

# Composite granite intrusions of SW Dartmoor, Devon

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The SW lobe of the Dartmoor granite (27km<sup>2</sup>), and the nearby Crownhill (3km<sup>2</sup>) and Hemerdon Ball intrusions, constitute the roof zones of composite granite intrusions. The earliest intrusive phase in the Dartmoor pluton is a variably porphyritic, coarse-grained, biotite/tourmaline ± muscovite, monzogranite/syenogranite. The monzogranite/syenogranite is intruded by cupolas of medium-grained, even-grained, tourmaline, alkali feldspar granite whose emplacement may have been influenced by active NW-trending faults, and by a major body of even-grained, moderately porphyritic, syenogranite/alkali feldspar granite and granite porphyry. The Crownhill intrusion comprises a core of strongly porphyritic, coarse-grained, biotite syenogranite, intruded by an even-grained syenogranite and a variably porphyritic alkali feldspar granite. The Hemerdon intrusion consists of porphyritic (megacrystic) biotite granite in the south and a NE-trending tabular body of granite porphyry with minor aplite porphyry. Aplite dyking with concomitant hydrothermal brecciation is common in the Dartmoor pluton and the Crownhill intrusion. Taken together, the field relationships and the petrography suggest that the SW Dartmoor granites represent a suite evolving from biotite granite to tourmaline granite. The diversity of rock textures (i.e. megacrystic to even-grained) and large range in phenocryst:groundmass ratios indicate wide fluctuations in the water content of the melt. Megacryst growth reflects nucleation and rapid growth in low viscosity volatile-rich magma while quench textures are the product of adiabatic crystallization following the catastrophic release of vapour. Even-grained fabrics probably formed under conditions of high confined P<sub>H<sub>2</sub>O</sub>. Escape of borosilicate fluids from the late evolved granites resulted in pervasive tourmalinization of the early granites and the emplacement of tourmaline breccias, lodes, dykes and vein swarms. The distribution of these phenomena are shown to be related to the geometry of the underlying cupolas of tourmaline granite.

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## Introduction

The 625km<sup>2</sup> Dartmoor pluton is the largest granite pluton in Britain. The pluton is essentially composed of biotite monzogranite and quartz monzonite though numerous workers (e.g. Reid *et al.* 1912; Brammall and Harwood 1923, 1932; Dangerfield and Hawkes 1981; Hawkes 1982) have demonstrated, on the basis of compositional and textural data, its composite nature. Approximately 98% of the exposed pluton is composed of coarse-grained (mean size of groundmass 2 to 4mm), variably porphyritic (<1 to >10% alkali feldspar phenocrysts), biotite or two mica granite, with fine- to medium-grained porphyritic and even-grained granite forming the remainder (Fig. 1). The latter is concentrated in the SE corner of the pluton but many scattered outcrops throughout the southern half of the pluton suggest that the lithology may be under-represented at the present exposure level. This report summarizes the results of a combined mapping and petrographic study of the southwestern portion of the Dartmoor pluton and its satellite intrusions, and presents unequivocal evidence of their composite nature.

## Geological setting

The irregular lobate projection of SW Dartmoor ranges up to 13km from the main mass (Fig. 1). The original form of the intrusion has been considerably modified by 2km of dextral displacement along the NW-SE trending Cornwood fault system (e.g. Holder and Leveridge 1986; Selwood *et al.* 1982). The contact with the killas is not exposed but a detailed gravity survey (Tombs 1980) suggests that the granite surface dips southwest at 50-70° from the outcrop. The gravity model also indicates that the flanks of the granite may be stepped. The Crownhill intrusion (Figs 1 and 2) underlies the area known as Crownhill Down and together with the Hemerdon Ball intrusion it forms a fault-bounded granitic promontory (Tombs 1980) running SSW from the main Dartmoor pluton. It is separated from the Hemerdon granite to the south by E-W trending faults. The gravity data of Tombs (1980) indicates that the granite margin is nearly vertical to the south of Hemerdon.

## Dartmoor granite lithologies

The *Lee Moor granite (G<sub>1</sub>)* is the prime lithology, forming 70% of the outcrop in S W Dartmoor (Fig. 1). It is a reddened, coarse-grained (3-5mm), weakly-porphyritic (<10% phenocrysts), biotite or tourmaline-bearing granite (Brammall and Harwood 1923, 1932; Hawkes 1982) with a variable colour index (C.I. <5 to ~ 10). *G<sub>1</sub>* varies in composition from monzogranite to a more dominant syenogranite (Streckeisen's (1976) scheme for classifying plutonic

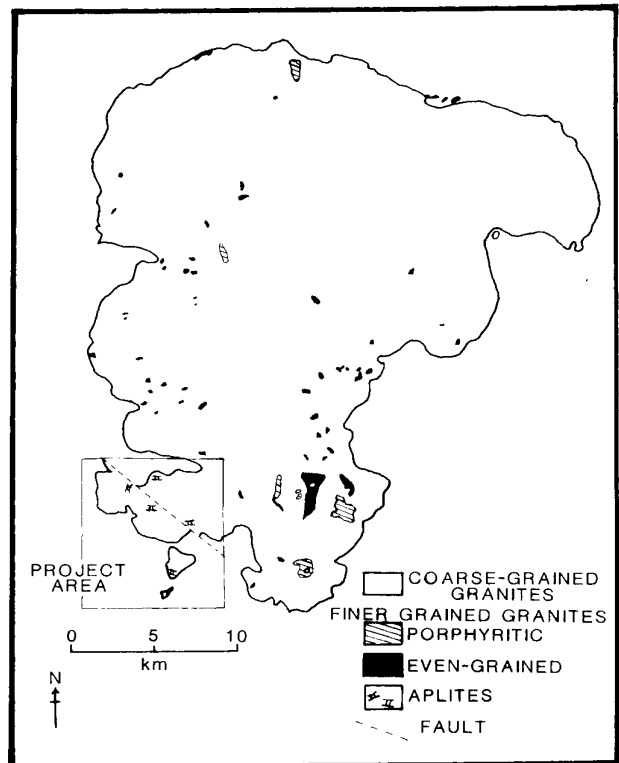


Figure 1. Dartmoor - distribution of the finer grained granites. From Hawkes (1982).

igneous rocks is used throughout; see Fig. 3): a lithology which is atypical of the Cornubian granites (Exley and Stone 1982; Willis-Richards and Jackson 1989). The granites are two-feldspar, subsolvus rocks containing 35-40% banded- and patch-microperthitic alkali-feldspar, 10-20% sodic plagioclase (An<sub>1-16</sub>), 25 to 37% quartz and subordinate amounts of dark brown or bleached biotite <1 to 6%, tourmaline < 1 to 6% and muscovite 1 to 5%. Alkali feldspar phenocrysts are tabular

and subhedral with an average size of 15 x 5mm. The main minerals form a hypidiomorphic inequi-granular texture often with a quartzlinked fabric (Durrance *et al.* 1982). The order in which minerals crystallized in this rock is similar to that proposed by Stone (1979) and slightly modified by Charoy (1986) for the crystallization of the coarse-grained megacrystic, type B, biotite granites. Biotite and plagioclase are the earliest minerals to form followed by quartz, alkali feldspar, muscovite and tourmaline. Biotite, which displays evidence of corrosion, contains numerous inclusions of zircon, monazite, apatite, urananite and opaque phases. Coarse flakes of muscovite are intergrown with uniformly-sized feldspars and quartz suggesting a primary origin, while the quartz-linked fabric suggests extensive subsolidus activity. Fluorite and topaz are subsolidus accessory phases having either an interstitial habit or pseudomorphing primary micas. Rb-Sr dating of the main granite lithology elsewhere in the pluton yields an age of  $280 \pm 1$ Ma (Darbyshire and Sheppard 1985).

The *Wigford Down granite* ( $G_{2a}$ ) is a fine- to medium-grained porphyritic granite that underlies the Wigford Down area. This lithology passes southeastwards into the *Wotter granite* ( $G_{2b}$ ) and granite porphyry which outcrop along the margin of the pluton for about 4km (Fig. 2).  $G_{2a}$  is a more strongly porphyritic equivalent of  $G_1$  and the phenocrysts (10 to 15%) are smaller (Hawkes 1982) with an average size of 10mm. Feldspar phenocrysts in both lithologies exhibit a roughly N-S alignment which is the main orientation of magmatic flow in southern Dartmoor. The *Wotter granite* ( $G_{2b}$ ) is a tourmaline-bearing, subsolvus, syenogranite/alkali feldspar granite and granite porphyry (Fig. 3) with a C.I. of 3 to ~ 15, containing 5 to 15% tabular-shaped phenocrysts (3 to 25mm) set in a fine-grained (0.1 to 0.4mm), even-grained groundmass. The phenocrysts are roughly equal proportions of banded microperthite and sodic plagioclase ( $An_{0-12}$  and mainly  $<An_5$ ). The inclusion of tourmaline in

groundmass quartz suggests that it might be a magmatic phase. Muscovite is however a subsolidus alteration product. Chemical data (not presented here) suggest that *Wotter granite* displays some affinities with the evolved  $G_4$  granite described later.

### Lithologies within the Lee Moor china clay pits

The china clay deposits (Fig. 2) are mainly hosted by leucocratic (C.I.  $<3$ ), coarse-grained, weakly porphyritic, tourmaline-muscovite granite (equivalent to  $G_1$ ) and subordinate, even-grained, fine- to medium-grained, tourmaline-muscovite granite ( $G_4$ ). Heavily reddened, strongly porphyritic, tourmaline-bearing granite ( $G_3$ ) is locally exposed in the clay pits and is common immediately adjacent to the pits. Tourmaline nearly always has a reciprocal modal relationship with biotite (Brammell and Hardwood 1925) and biotite generally does not occur within the pits. Where present, biotite is intergrown with muscovite,  $\pm$ chlorite,  $\pm$ tourmaline, rutile, and opaques. Biotite crystallized early, together with plagioclase ( $An_{1-16}$ ). The latter is almost completely replaced by late magmatic microperthitic feldspar, subsolidus albite ( $An_0$ ) and quartz.

$G_3$  is a strongly porphyritic, coarse-grained granite which is exposed at the northern end of Cholwich Town pit (Fig. 2). The outcrop pattern forms a roughly NW-SE trending 'kidney bean' shape and it has a gradational contact with  $G_1$ . It is distinguished from the main lithology by the absence of biotite (C.I.  $<5$ ), its reddened appearance, an elevated alkali feldspar content of banded microperthite (70%), sodic plagioclase (8%,  $An_{5-10}$ ) and reduced quartz content (25%). On a QAP plot it falls in the syenogranite field (Fig. 3).  $G_3$  locally exhibits large, tabular, microperthitic feldspar megacrysts (up to 100mm long) with near horizontal C-axis orientation. The phenocrysts show a close spatial relationship to radiating clusters (5 to 20mm diameter) of black tourmaline crystals. The granite contains sub-mm veinlets of alkali-feldspar, secondary tourmaline-filled cavities and the near total replacement of micas by subsolidus quartz and banded microperthitic alkali feldspar.

$G_4$  is a fine- to medium-grained, even-grained leucocratic granite (C.I.  $<3$ ) containing two discrete alkali feldspars (25-40% orthoclase, 2-5% microcline and 5-15% albite  $An_{1-7}$ ) and 27-40% quartz. Orthoclase has undergone an appreciable amount of structural reordering to microcline. The two main lithologies are a leucocratic, tourmaline-topaz  $\pm$ muscovite, alkali feldspar granite (Fig. 3) and a less common, crimson coloured, Li-mica-topaz  $\pm$ muscovite alkali feldspar granite. The former contains evenly dispersed tourmaline prisms or irregular poikilitic growths of tourmaline (cf. Brammell and Harwood 1925) up to 5mm across. This texture is interpreted as a late-magmatic boron -exsolution phenomenon and is mainly observed in a cupola in the western part of Lee Moor pit where  $<1$  to 8mm wide, anastomosing tourmaline veins appear to have emanated from this rock. Topaz is interstitial and thus late-stage. Muscovite is intergrown with quartz and feldspar and may be primary. Accessory minerals include apatite, zircon and very sparse fluorite. Apatite crystals are intergrown with (fine-grained, subsolidus) muscovite and are probably inherited from early magmatic biotite or Li-mica.  $G_4$  granite is exposed within the pits as:

1. The roof-zone of a 100m diameter cupola in the western part of Lee Moor pit (Fig. 2).

2. E-W trending, 20mm to 3m wide, subvertical dykes, generally lacking chilled margins (some of the dykes cut the  $G_4$  granite cupola).

Microscopic examination of the sharp contact between the  $G_1$  and  $G_4$  granites reveals that sub-mm 'veins' of  $G_4$  invade  $G_1$  producing a local microcataclastic fabric.

Computer-aided evaluation of the lithological information contained in over 400 borehole logs reveals that roughly 20% of the area occupied by clay pits is underlain by the  $G_4$  granite and the extent of the buried bodies is tentatively shown in Fig. 2. An isometric view of the present pit topographies and the surface of the  $G_4$  granites is shown in Fig. 4. The diagram clearly demonstrates that the fine- to medium-grained granites form a series of circular or elliptical (E-W and N-S trending) domes. The E-W orientation is sympathetic with

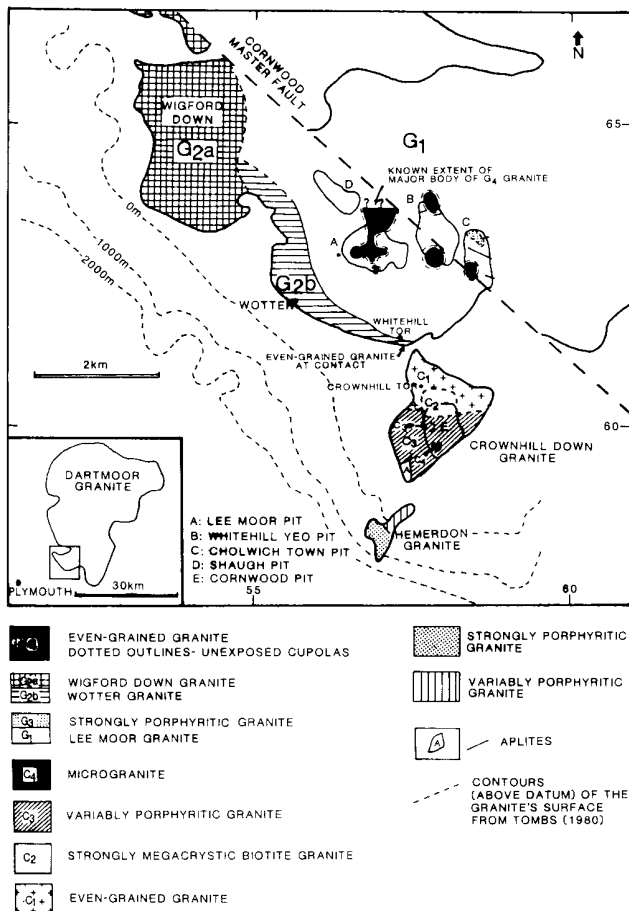


Figure 2. The igneous geology of SW Dartmoor. Contours of the pluton's surface are from Tombs (1980).

the E-W oriented lode-dyke swarms in south Dartmoor (Dines 1956; Moore 1975; Beer and Scrivener 1982). Haloes of tourmaline enrichment extend upwards and laterally from the G<sub>4</sub> granites and it is likely that they provided the source materials for the tourmaline lodes and vein swarms. G<sub>4</sub> is unquestionably a late-stage specialized granite (cf. Willis-Richards and Jackson 1989) and may approximate to the topaz granites of the St Austell area (Hill and Manning 1987) in terms of their texture, composition (including chemical data not presented here) and structural setting.

### Crownhill intrusion

Four distinct lithologies have been identified in the Crownhill intrusion (Fig. 2). Crownhill Tor (SX 576608) and the northern part of the Down are underlain by the *Crownhill Tor granite* (C<sub>1</sub>). It is a grey to pinkish coloured, even-grained 1-2mm syenogranite (Fig. 3),

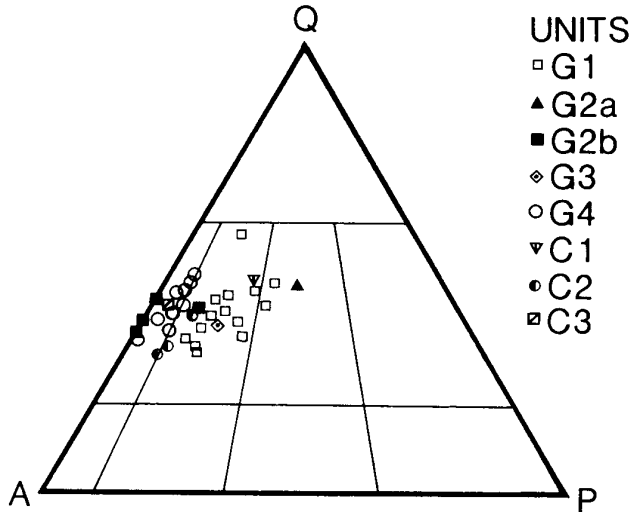


Figure 3. QAP diagram (see Streckeisen, 1976) of the modal data for the main lithological units. The amount of data points (400 points each) for each unit is weighted to their importance. The three fields occupied by the data are, from right to left; monzogranite, syenogranite and alkali feldspar granite, and is the evolutionary trend for the granites of SW Dartmoor.

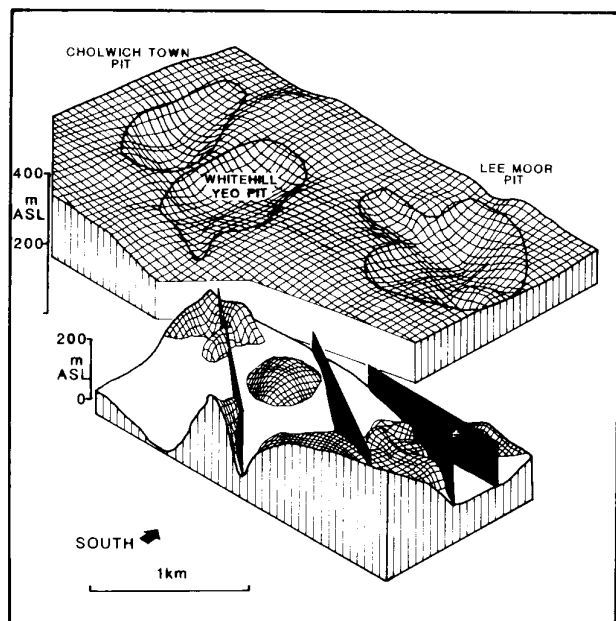


Figure 4. Isometric views of (upper block) the present day china clay pit topographies (E.C.C. Int. pits only) and (lower block) the geometry of the underlying G<sub>4</sub> granite cupolas. The latter demonstrate a positive spatial correlation to sheeted and stockworked vein-systems (and similarly related hydrothermal breccias) developed in the envelopes of G<sub>1</sub> granites around the cupolas. Only the major wrench faults are shown (black planes).

with C.I.<5. The granite contains two feldspars, ~40% pinkish alkali-feldspar and ~20% greenish-tinged plagioclase (An<sub>6-10</sub>), together with quartz (30-35%), biotite, muscovite, tourmaline and accessory purple fluorite. The relationship of this lithology to the other granites has not been observed. It does however bear a striking resemblance to the medium-grained granite exposed at Whitehill Tor (SX 577614) of the Dartmoor granite and bears a chemical resemblance (data not presented) to the *Wotter granite* (G<sub>2b</sub>). These petrographic similarities are an indication that the G<sub>2b</sub> and C<sub>1</sub> lithologies are part of the same petrological unit.

The central part of the Down is underlain by the *Cornwood granite* (C<sub>2</sub>), which is strongly -megacrystic biotite granite. It appears to form a roughly circular ~500m diameter body occupying the whole of the northern portion of the Cornwood china clay pit. The most distinctive feature is the presence of very large (20-70mm) tabular microperthitic feldspar phenocrysts which form 10-40% of the rock. The longer C-axes of the phenocrysts are steeply-inclined suggesting that this intrusion has the form of a vertical cylinder. The grain size of the matrix is 3-5mm but decreases to 1-2mm towards the margin. The matrix contains 20-30% quartz, 14-18% orthoclase, 3-8% normally-zoned plagioclase (An<sub>25-35</sub>) and 3-8% biotite. C<sub>2</sub> is therefore a monzogranite (Fig. 3). The microperthites are characterized by band and patch exsolution structures. Most of the granite has been tourmalinized and kaolinized with wholesale destruction of biotite and its replacement by black tourmaline. Biotite-bearing granite can however be seen in the NW wall of the pit and in rare unkaolinized corestones within the pit. The accessory minerals include zircon, monazite, urananite, and apatite all contained within biotite or secondary tourmaline.

The southern half of Crownhill Down is underlain by a variety of medium- to fine-grained granites (C<sub>3</sub> and C<sub>4</sub>). The *Crownhill granite* (C<sub>3</sub>) is the chief unit. Exposures in the Cornwood pit clearly show that this lithology intrudes the C<sub>2</sub> granite. The contact which dips north at about 10°, is sharp but undulatory, and dykes, veins and apophyses can be seen invading the coarse-grained granite. Immediately adjacent to the contact C<sub>2</sub> is heavily tourmalinized with partial to complete destruction of the feldspar phenocrysts, recrystallization of the matrix and the development of tourmaline aggregates (up to 15 modal % tourmaline). It is also noticeable that the abundance of tourmaline veins in C<sub>2</sub> increases as the contact is approached and some irregular masses of tourmaline appear to be rooted in the top of the C<sub>3</sub> granite. C<sub>3</sub> is a variably porphyritic granite containing 10-25mm long phenocrysts of microperthitic alkali feldspar or 4-6mm globular quartz, set in a 2-4mm, uneven-grained matrix of orthoclase (20%), albite An<sub>0.3</sub> quartz (30-35%) and irregular-shaped or radiating aggregates of tourmaline (5-10%). The proportion of the microperthite phenocrysts within C<sub>3</sub> varies between about 2-10% and exposures within the pits indicate the presence of at least one cupola (C<sub>3a</sub>) which appears to be compositionally similar to, but texturally distinct from, the host (C<sub>3</sub>) granite. The dome-like cupola consists of finer-grained granite with a higher proportion of phenocrysts than the host. It outcrops in the western wall of the pit where it displays a flat top about 8m above pit base and a gently dipping (10°N) contact. The contact is sharp but undulatory with small (0.3m high) dome-like protuberances. Feldspar phenocrysts in the C<sub>3a</sub> granite are oriented parallel to the contact. The upper 0.1-1m of the cupola granite appears to be quenched and is enriched in tourmaline (locally 30-40%). This zone clearly 'spawns' some of the tourmaline veins in the overlying granite. The C<sub>3</sub> host is also characterized by 2-10mm clots of tourmaline in a zone parallel to the contact. The cupola probably represents a stage in the crystallization history of the C<sub>3</sub> granite during which the magma was enriched in boron and water. It is postulated that the high boron content of the magma resulted in enhanced water solubility which promoted the growth of feldspar phenocrysts in the manner suggested by Vernon (1986). A sudden reduction in boron solubility, possibly concomitant with the exsolution of a vapour phase, would lead to the rapid precipitation of tourmaline at the interface between the magma and the crystalline carapace (Pichavant 1981; Pollard *et al.* 1987). Some of the boronsaturated vapour escaped along hydraulic fractures but most was trapped close to the roof of the cupola. The C<sub>3</sub> granite may contain

many of these local crystallization centres which may be identified in drill core on the basis of abrupt changes in grain size, proportions of phenocrysts and the abundance of tourmaline.

The SE corner of the Cornwood pit contains a finer grained, porphyritic, microgranite stock ( $C_4$ ) that is finer grained than the  $C_3$  granite. Contacts between the two lithologies were not observed, owing to active tipping and ripping of the working face, but  $C_4$  appears to form a stock-like body (vertically exposed for 8-10m) and of unknown diameter. At the base of the pit the principal lithology is a porphyritic microgranite containing about 5%, 10-20mm long feldspar phenocrysts set in a ~1mm even-grained felsic and tourmaline-rich matrix. This lithology passes upwards (at the top of the 8-10m high working face) into rhyolite porphyry containing 8-10%, 1-2mm, quartz phenocrysts and rare 10-20mm feldspar laths set in an aphanitic groundmass. This cap is clearly formed by isothermal decompression (adiabatic crystallization) of the microgranite magma. The stock is also the locus for borosilicate fluids and the microgranite is cut by hundreds of narrow tourmaline veins which form both sheeted vein swarms and anastomosing networks.

### Hemerdon Ball granite

The intrusion is divisible into two components: a N-S elongated 700m long x 200-400m wide porphyritic granite and a NE-elongated 650m long x 120-150m wide, steeply dipping tabular body of mineralized and hydrothermally altered granite porphyry (Ussher 1912; Cameron 1951). The contact between the two components is not exposed. The northeastern end of the dyke-like body is partly defined by a NW-SE trending fault. North of the fault, the granite splits into several NE-trending apophyses. Exposure of the earlier porphyritic granite is restricted to a small overgrown quarry (SX 570582) where reddened, strongly porphyritic (20%, 10-15mm long phenocrysts), fractured and tourmaline veined granite is exposed. The original biotite is partly to completely replaced by tourmaline.

The granite porphyry is exposed in the shallow Hemerdon open pit and can be observed in the diamond drill cores stored at the pit. The principal lithology is a leucocratic, variably altered, medium-grained, tourmaline-bearing granite porphyry, containing 5-10mm phenocrysts of globular quartz and tabular alkali feldspar set in a finer-grained (1-2mm) felsic groundmass. Phenocryst/groundmass ratios are typically 2:1 but significant variations in this ratio and variations in the abundance of phenocrysts indicates that the intrusion is a composite body. More equigranular, medium-grained (2.5mm) variants characterize the northern end of the intrusion. Mineral abrasion and dislocation textures in the granite porphyry are indicative of catastrophic quenching. Phenocrysts commonly show undulose extinction, are fractured, dislocated and display irregular angular and embayed grain boundaries. Quartz phenocrysts occasionally show rounded embayments indicative of magmatic corrosion.

### Aplites

Aplite dykes are exposed within the clay pits (Figs 1 and 2). They vary from 0.5 to 5m in width are subvertical and have WNW-ESE or WSW-ESE trends. Aplites are leucocratic or pinkish coloured and aphanitic, sugary textured rocks except for macroscopic radiating clusters and disseminated laths of tourmaline and sparse phenocrysts of alkali feldspar and rounded quartz. The largest, a 4m wide dyke located in the middle of Cholwich Town pit (Fig. 2), is light greenish coloured, displays flow banding, contains no tourmaline, and varies from very fine-grained at its chilled margins to an equigranular microgranite at its centre.

The aplites, and less commonly, the late-stage granite ( $G_4$ ) are spatially associated with tourmaline veins and tourmaline breccias. The latter are texturally and compositionally similar to the breccia dykes and pipes described by Allman-Ward *et al.* (1982) and Goode and Taylor (1980).

### Crystallization of the Dartmoor granites

The porphyritic granites of the SW Dartmoor region are classic

examples of the multistage crystallization of volatile-rich granite melts (Fig. 5). Petrographic studies indicate that initial undercooling (Swanson 1977) was characterized by the co-precipitation of biotite-plagioclase-quartz with accessory zircon, monazite and apatite preserved as inclusions within biotite. The local presence of compositional zoning in plagioclase ( $An_{35-25}$ ) implies a modest temperature decrease during crystallization and a degree of crystal fractionation. The presence of corroded margins to the plagioclase crystals indicates a degree of disequilibrium between the crystals and melt. This episode of crystallization was superseded by the growth of alkali feldspar pheno/megacrysts (which subsequently unmix to micropertthite), together with quartz and biotite. Nucleation of alkali feldspar occurred when there was 60-80% of melt remaining and megacryst growth may reflect an increase in the volatile content in the melt and consequent reduction in viscosity (Vernon 1986). With 30-50% of the melt remaining, undercooling of the system was increased and the residual melt crystallized (quartz-alkali feldspar-biotite or tourmaline and locally muscovite) as an even-grained intergrowth. Subsolidus re-equilibration resulted in the unmixing of alkali feldspar, alteration of biotite (to white mica or chlorite + rutile + opaques), the growth of secondary white mica and tourmaline and the development of quartz-linked fabrics (Durrance *et al.* 1982).

The medium and fine-grained granites generally display a more varied crystallization history. Porphyritic varieties began crystallizing quartz-alkali feldspar or two discrete feldspars (albite and microcline) and tourmaline (instead of biotite) and following rapid undercooling, crystallized quartz-albite-microcline-white mica and tourmaline. The Hemerdon granite porphyry is the best example of a granite porphyry system in the province. Initial crystallization of alkali feldspar, biotite and quartz, containing needles of sillimanite (?), was terminated by the crystallization of a fine-grained groundmass composed of quartz-orthoclase-albite-white mica-tourmaline. The contrast in size between the phenocryst and groundmass crystals (1.5 to 8mm) implies rapid undercooling, or more likely, adiabatic crystallization following a drastic reduction in pressure, concomitant with the exsolution and loss of a vapour phase (Swanson 1977), a supposition which is supported by extensive microfracturing, dislocation of phenocrysts, and the abundance of vapour-rich fluid inclusions in annealed microfractures which transgress the quartz. Highly embayed and cusped margins to quartz phenocrysts are interpreted as being due to flux line attack-enhanced dissolution in the vicinity of a vapour bubble. Considerable variations in the phenocryst to groundmass ratio demonstrate significant fluctuations in water pressure and repeated vapour exsolution events during the crystallization of the stock, as is typical of many porphyry systems (cf. Burnham and Ohmoto 1980).

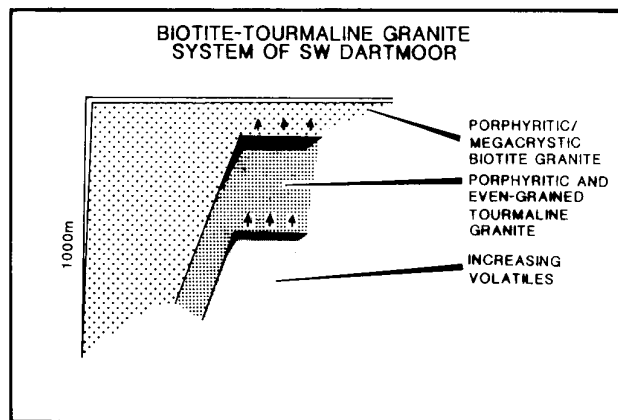


Figure 5. The scenario that resulted from multistage intrusion of progressively evolved granites (and finally aplites, not shown) in the SW Dartmoor pluton and its satellites. Dot-size is directly proportional to grain-size. The black ornamentation represents the boron rich melt fraction which accumulated in the apices of the late-stage granite cupolas. Subsequently, borosilicate fluids were expelled (arrows) into the older granites' carapaces through self-creating fractures.

The even-grained textures of much of the medium- and fine-grained granites indicate that they crystallized under more-or-less steady state conditions. Experimental studies (Fenn 1977; Swanson 1977) indicate that the differences in vapour saturation during low degrees of undercooling could explain the differences between the medium- and finer grained variants; the  $G_4$  granites being formed from vapour saturated melt, while the fine-grained granites formed from vapour depleted melt (quenched to lower undercooling). The subsolvus mineralogy (albite-microcline) and presence of abundant primary muscovite and tourmaline in these rocks can be explained with reference to the experimental data relating to the effects of boron on granitic melts (Pichavant 1981). This study demonstrates that a primary muscovite and a subsolvus association may form at much lower pressures and temperatures than in the pure water system (e.g. between 1.8-2.3kb and 600-630°C from a melt containing 6-12% B<sub>2</sub>O<sub>3</sub>). It is postulated that the even-grained subsolvus muscovite granites of SW Dartmoor crystallized from B-F-H<sub>2</sub>O rich melts. In some cases boron was more or less confined to the magmatic system as late solidus or early subsolidus tourmaline, while in other cases B partitioned into the vapour phase which exsolved from the magma and migrated out of the system through self-creating hydraulic fractures. Tourmaline vein swarms, stockworks and hydrothermal breccias which overlie the medium-grained granites are likely to have been sourced by these B-rich magmas.

### Concluding comments

The combination of topography, open pit china clay operations and exploration drilling provides a unique opportunity to study the upper 500m of the SW Dartmoor pluton and its satellite intrusions. One of the most interesting aspects of the igneous geology is the composite nature of all three intrusions and the identification of cupolas of finer grained granite intruding coarse-grained granite. These later granites appear to be the source of borosilicate fluids that formed the numerous veins and breccias, and caused extensive tourmalinization in the overlying rocks. It is pertinent to note that the only other area in the province where composite intrusions of this type have been described is the western part of the St Austell granite (Hill and Manning 1987) and possibly the Land's End granite (Booth and Exley 1987) and it is tempting to speculate that this is not an artifact of exposure but an intrinsic feature of the main china clay districts.

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