buckland Common. The dark rock at Birch Tor has a thickness of from four to seven feet (base not seen), and is exposed over a distance of thirteen yards. It shows strong pseudo-bedding conformable to that of the overlying normal granite. In a non-porphyritic facies of the 'blue granite' at the Haytor (east) quarry, one dark inclusion observed is 34 inches in diameter and is moderately porphyritic; it closely resembles a dark rock occurring in a boulder-belt on the slope immediately north of Wittabarrow.

(5) Altered killas, in which sedimentary banding is often well preserved. The fragments include several varieties of cordierite-hornfels. The original killas fragments, doubtless angular and slab-like, have been reduced to spheroidal masses ranging from walnut-size to nodules 7 inches in diameter.

The observed distribution of these inclusions in the granite is as follows:

In the lower ('blue') granite: types (1), (3), and (4).

[1] 'The Geology of Dartmoor' (Mem. Geol. Survey), 1912, pp. 30, 32, and 34.

[2] Idem, pp. 41–42.

In the upper ('giant') granite: types (2), (3), (4), and (5).

For reasons made clear in the sequel, types (2) and (5) may prove to occur sparingly in the lower granite. Only those of type (5) will be specially considered at this stage.

The Cordierite-hornfels Xenoliths.

Varieties[1] of these have been described by K. Busz, J. S. Flett and H. Dewey, and have been shown to contain cordierite and its alteration

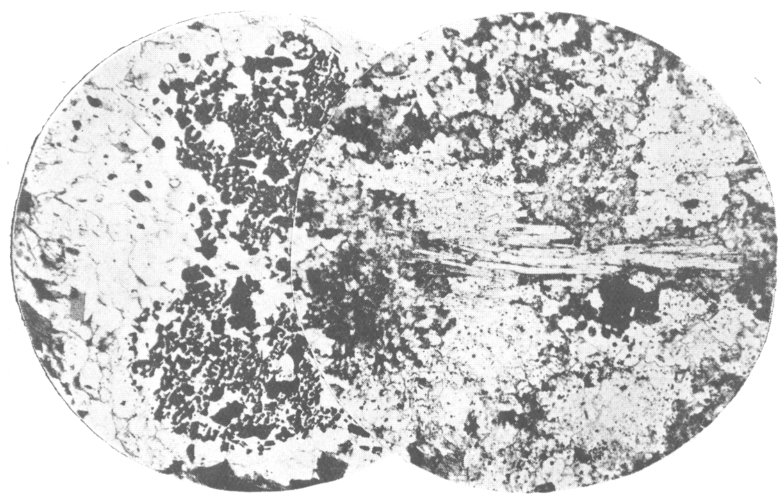


FIG. 2. FIG. 3.

FIG. 2. Photomicrograph: banded cordierite-hornfels (xenolith) from the granite of Tunhill Rocks. Showing a band composed of clear cordierite mosaic with inclusions of dark-green spinel. The adjoining band consists of quartz, felspar, and biotite, with small patches and stringers of pinite. ×27.

FIG. 3. Photomicrograph: cordierite-hornfels (xenolith) from the granite of Haytor Rocks. Showing sillimanite in a groundmass consisting of cordierite (with abundant dust-like inclusions), ill-developed biotite, ore-grains, felspar, and quartz. ×29. (See p. 48.)

products, andalusite, biotite, muscovite, quartz, and felspar, with accessory corundum, sillimanite, spinel, magnetite, zircon, apatite, &c.

A banded specimen from Tunhill Rocks (fig. 2) contains ovoid patches of cordierite mosaic enclosing abundant dark-green spinel, the two minerals

[1] For descriptions, and references to literature, see Survey Memoir (Dartmoor), pp. 45-46; also p. 102, plate 1, fig. 3.

being apparently in true micrographic intergrowth. A specimen from Haytor Rocks (fig. 3) records arrest of reconstitution processes before equilibrium conditions had been attained: well-formed sillimanite and cordierite are associated with ill-developed andalusite, biotite, and tourmaline. The cordierite contains an abundance of minute, rounded, opaque inclusions.

Flett, Dewey, and Barrow describe[1] similar inclusions (presumed to be magnetite and graphite) in cordierite of altered killas occurring in the aureole, and they consider such inclusions to be indicators of original cordierite when the latter has been completely altered.

The authors have identified graphite and titaniferous ore-dust in the insoluble residue obtained by digesting the cordierite of certain xenoliths in hydrofluoric acid. (Methods employed for isolating cordierite are given on p. 49.) The analyses of two killas samples from this area (analyses, nos. 10 and 11, p. 41) show a content of both carbon and titanium sufficient to account for the graphite and the titaniferous ore-dust observed, but the content of magnesia is much lower than is compatible with the amount of cordierite usually present in these xenoliths. Either the xenoliths record exchange of material between magma and killas inclusions or they represent original killas which were richer in magnesia than the killas samples analysed.

The occurrence of cordierite, andalusite, sillimanite, spinel, and corundum in the granite.

Crushed rocks were specially investigated for these minerals. The isolation of cordierite presented some difficulty. Cordierite and most of its alteration products float in bromoform, and their behaviour in the field of the small electromagnet of the laboratory was found to be unreliable. Attempts to isolate a few grains of cordierite, &c., from the mass of quartz and felspar grains with which they are associated, whether preliminary concentration be effected by panning or by the use of bromoform, proved unsatisfactory and excessively tedious. A rapid and fairly satisfactory separation was effected by means of the powerful Ulrich magnetic separator, which extracts feebly magnetic substances, such as cordierite, along with the heavier and more strongly magnetic minerals such as biotite. By passing the electromagnetic fraction thus obtained through bromoform, cordierite is concentrated in the portion that floats.

Samples of the 'blue granite' gave the following results: Neither

[1] Survey Memoir (Dartmoor), p. 45.

unaltered cordierite nor sillimanite has so far been observed. A few grains referred with certainty to andalusite have been noted in samples from the Haytor quarries. Grains which closely resemble altered cordierite have been detected.

Samples of the 'giant granite' yielded the following minerals: cordierite, micaceous and chloritic grains referred to altered cordierite; andalusite (both colourless and reddish grains); sillimanite and dark-green spinel. A few grains of corundum have been isolated from the Saddle Tor and Rippon Tor samples. The reddish andalusite has been observed only in granite from Saddle Tor, Rippon Tor, and The Nutcrackers immediately to the south of Rippon Tor.

An attempt to estimate approximately the content of cordierite in a selected sample of the Saddle Tor rock gave the following interesting result:

Weight of crushed material passing sieve (40 wires to the linear inch)	3278 grams.
Rock-flour lost by washing	407 ,,
Weight of crushed material passed through separator	2871 ,,
Tailings from separator	2633 ,,
Separated	238 ,,

The separated fraction was made up as follows:

Mineral grains of sp. gr. > 2·86. Biotite mainly, with tourmaline, garnet, magnetite, ilmenite, sphene, apatite, zircon, monazite	179 ,,
Mineral grains of sp. gr. < 2·86. (See Note below.)	
Cordierite and altered cordierite: assessed at	6·2 ,,
Quartz and felspar	52·8 ,,
	238 ,,

NOTE.—The fraction floating in bromoform was further separated into seven fractions by treatment with bromoform progressively diluted with benzole. Grains of both fresh and altered cordierite were found to be concentrated in three of these fractions; the total amount of these grains was assessed approximately, by micrometric determinations made on mounted samples of these fractions.

The amount of cordierite so assessed proves to be 0·21 % of the total weight of crushed material treated. The tailings from the Ulrich separator also yielded a little cordierite, some grains of which are beautifully fresh and show the characteristic pleochroic spots.

These results establish a further contrast between the two main granite types. Topographical and structural relationship, texture, index-figure, bulk-composition, kind of inclusions, content of felspar phenocrysts, of garnet, of fluor, and of cordierite, andalusite, &c., have been utilized to aid, or to check, a correlation. To cite only two cases:

(*a*) The granite of The Nutcrackers (Rippon Tor) has an index-figure and a content of biotite, garnet, &c., which link it with the Rippon Tor granite; but its groundmass is much finer, and its field relationships recall those of a vertical rather than a horizontal sheet. Mineral analysis proved the presence of andalusite, cordierite, and spinel. Close affinity with the 'giant granite' is thus indicated. A few thin intercalates of this type occur in the Rippon Tor mass, and an inclusion of this type has been identified in 'blue granite'. The type is therefore of a pre-'blue granite' age, and probably of late 'giant granite' age.

(*b*) The granite of Greator Rocks[1] is intermediate in composition between the typical 'blue' and 'giant' granites (see analysis, no. 6, p. 41), and its general characteristics are those of the latter rather than the former. But the Greator Rocks show strong vertical jointing, and seen from a distance they are in marked contrast with neighbouring tors, which show strong pseudo-bedding. Thin sections reveal a pronounced mylonitic structure, and the Greator Rocks as a whole are traversed by aplites to an unusual extent. This mass appears to record the effects of special conditions which operated locally, and the presence of andalusite and cordierite is therefore to be interpreted with due regard to the associated phenomena.

Description of the mineral grains.

Cordierite.—(1) Bluish grains containing shredded or clot-like opaque inclusions, around which pleochroism (in blues) is intense. (2) Blue-grey, greenish, yellow-green, and almost colourless grains, usually with spots which are strongly pleochroic (colourless to yellow). Lustre, sub-vitreous to dull. Inclusions: green spinel, and minute spheroidal bodies, which are commonly black and opaque, but are occasionally umber-brown and translucent.

Altered Cordierite.—Composite grains composed of light and dark micas and chlorite, in varying proportions. Brownish, bluish, greenish to strong green; occasionally grey or yellow. Lustre, usually dull, sometimes distinctly silky. Coloured grains are bleached but not dissolved completely by prolonged boiling with strong hydrochloric acid. Inclusions of minute spheroidal bodies are common; one grain (bright green) isolated from the Saddle Tor granite encloses a small prism and a granule of red

[1] See also Survey Memoir (Dartmoor), p. 33.

and strongly pleochroic andalusite. The flaky components of these grains may be disposed in parallel laminae, as in gigantolite (mainly micaceous) and prasiolite (mainly chloritic); or they may be without obvious parallelism, as in pinite (mainly micaceous) and chlorophyllite (mainly chloritic). The alteration of the dark mica to chlorite may explain these comparable pairs.

Andalusite.—(1) Colourless, greenish, grey, pink or reddish, with scanty dust-like inclusions. Pleochroism usually strong. The grains may be zoned or banded—colourless and reddish. (2) Greyish to dark grey; containing inclusions of shredded or clot-like carbon. Often feebly pleochroic.

Sillimanite, Spinel, and Corundum.—Fragments of these minerals present no unusual features.

Garnet.

The occurrence of garnet in the granite itself was first recorded by McMahon,[1] who identified the mineral in specimens from west Dartmoor. But as garnet was not observed in any of the granite sections examined by Flett and Dewey in connexion with the subsequent geological survey of Dartmoor, McMahon's identification was deemed doubtful.[2]

At an early stage of the present investigation garnet was found to be a constant constituent of Dartmoor stream-sands. The main source of the stream-garnet in the Widecombe district proves to be the 'giant granite'. The Chinkwell Tor rock is highly garnetiferous: some samples contain garnet patches up to 1 inch in diameter. The red garnet of Chinkwell Tor is shown by the following analysis to be a manganiferous almandine containing 20·9% of the spessartite molecule.

SiO_2.	Al_2O_3.	Fe_2O_3.	FeO.	MgO.	CaO.	MnO.	TiO_2.	H_2O (110°).	H_2O (>110°).	Total.
37·60	17·78?	1·33	29·67	2·00	1·31	9·01	nil	0·13	0·57	99·40

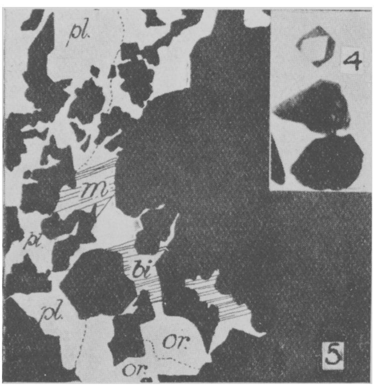
Distribution and habit of the Garnet.

In the normal 'blue granite' of the Haytor area, and in a somewhat similar type quarried at Princetown, the content of garnet is almost negligible; the grains are commonly euhedral, and always minute: the maximum diameter observed is 1·11 mm. Euhedrons include the common forms {110} and {211}, either singly or in combination, and also the very rare combination of cube (dominant) and octahedron (fig. 4). These minute crystals are undoubtedly primary.

[1] C. A. McMahon, 'Notes on Dartmoor.' Quart. Journ. Geol. Soc., 1893, vol. 49, p. 386.

[2] Survey Memoir (Dartmoor), p. 40.

In the 'giant granite' the garnet occurs as large and small anhedral grains which may be aggregated in conspicuous patches up to 1 inch in diameter. A thin section of such a patch (fig. 5) shows large plates of garnet traversed by gaping fractures infilled with greenish and somewhat indefinite light mica. These large plates are surrounded by 'outliers' of similar but smaller plates embedded in orthoclase and plagioclase indifferently. The quartz contains only a few very minute angular grains of garnet. Muscovite is unusually conspicuous. Ores, biotite, apatite, zircon, &c., are present. Occasionally rather rounded grains of



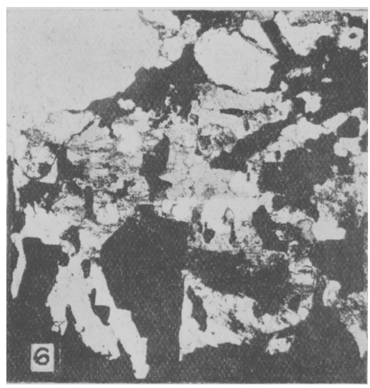


FIG. 4. Photomicrograph of a garnet crystal combining the cube and the octahedron. Princetown granite. × 11.

FIG. 5. Diagram showing the microstructure of a garnet patch in the granite of Chinkwell Tor. The black areas represent garnet. × 9.

FIG. 6. Photomicrograph showing the micrographic intergrowth of garnet and orthoclase (Carlsbad-twin) in a garnet patch of the Chinkwell Tor granite. × 22. Crossed nicols.

garnet are enclosed in biotite; the latter may be in parallel intergrowth with muscovite. The garnet-felspar areas display very definitely the features which are characteristic of micrographic intergrowth: the straight edges of the garnet plates show marked parallelism, even when these plates extend across a twin-crystal. (See fig. 6.)

There is no reason to assume that such garnet is other than primary. In the opinion of Dr. J. S. Flett (whose kindness in reading through the authors' manuscript is here acknowledged) the garnet suggests the contamination of the magma with manganese-rich country-rock, probably killas.

Summary and conclusions.

The field evidence afforded by the granite exposed in the Widecombe district confirms the conclusion recorded,[1] in the Survey Memoir on Dartmoor, that the granite as a whole forms a gigantic laccolite, which was intruded under a cover of country-rock. The facts observed may be interpreted more particularly as follows:

(1) The granite of east Dartmoor is a composite intrusion, which displays a certain amount of differentiation phenomena.

(2) If, as seems highly probable, some of the dark granitic nodules in the granite are inclusions, intrusion was effected in four main stages:

Stage 1. Recorded by relics of dark and relatively basic sheets which yielded inclusions to the granite.

Stage 2. Recorded by the 'giant granite', which, in general, is the upper of the two main granite sheets.

Stage 3. Recorded by the 'blue granite', which is the lower of the two main granite sheets, and by minor intrusions of this granite into the upper sheet.

Stage 4. Recorded by certain minor intrusions in both sheets.

(3) The order of intrusion is the order of decreasing basicity.

(4) The 'giant granite' was intruded immediately below a cover of country-rock, which comprised killas, 'greenstones', and probably also basaltic rocks. An appreciable amount of country-rock was assimilated by this intrusion either (*a*) completely or (*b*) partially, the residue being preserved as xenoliths. Assimilation is recorded by characteristic minerals, namely, garnet, andalusite, sillimanite, cordierite, spinel, and corundum.

(5) The 'blue granite' is intrusive in the 'giant granite', which it splits into two or more subordinate sheets. Its more or less complete isolation from roof and possible floor of country-rock may account for its negligible content of the characteristic minerals mentioned above.

To a limited extent, and locally, this granite may be expected to possess assimilation characteristics, acquired indirectly, i.e. by reaction, when in the fluid state, with the 'giant granite' into which it was intruded.

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[1] Survey Memoir (Dartmoor), p. 27.