TEXTURAL FEATURES OF SOUTH-WEST ENGLAND GRANITES: A REINTERPRETATION

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The granite plutons of South-West England are individually distinguished on the basis of their coarse grained textures, designated here as primary texture granite units. The Carnmenellis, Bodmin and St Austell plutons each have one such primary texture unit whereas Lands End has two and Dartmoor three. In addition granites distinguished as two-phase granites are interpreted as magmatic breccias, derived from the primary texture granite units, with which they have textural affinity. These rocks are characterised by megacrysts of feldspars, quartz and biotite, within a fine-grained groundmass of aplitic appearance. They occur as a well-defined central core in the Carnmenellis Granite, but in the Dartmoor, Lands End, Bodmin and St Austell granites they form extensive but poorly defined areas of outcrop. The textural features reported here are similar to those established for the granites of the South-East Asian Tin Belt. One of us has also observed identical patterns of textural variation in South-East China, and in the Eskdale and other granites of the British Caledonides. It is proposed that such variations are a normal feature of highly evolved granites.

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INTRODUCTION

The textural features of south-west England granites considered in this contribution, were first recognised by Hall (1974). He demonstrated a sequence of textural evolution from coarse grained granites with complex grain boundary relationships, through porphyritic variants containing lithic granite fragments and megacrysts of quartz, K-feldspar, plagioclase and biotite in a fine-grained groundmass of aplitic aspect, to microgranites with few megacrysts. He interpreted these features as having resulted from a sudden loss of pressure at an advanced stage of crystallization. Later authors (e.g. Hawkes and Dangerfield, 1978; Stone, 1975; Exley *et al*., 1983; Chen *et al*., 1993; Salmon, 1994; Salmon and Powell, 1998; Pembroke and D'Lemos, 1996; Powell *et al*., 1999) have not followed Hall (1974) in their interpretation of the textures. However, a similar interpretation to that of Hall (1974) was subsequently applied to the granite plutons of the South-East Asian Tin Belt (Cobbing, 1987, 2000; Cobbing *et al*., 1986, 1992; Pitfield *et al*., 1990), i.e. an origin resulting from a series of decompression events.

Accordingly a reconnaissance visit to Devon and Cornwall was made during May 2002 with a view to establishing the patterns of textural variation within the granite plutons of South-West England. It was found that granitic textures distinguished in South-East Asia as being of both primary and two-phase origin are present in all the mainland plutons of South-West England.

TEXTURAL FEATURES OF SOUTH-EAST ASIAN GRANITES

The paucity of outcrop in jungle terrain required a systematic but flexible scheme for the field description of granite exposures. It was found that each pluton in the batholiths of South-East Asia was distinguished from all others by the distinctive nature of their coarse grained crystalline textures, which were generally allotriomorphic. Granites with such textures were informally designated as 'primary texture granites', since these textures formed the basis for the field distinction of plutons within the batholiths. Most plutons comprised only one primary texture unit, but some had two or three.

Many plutons were additionally characterised by granites of finer grain size, carrying megacrysts of K-feldspar, plagioclase, quartz and biotite, together with clumps of these minerals, which are granite fragments. These features were considered to have resulted from the disaggregation of the coarse granite by loss of pressure and the disruptive intrusion of later fine-grained granites. Granites with these characteristics were distinguished as 'two-phase granites' or 'disequilibrium texture granites'. In what follows the textural features of the granites of South-West England are considered in terms of a simple textural progression similar to those developed in the granites of South-East Asia, (Cobbing, 1987, 2000; Cobbing *et al*., 1986; 1992).

GRANITE TEXTURES

Primary (equilibrium) textures

The distinguishing features of primary texture granites result from the progressive crystallisation of minerals from a melt, to form a rock with interlocking grain boundaries. These boundaries develop complex shapes, determined by the continuous growth of crystals until further growth is impeded by the progressive 'locking up' of the system as the available space is filled. The growing crystals coalesce to form a holocrystalline texture with complex grain boundary relationships. In tonalites and granodiorites the earlier crystals, such as the mafics and plagioclase, which are euhedral and are evenly distributed, provide a partial framework within which later quartz and K-feldspar may be located. In these rocks the textures are dominated by plagioclase, which forms a framework of interlocking tabular crystals with interstial spaces in which the mafics, quartz and K-feldspar are located (Byron *et al*., 1995, 1996).

The textures of monzogranites and the more acid granodiorites differ, in that the crystal framework is dominated by quartz and K-feldspar, both of which tend to form allotriomorphic grain boundaries. These crystals commonly form an interlocking mosaic of quartz, K-feldspar and plagioclase, which may be approximately equigranular, or porphyritic, with larger crystals of K-feldspar which is normally the only porphyritic mineral. These minerals, and especially quartz and K-feldspar, develop complex, irregular grain boundaries as a result of their progressive growth to fill all the available space.

Quartz is allotriomorphic in character and is not normally present as single crystals, but forms polycrystalline aggregates, which may be of many shapes and sizes, depending on the history of crystallization, and of the magmatic, tectonic or emplacement processes which may have been active. It is also very commonly the case, that in monzogranites the large quartz aggregates are readily distinguished in the field by their dark colour, in shades of grey or blue. If a linear fabric is at all well defined it is common to find that the mafic minerals are located in linear aggregates near the quartz-feldspar boundaries.

During field mapping in South-East Asia it was found that each pluton within the composite batholiths of that region were characterised by distinctive primary textures, enabling the identification of individual plutons within those batholiths. It has also been subsequently found, that all the granites of South-West England, as well as many of the Caledonian granites, are individually distinctive. For example, there is only one Shap Granite, and virtually all British geologists are familiar with the textural features of that body as a result of its widespread use as an ornamental stone.

In general, it is found that in primary texture monzogranites there are three principal categories which represent different stages in a broad continuum between two end-member textural states. 1. Coarse grained inequigranular with no K-feldspar megacrysts e.g. the Nal and Kuantan granites of the Eastern Province of Peninsular Malaysia (Cobbing *et al.*, 1992). 2. Coarse grained with 10-20 % K-feldspar megacrysts evenly spaced and with strong visual contrast with the finer groundmass (e.g. the Shap Granite). 3. Coarse and very coarse grained granites with abundant K-feldspar megacrysts comprising perhaps 50% of the rock and which are outlined by anastamosing quartz ribbons (e.g. the Gap Granite of the Main Range of Peninsular Malaysia) (Cobbing *et al.*, 1992).

Of these three categories, it is only the second, which is porphyritic in the sense that there is a strong visual contrast between megacrysts and groundmass. Additional diversity is provided by differences in the habit and size of the K-feldspar megacrysts. These can be either moderately tabular as in the Shap Granite, or thin and elongate as in the Bodmin Moor Granite of South-West England and the Fleet Granite of the Southern Uplands. A further variety of K-feldspar habit is their rounded form in the Rapakivi granites of Scandinavia.

Disequilibrium (two-phase textures)

In addition to primary texture granite units, which only carry K-feldspar megacrysts, many plutons have zones containing megacrysts of K-feldspar, quartz and plagioclase, set in a groundmass, which is commonly finer grained and may be of aplitic aspect. As well as single crystals, they also carry aggregates of these minerals, which have allotriomorphic grain boundary relationships and are therefore clasts of granite. All the megacrysts and the lithic clasts are in disequilibrium with the fine-grained groundmass, and the feldspars and biotites show evidence of partial resorption. Since all the granite plutons of South-East Asia are each texturally distinctive (Cobbing, 1987; Cobbing *et al.*, 1986, 1992) it was possible to match the lithologies of the clasts with the parent granite pluton and it was shown that each pluton had its own suite of textural derivatives. It was demonstrated that each of the derivative suites showed a progressive evolution from those with a very high content of granite clasts, crystal aggregates and single crystals, through a sequence with progressively smaller proportions of megacrysts and crystal aggregates, to megacrystic microgranites and, eventually, greisens associated with tin mineralisation. It was found that the textural sequence from each individual pluton corresponded to a sequence of geochemical evolution.

Two-phase textures are formed when a quenching event occurs late in the crystallisation sequence when a crystal framework will already have been formed, with residual magma located in the intergranular spaces. Quenching at this stage results in the disruption of the rock-magma system into a mixture of crystal and lithic fragments contained within a fine grained groundmass.

Cobbing *et al.* (1986, 1992), Cobbing (1987, 2000) and Pitfield *et al.* (1990) distinguished these granites as both secondary texture granites and two-phase variants. In this account two-phase is used throughout since it more accurately reflects the derivative nature of these rocks and the dynamics of the process.

Because the grain boundary relationships of the included clasts showed that they had been derived from a primary texture holocrystalline granite, it was plain that the crystals and crystal aggregates were actually magmatic breccias. It was postulated that the observed textures of the groundmass were caused by a decompression event, which resulted in the crystallisation of the residual magma, to form a quench fabric of small equigranular crystals, which also included crystal and lithic clasts derived from the mother granite. Because these derivatives formed a textural sequence of rocks, from those with many megacrysts and lithic fragments, to microgranite with few, there must have been a number of such events affecting each pluton, most probably during the process of emplacement to higher crustal levels.

In South-East Asia a total of 227 plutons were recognised and full geochemical analyses were made from 189 of these. All the plutons were characterised by primary textures, but 77 of them, mainly from the S-type granites of the Main Range Province, had two-phase textures as well. The complete data set of over 500 chemical analyses, together with full descriptions and illustrations, is provided in Cobbing *et al.* (1992). In any single pluton the textural sequence from primary texture granite through secondary variants to microgranite with a decreasing proportion of lithic and crystal clasts, corresponds to a sequence of geochemical evolution. Binary diagrams show that increasing textural modification is accompanied by increasing total alkalies (Pitfield *et al.*, 1990 figure 4). Trace element patterns show an overall enrichment in Nb, Rb, Sn, U and W and a depletion in Ba, Sr, Th, V, and Zr giving rise to progressive increase in the ratios Rb/Sr, Rb/Ba and Rb/Zr and a decrease in K/Rb.

Such geochemical trends are well known indicators of the potential presence of Sn-W mineralisation, an instructive example being described from the Hatapang Granite in Central Sumatra (Clarke and Beddoe-Stephens, 1987). In this case mineralogical and geochemical continuity was demonstrated from marginal (*cf.* two-phase textured granite), to tin and tungsten mineralised greisens and quartz veins of both exo-and endo-contact nature. The process invoked was autometasomatism by late stage volatile rich fluids driven upwards and outwards from the consolidating pluton, essentially the final stage of a process which may have started with pervasive fracturing and two-phase textural formation discussed herein.

Diversity of the primary textures in South -West England granites

The small megacryst and the large megacryst division of Hawkes and Dangerfield (1978) and Dangerfield and Hawkes (1981) successfully distinguished the granites of South-West England into two major categories (Figures 1a and 1b). Bodmin Moor, Carnmenellis and the Scilly Isles fall into the small megacryst category, while Lands End, St Austell and Dartmoor all have large megacrysts. However, it is not just the size of the megacrysts which distinguish these plutons but also their shape and relative abundance.

The K-feldspar crystals of the large megacryst type are tabular with aspect ratios generally of 1:2-1:4 but these only form 10-20% of the rock and are consequently widely spaced within a groundmass which, though coarse, is finer than that of the small megacryst type. Because of this contrast in size,

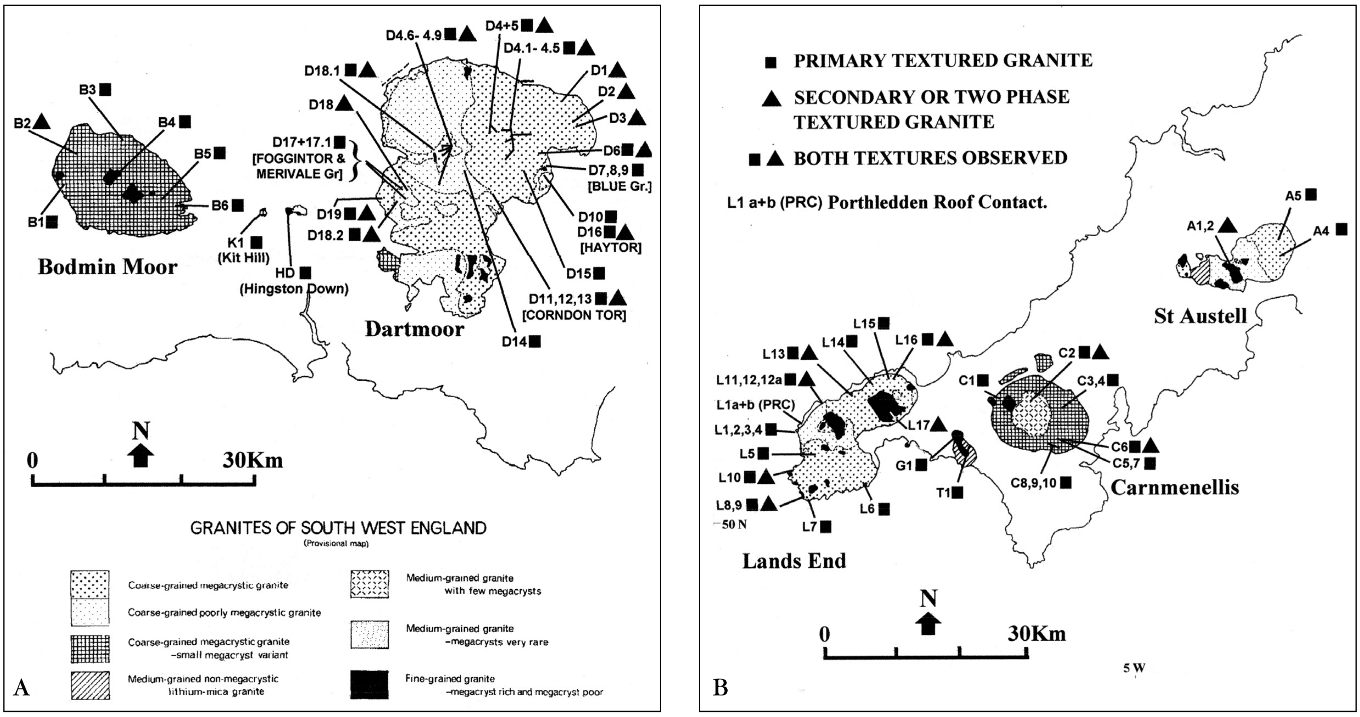


***Figure 1. A.** Outline map of the Dartmoor and Bodmin Moor plutons showing sample locations as listed in tables 1 and 4 superimposed on granite boundaries of figure 1 in Dangerfield and Hawkes (1981). **B.** Outline map of the Lands End, Carnmenellis and St Austell plutons showing sample locations as listed in tables 2, 3 and 4 superimposed on granite boundaries of figure 1 in Dangerfield and Hawkes (1981).*

abundance and colour, they stand out more prominently from the relatively finer matrix, to provide a classical porphyritic texture.

The distinguishing feature of the small megacryst type is not that the megacrysts are small, but that the granites are not porphryritic, since the megacrysts provide about 60% of the rock. The megacrysts of this type are not always small, in some cases they may be as long as 6 cm, equal in length to the largest of the large megacryst type. They do however, differ in their shape, being more tabular with aspect ratios between 1:4 and 1:6. These plutons are texturally distinctive, with the feldspar fabric providing a mesh of interlocking crystals, and with the quartz located within the mesh, commonly as elongate, interlocking aggregates of irregular shape and with the mafic minerals located mostly at the margins between the quartz and feldspars.

In the small megacryst type, the mesh like character of the feldspar framework resembles the hypidiomorphic texture of tonalites and granodiorites, which are effectively controlled by the early crystallization of plagioclase. The large megacryst granites have fewer K-feldspar megacrysts, which are widely separated within a matrix of finer grain size, and are porphyritic. In granites world wide it is the latter pattern which is generally regarded as being most typical, and occurrences elsewhere of the small megacryst type seem to be unusual.

Darbyshire and Shepherd (1985) analysed 43 representative samples from the granite plutons of South-West England for major elements and 28 trace elements. They found that the small megacryst granites of the Carnmenellis and Bodmin plutons had different rare earth patterns from those for the large megacryst granites of Lands End and Dartmoor, having a steeper slope and a small Eu anomaly. The granites of Dartmoor and Lands End had a shallower slope and a marked Eu anomaly. Inspection of their data also shows that the Carnmenellis and Bodmin plutons have lower values for Nb and Y than the Lands End and Dartmoor granites. Darbyshire and Shepherd (1985) considered that the anomaly signified less extreme fractional crystallization, or crystallization under more oxidising conditions. They also considered the steep rare earth profiles to have resulted from either a smaller degree of partial melting in the source region, or from a chemical difference in the source. The coincidence of the textural difference with the rare earth geochemistry suggests the interdependence of these factors.

DIVERSITY OF THE TWO-PHASE TEXTURES

The chief problem relating to two-phase texture granites is that the geological implications of their textural features are commonly not appreciated, and as a result they are usually described in terms which do not reflect the geological processes by which they were formed. In most cases they are not distinguished as being in any way different from the holocrystalline granites from which they were derived. In those cases where they are distinguished as a separate facies, they are most commonly referred to as quartz, feldspar porphyries, which implies that individual crystals of quartz, K-feldspar, plagioclase and biotite were precipitated from a granite melt, which was quenched before a coarse groundmass could be formed. Quartz-feldspar porphyries of this type do occur, and are present in the young, high level plutons of Andinotype granites associated with volcanic sequences, where they are commonly mineralised. However, even in these granites not all of the quartz-feldspar porphyries are of this nature, some have similar textural features to the two-phase granites considered here (Cobbing, 1987, 2000; Cobbing *et al.*, 1986, 1992; Sanchez *et al.*, 1995). Although only a few plutons with two-phase characteristics have been distinguished in Andinotype granite batholiths, it is likely that more may be recognised as geologists become aware of that possibility.

Two-phase texture granites, as established in South-East Asia (Cobbing, 1987; Cobbing *et al.*,1986, 1992), are commonly developed in highly evolved S-type and crustal I-type granites. They are readily distinguished from quartz-feldspar porphyries by the presence of crystal aggregates of quartz, K-feldspar, plagioclase and biotite, within a matrix of finer grain size. These aggregates are lithic clasts of granite with textures which can be matched with those of the primary texture precursor. They exhibit complex grain boundary relationships, which could only have developed by the complete crystallisation of the magma, to form a holocrystalline rock with a 'touching fabric'. That is, a rock in which all the grain boundaries of the constituent crystals impinge together, to form a mosaic of interlocking crystals with complex and sinuous grain boundary relationships. This texture is so well known that geologists take it as a 'given' and refer to it as a 'granitic texture'. However, the presence of crystal aggregates with such a texture, in a rock with a finer grained groundmass, normally interpreted as a porphyry, shows that these rocks are not porphyries but breccias. Similarly, isolated crystals of quartz, feldspars and biotite in these rocks are not phenocrysts but xenocrysts.

Certain textural features are specific to these rocks. Isolated K-feldspar megacrysts commonly contain small quartz blebs in a border zone next to the fine-grained matrix. These quartz blebs all extinguish together on rotation of the stage, and those on opposite sides of the twin plane extinguish separately. It is common to find that in the apices of the crystals the quartz blebs become vermiform and resemble a granophyric texture. There is also commonly some degree of outgrowth of feldspar in the marginal zone into the finer grained groundmass. In those cases where a K-feldspar megacryst is in contact with the matrix on one side of the crystal but is protected on the other side by adjacent minerals of the clast, it is only the unprotected margin which develops these marginal quartz blebs. Granites with these textures were illustrated by Aleva (1960) and subsequently by Cobbing *et al.*, (1986, 1992) and Pitfield *et al.*, (1990). Those with a high megacryst content of K-feldspar, quartz, plagioclase and biotite may also contain clumps of these minerals, which are derived pieces of holocrystalline granite (Cobbing *et al.*, 1986, 1992; Cobbing, 1987; Pitfield *et al.*, 1990).

Stone (1968) in a study of the elvan dykes of South-West England, noted the presence of compound aggregates of quartz, clumps of quartz and potash feldspar, and larger crystal aggregates. He concluded that they were xenoliths and xenocrysts, which were derived from the granite through which the dyke had been intruded. He did not, however, extend this interpretation to components of granite plutons with the same textures. The concept was subsequently developed by Hall (1974), who made three line drawings illustrating the textural development. The first was from the porphyritic granite at Carn Brea at the northern margin of the Carnmenellis Granite, which illustrated the interlocking nature of all the grain boundaries in the coarse, primary texture granite. The second, from the Cligga Head pluton, showed lithic fragments as well as single crystals in a fine-grained groundmass. The third from Hingston Down Quarry near Gunnislake, an isolated body between Dartmoor and Bodmin Moor, consisted mainly of a fine-grained groundmass with sparse megacrysts of quartz and feldspars and with occasional compound grain aggregates and lithic fragments.

These drawings illustrate the progressive disruption of a holocrystalline granite to a ‘porphyry’ by a process of magmatic brecciation. Although they were taken from different areas, and one of them from a dyke rather than a pluton, they

No.	G.R.	Locality	Type	Notes
D1	SX 777 856	Hingston Down	STG	Coarse grained megacrystic granite with secondary texture
D2	SX 784 837	Blackinstone Quarry	STG	Coarse grained megacrystic granite with secondary texture
D3	SX 782 832	East Wray Quarry	STG	Coarse grained megacrystic granite with secondary texture
D4	SX 677 813	Birch Tor	STG	One of a number of nearby tors with extensive STG leucocratic outcrops (Figure 3a)
D4.1	SX 698 829	Shapley Tor	STG	EJC had previously noted similar two phase or STG in a number of nearby localities listed here and in the text and maps as D4.1 to D4.5
D4.2	SX 703 806	Hameldown Tor	STG	
D4.3	SX 702 786	Blackaton Tor	STG	
D4.4	SX 708 789	Hameldown Beacon	STG	
D4.5	SX 729 823	Easdon Tor	STG	
D4.6	SX 615 753	Crockern Tor	STG	EJC had previously observed similar leucocratic STG occurrences at 4 localities NW of Postbridge. These are listed here as D4.6 to D4.9
D4.7	SX 619 787	Higher White Tor	STG	
D4.8	SX 619 793	Lower White Tor	STG	
D4.9	SX 614 805	Little Flat Tor	STG	
D5	SX 615 816	Shipley Tor	STG	Extensive areas of STG observed
D6	SX 743 790	Hounds Tor	STG + PTG	Sill of STG in sharp contact with PTG which forms most of this tor
D7	SX 760 775	Blue Granite Quarry	PTG	Blue Granite type PTG (no megacrysts) (Figure 2b)
D8	SX 751 777	Holwell Tor Quarry	PTG	Blue Granite type PTG with some K megacrysts
D9	SX 755 775	Quarry N of Haytor	PTG	Blue Granite type PTG with some K megacrysts
D10	SX 758 771	Haytor	PTG	Most of this tor is PTG of Giant Granite type (Figure 2a)
D10	SX 758 771	Loose block	Contact	PTG cut by microgranite with xenocrysts (Figure 4a)
D11	SX 687 743	Corndon Tor	PTG	Giant Granite
D12	SX 687 744	Corndon Tor, small quarry	STG	Finer grained with sparse quartz and feldspar megacrysts
D13	SX 687 743	Corndon Tor	STG	BGS photomicrograph 42031 (in xp) showing invasion/brecciation of PTG by a finer grained phase - i.e. this is a 2 phase texture (Figure 4b)
D14	SX 635 770	Carpark below Bellever Tor	PTG	Weathered outcrop with sparse megacrysts
D15	SX 732 775	Bonehill Tor	PTG	Giant Granite
D16	SX 757 712	Haytor west crag	PTG + STG	Low dipping 5 m thick aplite cuts PTG
D17	SX 566 735	Foggintor Quarry	PTG	Equigranular, Foggintor type PTG with sparse K feldspar megacrysts
D17.1	SX 559 751	Merivale Quarry	PTG	EJC has previously related this PTG with that at Foggintor (Figure 2c)
D18	SX 565 746	nr Princeton	STG	Good fresh STG of dark Princeton type (Figure 3b)
D18.1	SX 606 798	Rough Tor	STG	EJC has previously observed that from Rough Tor westward and at Sweltor STGs are darker coloured, carrying more biotite. These resemble the Princeton example (D18)
D18.2	SX 559 733	Sweltor	STG	
D19	SX 533 735	Pew Tor	STG	Leucocratic STG as at Birch Tor (D4)

Table 1. *Dartmoor. Locality and sample listings. PTG - primary texture granites, STG - secondary texture (two-phase) granites.*

illustrate exactly the same process of textural evolution as that shown by (Cobbing, 1987; Cobbing *et al.*,1986, 1992; Pitfield *et al.*, 1990) from the plutons in the South-East Asian tin belt.

Hall (1974) interpreted the textures as breccias and it is worth quoting the implications of his interpretation in full. 'The inference which can be drawn from the trimodal grain size distribution is that crystallisation initially followed a course similar to that of a normal coarse porphyritic granite, but a sudden change in physical conditions at an advanced stage of crystallisation resulted in the formation of a chilled groundmass similar to that of the rhyolite porphyry dykes. The switch during crystallisation from coarse crystals to chilled groundmass in both granite porphyry intrusions and rhyolite porphyry dykes must presumably be attributed to elevation of the liquidus by pressure release. Only a water pressure reduction could account for the sudden and sharp change to more rapid crystallisation'.

He went on to say that granites with similar textures occurred in the Lands End Granite, the Variscan granites of the Massif Central and southern Portugal and also suggested a link with porphyry copper systems. It is now evident that Hall (1974) fully understood the geological implications of the textures he had described, but his interpretation of those textures does not seem to have been followed by other workers in that region, since there has been no implementation of his model of textural evolution to the plutons. Consequently, when granites with identical textures were independently distinguished in the plutons of the South-East Asian granite batholiths, it was thought to be the first time that the process had been recognised, whereas in reality it was the second.

FIELD OBSERVATIONS

All the plutons of mainland South-West England were visited during May 2002 and both primary and secondary textures were recognised in all of them. However, the main focus of our work was directed towards the Dartmoor and Lands End plutons, as there was reason to believe that they were more complex. The other plutons were only briefly seen and partially traversed. A total of 61 localities were examined in detail and over 100 samples collected for further examination and reference. The observations made in 2002 have been augmented by earlier work of one of us (J.C.). The locality, observational and interpretational data are given in tabular and map form (Tables 1-4, Figures 1a & 1b). The results are summarised here, illustrated by photographs from outcrop, and of hand specimens (Figures 2-8).

Dartmoor (Table 1, Figure 1a)

Our observations confirm the findings of Brammall (1926), and Brammall and Harwood (1923, and 1930) that there are two major primary texture granite units, the Giant Granite and the Blue Granite. In addition the Foggintor-Merrivale Granite occupies a small area in the western part of the pluton. The traverse began at Hingston Down near the eastern margin of the pluton and continued via Birch Tor, Shapley Tor, Hounds Tor, Holwell Tor, Hay Tor, Corndon Tor, Two Bridges, Foggintor, Sweltor and Pew Tor.

The primary texture granites. The Giant Granite (Figure 2a) is a very coarse grained biotite granite with up to 30% robust K-feldspar megacrysts set in a coarse primary texture matrix of quartz, feldspar, biotite and some tourmaline. It forms a N-S trending linear outcrop with an E-W extent from Hay Tor (D10) to Widecombe. The Blue Granite (Figure 2b) was observed in lower ground to the east and north of Hay Tor and is present in three quarries 500 m NNE of Hay Tor (D7) below Holwell Tor (D 8) and 500 m NW of Hay Tor (D9). It is a fine to medium grained equigranular biotite granite with occasional quartz megacrysts and is commonly without K-feldspar megacrysts. In some areas however, K-feldspar megacrysts are present, but are generally widely dispersed. They do not give the impression of being an essential component of the rock.

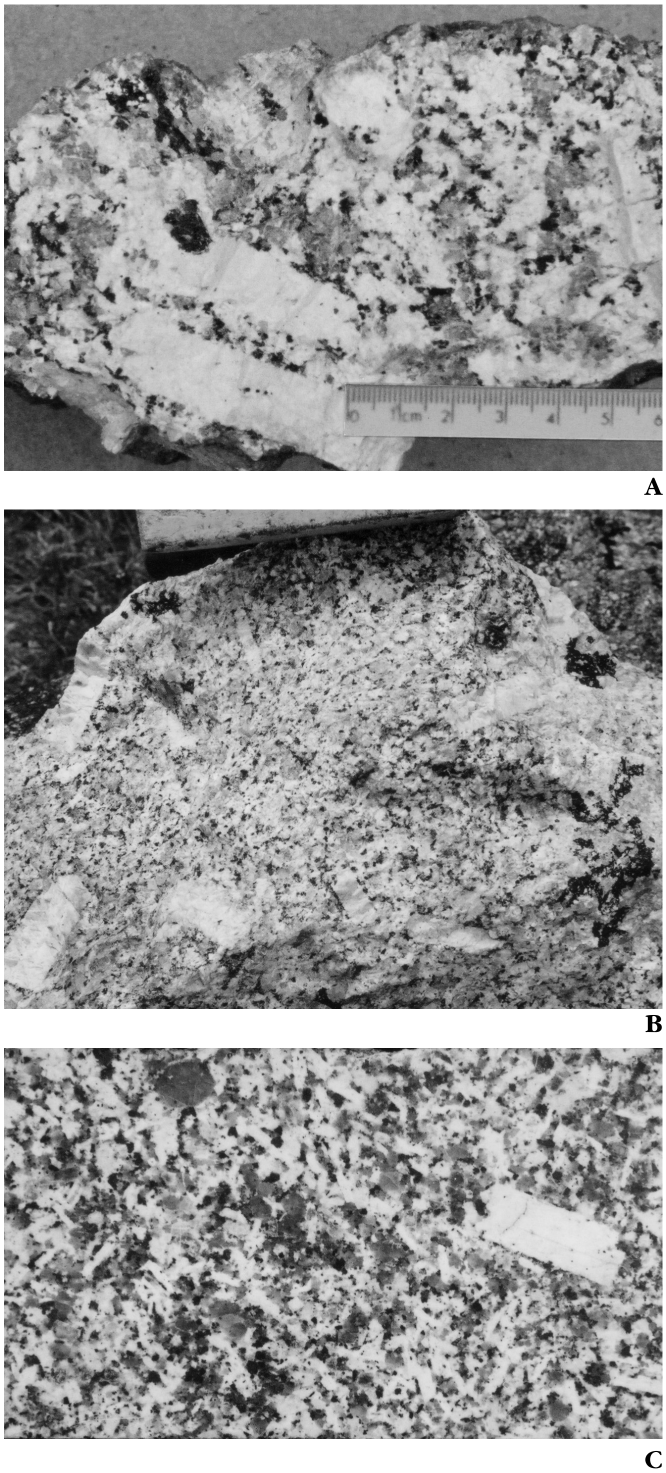
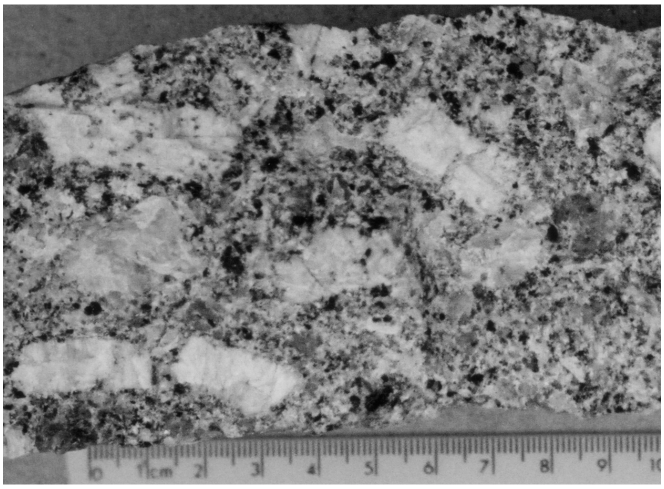


Figure 2A. *The Giant Granite, Hay Tor. Primary texture biotite granite with K-feldspar megacrysts in a coarse grained holocrystalline groundmass of brown tinted quartz, feldspars and biotite. Locality Hay Tor. cm scale bar. (D10).* ***B.*** *The Blue Granite. Primary texture biotite granite with sparse K-feldspar megacrysts in a medium grained groundmass. Hammer head 11 cm. (D7).* ***C.*** *The Merivale Granite. Primary texture granite dominated by the abundant lath like feldspars. Occasional megacrysts of quartz and K-feldspar. Scale of magnification X 0·6. (D17.1).*

The Foggintor-Merrivale Granite (Figure 2c) which crops out to the west of Princeton in two quarries (D17) and (D17.1), is a medium to coarse grained granite with a distinctive lithology, due principally to the presence of abundant small K-feldspar megacrysts, which provide a felted fabric forming the greater part of the rock. In some cases larger K-feldspars and large

A



B

Figure 3A. *Birch Tor. Two-phase texture granite with megacrysts of feldspars and quartz in a fine grained sugary groundmass. Coin 2 cm. (D 4)* ***B.*** *Princeton area. Two-phase texture granite with abundant large megacrysts of feldspar, together with smaller megacrysts of quartz and biotite in a fine grained groundmass. (D 6).*

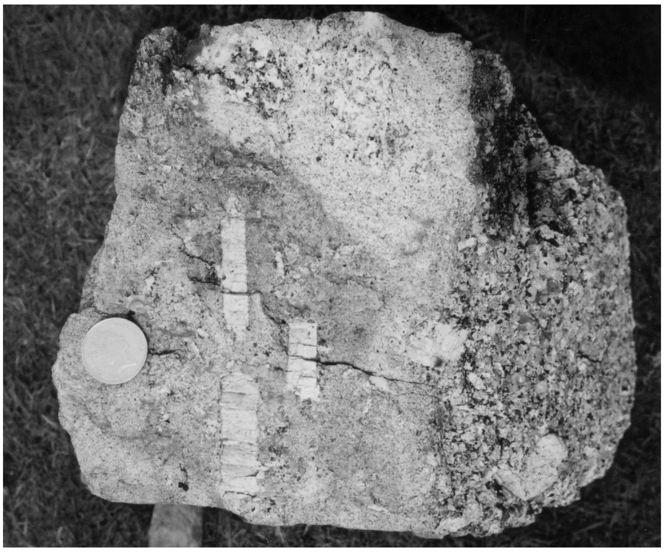
quartzes are also present (Figure 2c). The high content of small tabular K-feldspar megacrysts suggests a general affinity with the Bodmin Moor and Carnmenellis plutons.

The two phase texture variants of the Giant Granite (Figure 3a). A clear relationship between the primary and two-phase texture granites is seen at Hounds Tor (D 6) where a horizontal sheet of two-phase texture granite is present at the base of the tor, the rest of which is formed of normal Giant Granite. A similar relationship is seen on Corndon Tor (D11 and 12) where the Giant Granite is present as spectacular pavements at the crest of the tor. A few metres below the crest, outcrops of two-phase texture granite are present which contain megacrysts of quartz and feldspar. These two occurrences indicate that these rather leucocratic two-phase texture granites, which are certainly hosted by the Giant Granite, may have been derived from it. There is also a very local development of incipient two-phase texture facies at Hay Tor, which is predominantly formed of the Giant Granite.

Texturally variable, leucocratic two-phase texture granites of similar lithology, with abundant megacrysts of K-feldspar, quartz, plagioclase and biotite in a fine grained sugary matrix, form extensive outcrops on Birch Tor (D4) (Figure 3a) and had been previously noted by J.C. at Shapley (D4.1), and southwards through Hamel Down Tor (D4.2) Blackaton Tor (D4.3) the Hameldown Beacon (D4.4), also at Easdon Tor (D4.5), forming a continuous outcrop to the west of the Giant Granite in the Hay Tor region. It is considered that these particular outcrops may have been derived from that unit.

Two-phase texture rocks of similar, rather leucocratic appearance had also previously been observed, NW of Postbridge, at Crockern Tor (D4.6), Higher White Tor (D4.7), Lower White Tor (D4.8) and Little Flat Tor (D4.9). However, from Rough Tor (D18.1) westwards all the outcrops are darker with a higher biotite content and resemble the two-phase texture granites of the Princeton area (D18) (Figure 3b). Leucocratic two-phase texture rocks reappear to the west of the Foggintor granite, e.g. at Pew Tor (D19), where the rock carries abundant megacrysts of quartz, feldspar and biotite in a fine-grained matrix. There is also abundant tourmaline. The granites at Sweltor (D18.2) are melanocratic two-phase texture rocks resembling those at Princeton.

Two-phase texture granites form most of the outcrop to the west of Corndon Tor, with the exception of a small area around Two Bridges and the Foggintor-Merrivale Granite. Whereas the observations at Hounds Tor, Corndon Tor and Hay Tor, suggest derivation of these variants from the Giant Granite, it has not been possible to establish such a relationship for the



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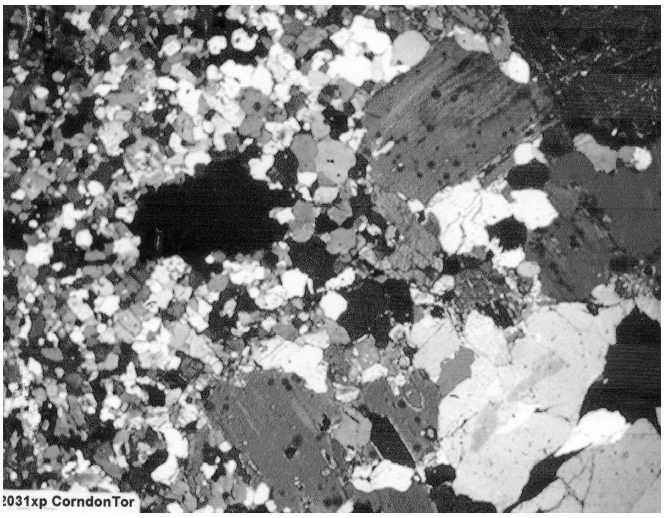


B

Figure 4A. *Hay Tor. Loose block showing sharp contact of coarse grained Giant Granite with a vein of finer grained granite with K-feldspar megacrysts and lithic granite fragments. A K-feldspar megacryst protrudes from the coarse granite into the finer grained granite. Coin 2 cm. (D10).* ***B.*** *Corndon Tor. Photomicrograph of coarse grained granite with an irregular contact of fine grained granite with coarse grained primary texture granite. Note the infiltration of the finer grained granite into the coarse granite along some grain boundaries. Scale of magnification X 6. (D13).*

Blue Granite. The quarries on Dartmoor are either in two-phase texture granites, Princeton, Pew Tor, Sweltor, Blackinstone, East Wray, or in the primary texture Blue Granite in the three quarries north of Hay Tor, or the primary texture Foggintor-Merrivale granite. There are no quarries in the Giant Granite in this area.

The three granite localities (D1, 2 and 3) observed east of the Sticklepath Fault (Hingston Down, Blackinstone and East Wray) all exhibit two-phase textural features and are probably derived from the Giant Granite, despite the pink colour of some megacrysts. Two further examples of variation in the Giant Granite are illustrated in Figure 4a, b. The first is a block at Hay Tor (D10) which shows many of the criteria which distinguish both primary and two-phase texture granites. A primary texture granite is in sharp contact with a much finer granitic phase, which encloses xenoliths and xenocrysts with textural affinities with the adjacent Giant Granite from which they were derived. The sharp contact, however, indicates that the finer grained phase is a dyke and is therefore a later stage in the evolutionary sequence than that examined in this paper.

The second (Figure 4b) listed here as (D13), is a photomicrograph of a sample in the BGS collection labelled "Corndon Tor". The field coincides with an irregular but sharp contact between coarse grained primary texture granite and a finer grained two-phase texture granite phase. Such relationships are similar to those discussed and illustrated in the South-East Asia studies (e.g. Pitfield *et al.*, 1990; Cobbing *et al.*, 1992).

Summary. The Blue Granite and the Giant Granite are both primary texture granites and the area of their known outcrop is confined to a fairly narrow N-S trending belt extending from Widecombe in the west to the lower quarries north of Hay Tor. All the other outcrops in this section are of secondary texture with the exception of a small area around Two Bridges which seems to be of Hay Tor type, and the Foggintor-Merivale granite, which is a distinctive, small megacryst primary texture granite.

No.	G.R.	Locality	Type	Notes
L1a	SW 357 324	Kenidjack Mine area	Various	Derelict mine workings and chimney blocks include very coarse grained PTG + aphyric medium grained pink granite
L1b	SW 354 323	Porthledden Beach contact	Roof contact	Low angle west dipping contact with Mylor Slates complicated by cross strike joint controls. K feldspar megacryst rich outer skin, sometimes with sidewall style K feldspar growth. This intruded in turn by coarse megacrystic granite sheets and dykes with packed K feldspar megacrysts which are often aligned subparallel to contact
L1	SW 352 318	Cape Cornwall	Fine grained microgranite	Fine grained equigranular microgranite (aphyric type)
L2	SW 353 313	Carn Gloose Point	Fine grained microgranite	Fine grained equigranular microgranite (aphyric type) with occasional quartz megacrysts. Tourmaline common in the groundmass
L3	SW 356 310	Porth Nanven	Fine grained microgranite	As Carn Gloose with occasional K feldspar megacrysts
L4	SW 356 307	Headland S of L3	PTG	Equigranular medium grained interlocking grain boundaries of quartz and feldspar (5-10%) plus biotite and some tourmaline
L5	SW 385 282	Carn Brae Hill	PTG	Very coarse grained PTG with aligned tabular K megacrysts <10 cm (aspect ratio 1:6). Prominent globular quartz proto ribbons (Figure 5a)
L6	SW 452 244	Quarry above Lamorna Cove	PTG	Small K feldsapr megacrysts (2-3 cm). Fine biotite rich groundmass with some larger flakes
L7	SW 372 217	Porthgwarra Beach nr slipway	PTG	Deeply weathered megacrystic PTG with subhorizontal K feldspar megacrysts. Relatively fine grained groundmass
L8	SW 364 216	Clifftop nr watch tower	PTG + STG	Rapid transition from PTG to STG in this area. This sample has typical secondary texture (Figure 5b)
L9	SW 364 217	Beach nr Chair Ladder	PTG + STG	Boulders of both primary and secondary texture granite are present
L10	SW 347 263	Sennen Cove	PTG + STG	PTG with abundant tabular K feldspar megacrysts. Rapid transition to fine grained and secondary texture
L11	SW 390 358	Portheras Cove east	PTG + STG	Medium grained, equigranular, sparsely megacrystic (?aphyric) with some quartz megacrysts. Possibly a minor intrusion, has no clear affinity with either Porthgwarra or Carn Galver types
L12	SW 387 358	Portheras Cove centre	STG	Abundant K feldspar and quartz megacrysts. Equates with Carn Galver STG
L12a	SW 385 358	Portheras Cove west	Fine grained microgranite	Microgranite similar to that around St Just (L1, 2 and 3)
L13	SW 424 365	Carn Galver	STG	Coarse grained megacrystic STG. Small K feldspar megacrysts (Figure 6b)
L14	SW 462 387	N side of Loganstone	PTG	Very coarse, equigranular PTG. No K feldspar megacrysts. Good example of Carn Galvar type (Figure 6a)
L15	SW 487 392	Rosewall Hill	PTG	Very coarse K feldspar megacrysts <4 cm. Quartz forms linear ribbons along K feldspar margins (Figure 7a)
L16	SW 496 393	Rosewall Hill mine workings	PTG + STG	Both very coarse PTG and microgranites of STG type are present on mine dumps (Figure 7b)
L17	SW 485 345	Castle an Dinas quarry product	STG	Very fine grained microgranite with sparse K feldspar megacrysts, more abundant quartz megacrysts and a few biotite megacrysts

Table 2. *Lands-End. Locality and sample listings. PTG - primary texture granites, STG - secondary texture (two-phase) granites.*

There is definite field evidence of two-phase texture development within the Giant Granite at Hay Tor, Hounds Tor and Corndon Tor. A transition from the Giant Granite to secondary texture granite was observed to the west of the Fernworthy Reservoir. There is no sign of this kind of development in the Blue Granite. On this basis it seems most reasonable to relate all the two-phase variation of this pluton to processes affecting the Giant Granite only. The ubiquitous presence of large K-feldspar megacrysts in all of the two-phase variants supports that interpretation. This would imply that the two-phase texture granites to the east of the Sticklepath Fault are also derivatives of the Giant Granite.

The Foggintor-Merrivale Granite is distinctive with textural features similar to those of the Bodmin Moor and Carnmenellis plutons. There are no visible examples of the field relationships and order of intrusion. No two-phase textures have been observed in that body.

Lands End (Table 2, Figure 1b)

Chen *et al*., (1993) and Powell *et al*., (1999) established the complex nature of the pluton. Powell *et al*., (1999) distinguished the St Buryan Lobe in the southern part from the Zennor Lobe to the North, separated by an extensive East-West trending complex of finer grained granites. The short duration of our visit only permitted the formation of a gross outline of the situation. It was found that there are at least two primary texture granite units, distinguished on the basis of their textural features at specific outcrops. Accordingly, the granite in the southern part of the pluton, the Porthgwarra Granite was named from the granite cliff at Porthgwarra Bay (L7). In the northern part of the Lands End Pluton, the Carn Galvar Granite was recognised at the tor of that name (L13) and at the Loganstone (L14). The two granite units are each additionally characterised by two-phase texture derivatives which have textural affinities with each primary texture unit. These observations support the recognition of a northern Zennor Lobe and a southern St Buryan Lobe by Powell *et al*., (1999). However, we have not followed the nomenclature of Powell *et al*., (1999) as it was considered to be more useful to distinguish the textural characteristics of each granite unit on the basis of their occurrence at specific outcrops which can be checked, as was done in all the other plutons.

In addition it was found that much of the central part of the pluton in the St Just region is formed of a suite of fine-grained granites which also carry K-feldspar and quartz megacrysts. Granite outcrops with these gross characteristics were observed at Cape Cornwall (L1), Carn Gloose (L2), Porth Nanven (L3) and Portheras Cove (L11). In addition to K-feldspar megacrysts the fine-grained granites also carry occasional small quartz megacrysts and consequently may be considered to be of two-phase texture affinity. The associated primary texture granites more closely resembled the Porthgwarra granites than Carn Galvar.

Granites of the southern lobe; the primary texture granite. The outcrops of primary texture granite in the southern lobe seen by us, from Lamorna Cove to Sennen Cove and Lands End, are provisionally assigned to the Porthgwarra Granite type based on the textural characteristics of the granite forming the cliff at Porthgwarra Bay (L7) and also at Carn Brea (L5).

The primary textured granite (Figure 5a) is coarse grained with 10–30% of tabular K-feldspar megacrysts with aspect ratio 1:4-1:6 horizontally aligned and set in a coarse groundmass with 5-10% biotite in crystals of about 2 mm average size and which do not exceed 3 mm. Quartz is present as isolated pale grey crystals and as intermittently connected clusters from 2-10 mm. Although the granite at Lamorna Cove (L6) has some incipient two-phase texture features it also has many textural aspects which are characteristic of primary texture granites. We had considerable difficulty with this rock, but it is clear that it has more affinity with the Porthgwarra Granite rather than Carn Galvar.

Primary- two-phase texture granite relationships. There is a virtually continuous section of both primary and two-phase texture granites from Porthgwarra Beach to Lands End and Sennen Cove. Abundant discontinuous outcrops of the Porthgwarra Granite can be seen along the cliff walk as far as the Coast Watch Tower (L8). A little beyond this point a gully leads down to a beach, where there is an outcrop of two-phase texture granites (L9) (Figure 5b). Granites with areas of two-phase textural characteristics continue along the coast

A

B

Figure 5A. *The Porthgwarra Granite. Coarse grained primary texture granite with sparse K-feldspar megacrysts in granite dominated by smaller, lath like feldspars. Grey quartz follows feldspar boundaries. (L5).* ***B.*** *The Porthgwarra Granite. Two-phase texture with megacrysts of feldspars, quartz and biotite in a medium grained heterogeneous matrix. (L8).*

through Lands End as far as Sennen Cove L10 where both primary and two-phase granites are present. At Sennen Cove there is a sharp N-S trending contact between primary texture granite and two-phase texture granite, which forms the headland.

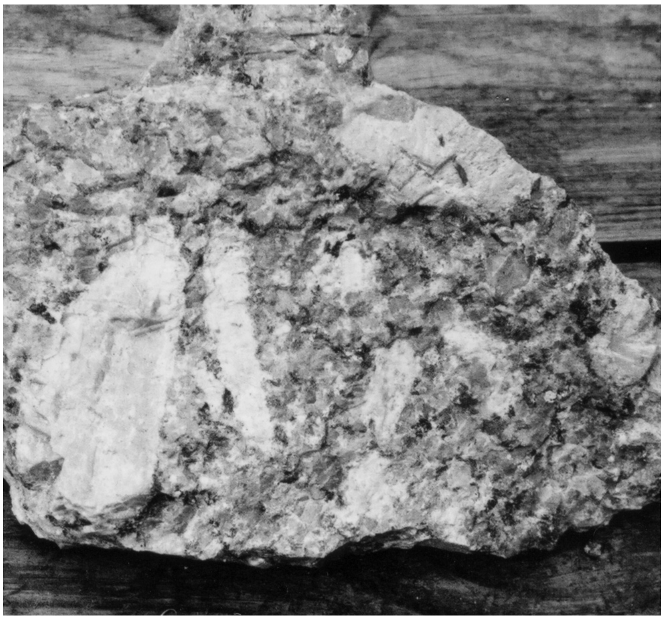
A

B

Figure 6A. *The Carn Galvar Granite. Coarse grained primary texture granite with K-feldspar megacrysts and large biotite crystals. (L14).* ***B.*** *The Carn Galvar Granite. Two-phase texture variant with megacrysts of feldspar, quartz and biotite in a finer grained matrix. (L13).*

Granites of the northern lobe, primary texture granites. The Carn Galvar Granite forms a considerable outcrop and is very coarse grained with 5-10% biotite in evenly dispersed crystals of up to 5 mm in size. K-feldspar megacrysts in large tabular crystals up to 4 cm form an aligned crystal framework enclosing quartz in brownish grey aggregates, as well as smaller feldspars and mafics in a very coarse groundmass (Figure 6a). The textural features of the Carn Galvar Granite were described from extensive outcrops at Carn Galvar (L13) and at the Loganstone (L14) (Figure 6b).

The granite at Rosewall Hill (L15) (Figures 7a & b) is even coarser and differs from the Carn Galvar Granite in having pink K-feldspar in both groundmass and megacrysts. It is also charcterised by distinctive two-phase variants. This is either a new granite, or alternatively a more coarsely grained facies of Carn Galvar. At present this latter option seems to be most likely. The biotite crystals in the Carn Galvar and Rosewall Hill granites range from 3-5 mm in size.



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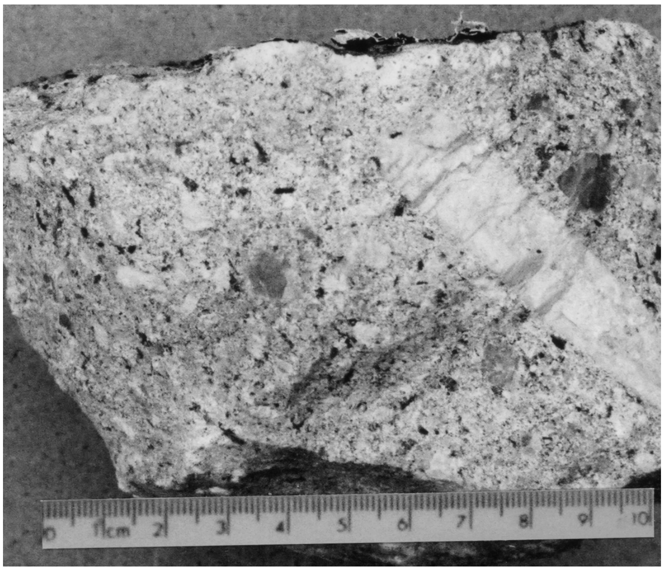


B

Figure 7A. *Rosewall Hill. Very coarse grained primary texture granite with pink K-feldspar megacrysts in a fine grained matrix. (L15).* ***B.*** *Rosewall Hill. Fine grained granite with megacrysts of K-feldspar, quartz and biotite set in a fine grained matrix. Ruler 10 cm. (L16)*

Two-phase texture granites. In the northern part of the pluton at Porpheras Cove (L12), outcrops of rather variable two-phase texture granites and microgranites are present. Most of these did not show any apparent affinity with any of the primary texture granites, but at the northernmost end of the cove (L11) an outcrop of very coarse grained (two-phase) texture granite with large biotite crystals was seen, which subsequently proved to have close textural affinities with the Carn Galvar primary texture granite. Accordingly the outcrop of that granite is considered to begin from that point and to extend northwards towards Rosewall Hill. Several areas of well developed two-phase texture granites were seen within the outcrop of the Carn Galvar Granite e.g. (L13) (Figure 6b). Examples of both primary and two-phase textural variants are well exemplified in the rock pile at the Rosewall Hill shaft site (L16).

Bodmin (Table 4 and Figure 1a)

Most of the outcrop seen on our traverse from the Hantergantick Quarry (B1) to the Cheesewring Quarry (B6) comprised primary texture granites with abundant K-feldspar megacrysts with high aspect ratios of 1:4 to 1:6 and with discontinuous quartz ribbons. Although there was some variation in the size and abundance of the feldspar megacrysts, there was no reason to suppose that more than one granite unit was represented. Granites within the outcrop of the Godaver Granite (Ghosh, 1929) were found to be of primary texture, and there was no indication of the fine-grained textural features recorded by Ghosh (1929). The only variation seen was a diminution in the abundance of the K-feldspar megacrysts at Hill Tor (B5) and to the north of Jamaica Inn (B4) (Exley, 1996), where the granites are of smaller grain size, and only carry occasional small feldspar megacrysts.

The only certain occurrence of two-phase texture granite seen by us was in the clay pit at the Stanion China Clay Works (B2). It is possible that the outcrops identified by Exley (1996) to the North West of the Jamaica Inn may be of two-phase nature, but all the outcrops in that area seen by us were of primary texture granite.

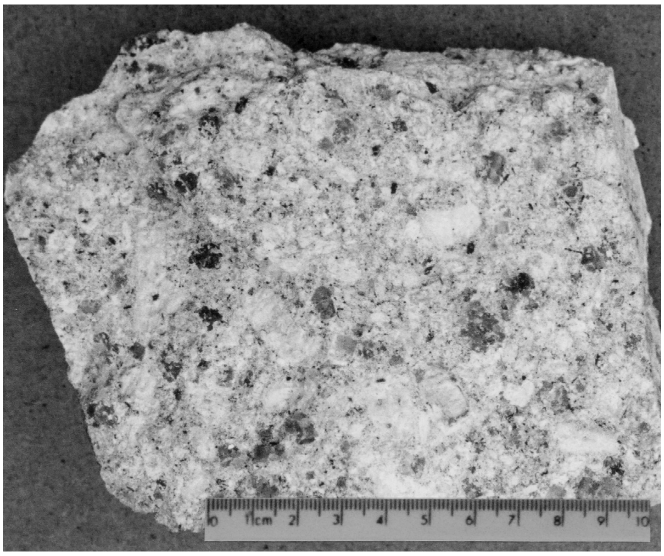
Carnmenellis (Table 3 and Figure 1b)

The main features of the Carnmenellis Pluton as established by Ghosh (1934) and subsequent workers were confirmed. The outer coarse primary texture granite has abundant feldspar megacrysts forming a felted fabric of tabular feldspars, with discontinuous lenticles of grey to darker grey quartz located within the feldspar fabric and with biotite up to 3 mm. Granites with these textural characteristics provided most of the main outer granite and were sampled from the quarry at locality (C1).

The well defined central inner granite, which forms the Carnmenellis Beacon (C2), is a two-phase texture granite with megacrysts of feldspar, quartz and with biotite up to 3 mm as well as groundmass crystals of these species. An attempt was made to address the problem of the Type 2 granite, distinguished by Ghosh (1934) as forming a N-S trending belt towards the eastern margin of the pluton, and which later workers have questioned. Many of the quarries in the region of the Type 2 granite are large working quarries for which we were unable to gain access. However, there are a number of abandoned quarries, as well as small natural outcrops, which provide enough information to provide a basis for comment (C3,4,5,6,7,8 and 9).

All the outcrops seen in that sector and typically at the Chywoon Quarry (C4) were of texturally variable, coarse grained primary texture granites ranging from non megacrystic to moderately megacrystic, with up to 10% of small, tabular K-feldspar megacrysts. All the granites in this sector have notably fewer feldspar megacrysts than the main body of the outer granite It may be these textural characteristic which determines the high concentration of working and abandoned quarries in the area, with those in production currently producing road metal. However, we were unable to identify textures similar to those described by Ghosh (1934), which suggested the presence of a secondary component to this facies. Our observations provisionally suggest that the Type 2 Granite may be a textural variant of Type 1 with fewer feldspar megacrysts.

The two outlying bodies of Carn Brea and Carn Marth to the North of the pluton, were not visited. However, the Carn Marth body was seen by one of us (J.C.) on a former occasion. It was described as primary texture granite, with sub-horizontally aligned K-feldspar megacrysts and having a slight secondary overprint at the entrance to the quarry. Microgranite xenoliths up to tens of metres in size were veined by coarse granite. The primary texture granite was considered to have textural affinities with the main granite.



A

B

Figure 8A. *Sample from the clay pits. Kaolinised two-phase texture granite with megacrysts of K-feldspar, quartz and biotite set in a heterogeneous fine grained quartzo-feldspathic matrix (A1).* ***B.*** *Luxullyan Quarry. Coarse grained primary texture granite with K-feldspar megacrysts of variable size, set in a coarse matrix formed by crystals of quartz, feldspars and biotite, with interlocking grain boundaries (A4).*

St Austell (Table 4 and Figure 1b)

The granites of this pluton are unique in the South-West England batholith for the extensive kaolinisation in the western part of the body. The limited duration of our observations did not allow for a complete assesment of the textural features of the pluton. However, it was established that the outcrops seen were of granites which were texturally distinctive and which differed from all other granites seen in the batholith.

Granites with both primary and secondary textures were observed in the clay pits at (A1) (Figure 8a) confirming the observations of Hill and Manning (1987) that although these rocks are heavily kaolinised, their original textural features are well preserved. The textural characteristics of both primary and two-phase texture granites can be readily distinguished. A distinctive primary texture granite with *c.* 20% K-feldspar megacrysts and with no hint of kaolinisation, forms a large outcrop in the eastern part of the pluton. It has no apparent textural affinity with the granites seen in the clay pits and was sampled at the Luxulyan Quarry (A4) (Figure 8b) and at Helman Tor (A5). This granite may form the principal rock unit of the pluton.

The granites seen in the clay pits, did not appear to have any textural affinity with the unaltered granites in the eastern part of the granite outcrop, which may suggest that the granites of the clay pits form a separate component of the pluton.

No.	G.R.	Locality	Type	Notes
C1	SW 658 367	Near test mine adit	PTG	Very coarse grained with linking quartz clusters. Very abundant aligned K feldspar megacrysts
C2	SW 695 364	Carnmenellis Beacon	STG	Small megacrysts of feldspar, quartz and biotite in a fine grained aplitic matrix
C3	SW 743 344	Rogers and Sons quarry	PTG	Tabular 1-2 cm K feldspar megacrysts, incipient quartz ribbons
C4	SW 747 346	Chywoon Quarry	PTG	Similar to De Lank type but less well aligned megacrysts
C5	SW 739 302	Constantine Farm	PTG	Coarse equigranular PTG. Rare megacrysts are small. Small (<5 cm wide) quartz/feldspar/muscovite pegmatites
C6	SW 735 309	Near Maen Pern	PTG + STG	Inclusions of rounded decimeter sized masses of fine grain (secondary?) granite in coarse grain megacrystic granite
C7	SW 733 313	Maen Pern quarries	PTG	Small megacryst type. Outer granite of Ghosh (1934)
C8	SW 727 298	Bosahan Quarry	PTG	Normal Carnmenellis type PTG. Unfoliated to weakly foliated
C9	SW 736 294	Stream N of Constantine	PTG	Near contact of the type 2 granite of Ghosh (1934). Boulder of PTG with small aligned K feldspar megacrysts
C10	SW 738 290	Roadside E of Constantine	PTG + sheets	Deeply weathered outcrop of PTG cut by <12 cm sheets of aphyric granite.
T1	SW 606 294	Tregonning Hill	Mesogranite	Medium grained aphyric granite
G1	SW 593 313	Godolphin Hill	PTG + STG	K feldspar megacrysts 1-2 cm. Aspect ration 1:5-6. Both PTG and STG textures are present

Table 3. *Carnmenellis and Tregonning-Godolphin. Locality and sample listings. PTG - primary texture granites, STG - secondary texture (two-phase) granites.*

No.	G.R.	Locality	Type	Notes
A1a, b	SW 993 565	Central china clay pit	PTG + STG	Both heavily kaolinised but show clear textural characters. sample A1a is a coarse grained PTG. Sample A1b has secondary texture with quartz and K feldspar megacrysts (Figure 8a)
A2a, b	SW 992 575	Hensbarrow Beacon entrance	Li mica granite + microgranite	Sample A2a is a Li mica granite. A2b is a fine microgranite. Both kaolinised but show good texture
A3	SW 991 596	Roche Rock	Quartz tourmaline	Hard quartz tourmaline rock - unsampled
A4	SX 053 593	Luxulyan Quarry	PTG	Very coarse grained PTG. K feldspar megacryst <9 cm, average 5 cm. Matrix of coarse interlocking grains (Figure 8b)
A5	SX 063 616	Helman Tor	PTG	PTG very similar to A4
B1	SX 103 757	Huntergantick Quarry	PTG + fine grained granite	PTG has small aligned K feldspar megacrysts. Also seen blocks of fine grained granite, equivalent to Exley (1996) FGG
B2	SX 124 804	Stannion china clay works	STG	Kaolinised and heavily altered STG.
B3	SX 189 825	Bray Down	PTG	No sample taken
B4	SX 177 765	N of Jamaica Inn	PTG	Fine grained granite with occasional K feldspar megacrysts <15 mm. Groundmass K feldspar <5 mm
B5	SX 225 739	Hill Tor	PTG	Continuous outcrop of PTG from the farm to the Tor. Megacrysts generally small (K feldspar megacrysts <4 cm) and increasing in abundance to the top.
B6	SX 258 724	Cheesewring Quarry	PTG	Coarse grained muscovite bearing PTG. The granite is little altered despite the proximity of some Cu/Fe mineralisation
K1	SX 375 713	Kit Hill top	PTG	Coarse grained K feldspar megacrystic PTG. Biotite rich
HD	SX 410 720	Hingston Down	Microgranite	Fine grained microgranite with very small megacrysts of K feldspar and quartz

Table 4. *St Austell and Bodmin. Locality and sample listings. PTG - primary texture granites, STG - secondary texture (two-phase) granites.*

Discussion

In the case of the granites of South-West England there are two levels of textural diversity in the primary texture granites, a major level which distinguishes two groups, the large and small megacryst granites, and a lesser level in which each granite is individually distinctive, but yet has a degree of textural affinity with other plutons within the group.

The primary textures

Darbyshire and Shepherd (1985) found that the small megacryst granites of Carnmenellis and Bodmin differed from Dartmoor, St Austell and Lands End in having steeper rare earth profiles and weak europium anomalies. They attributed this difference in the rare earth patterns either to different degrees of partial melting or to compositional differences in the source regions. In accordance with this evidence, it would seem that the source regions for the granites may be compositionally diverse, with slight local compositional differences accounting for differences in the primary textures of each granite, and with major differences in the rare earth patterns being associated with the small and large megacryst variants. Stone (2000) in his regional geochemical study of the plutons of Carnmenellis, Bodmin and Scilly, confirmed the findings of Darbyshire and Shepherd (1985) and suggested that the zoned, concentric structure of both the Carnmenellis and Bodmin Moor plutons, in contrast to the unzoned nature all the other plutons, was related to the compositional differences between them.

In general these findings are similar to those found in South-East Asia where the primary textures in all of the plutons are individually distinctive and which, in the case of the granites of the Main Range Batholith, mostly resembled the large megacryst type of South-West England. It seems to be most likely that the individual diversity in the primary textures of all the granites reflects the heterogeneity of the source region, perhaps in combination with local variations in PT conditions at the time of their formation.

The two-phase textures

These textures are well developed in all the South-West England granite plutons. In the Carnmenellis pluton they are well defined and form the central inner granite. At present the status of the Type 2 granite of the Carnmenellis pluton is uncertain, though all our observations from the relevant area were of primary texture granites, albeit with fewer K-feldspar megacrysts than was typical for the outer granite.

In all of the large K-feldspar megacryst granites, two-phase textured granite form a considerable proportion of the outcrop and their textural features can be matched with those of their primary texture precursors. The Giant Granite on Dartmoor, the primary texture granite of the clay pits of St Austell and the Carn Brea and Carn Galvar granites on Lands End. The field relationships of these variants to the primary texture precursor granites are generally not well defined. However, they are demonstrably younger, since they contain lithic fragments and megacrysts of feldspars, quartz and biotite, derived from the primary texture parent. The textures of these variants are identical in their essential characteristics to those formerly identified in South-East Asia. There is great local diversity, both within and between plutons, depending upon the proportion of megacrysts to groundmass, and on the textures and grain size of the crystals in the primary texture precursor granite.

At the present time the occurrence of these two-phase variants, does not seem to have been generally reported. In addition to their occurrence in South-West England and South-East Asia, they have been observed by the writers in South-East China and the Fanos Granite in Northern Greece. They have also been reported from the Campanaria La Haba Pluton in Spain (Alonso Olazabal, 2001) and from several locations along the Eastern flank of the Peruvian Coastal Batholith (Sanchez *et al.*, 1995; Cobbing, 2000). Consequently, granites with these textures are now known to be of widespread occurrence in Asia and Europe and more rarely in the Andes, yet they are only rarely distinguished.

The reasons for this are not far to seek. The crystal and lithic aggregates they contain are derived from the primary texture granite and are consequently identical to the same minerals in the parent granite. Moreover, the groundmass, though finer, is of 'granitic' character. As a result these rocks have not been perceived as magmatic breccias, but as ordinary, locally developed, finer grained variants of no particular significance. However, once recognised, their status and importance is clear enough, since they provide the first stage of textural and chemical evolution leading towards mineralization (Cobbing *et al.*, 1986; Pitfield *et al.*, 1990; Cobbing *et al.*, 1992).

The patterns of their occurrence may be as distinct central cores as in Bodmin and Carnmenellis, or as sub horizontal sheets as is apparently the case in Dartmoor. In South-East Asia mapping difficulties impeded the identification of their shape and geological relationships, but they are known to form a significant proportion of the total outcrop, where they have been distinguished principally in granites of S-type affinity and to a lesser extent in those of I, and A-type affinity (Cobbing *et al.*, 1992). In the Campanaria La Haba Granite of central Spain they form the G2 and G3 granites of that body (Alonzo Alazabal, 2001). They have been identified at several localities in the Andes (Sanchez *et al.*, 1995, Cobbing, 2000) but are relatively rare in that tectonic setting. Decompression events in Andinotype granites are more commonly represented by pebble dykes and tuffisites (Cobbing, 2000).

These variants are later than the primary texture granites with which they are associated, since they contain composite granite fragments and crystals with clear textural evidence of having been derived from a holocrystalline granite, with which they can be matched. The later groundmass is more leucocratic and is probably more highly evolved. The great degree of variation in the proportion of clasts and megacryst to groundmass and the increasing proportion of the groundmass in the later components, suggests the episodic derivation from a reservoir of progressively more highly evolved magma, which intruded, brecciated and entrained earlier components of the pluton. These factors suggest a process of rapid changes in the physico-chemical condition of the residual magma at an advanced stage of crystallisation. These may have been caused by sudden reductions in pressure as the granites were intruded towards higher levels. The sudden loss of pressure could have resulted in the partial fluidisation of the magma and its violent, disruptive emplacement into the primary texture granite (Swanson, 1977; Swanson *et al.*, 1988).

Conclusion

It has been confirmed that all the granite plutons of Southwest England are characterised by distinctive granite units, each of which provides a textural fingerprint enabling their distinction from each other and from all other granites by field mapping. These units have textures in which the component crystals are in continous contact with complex grain boundary relationships. It is these textural features which have enabled the identification of distinctive granite units for each pluton and, in the case of Dartmoor and Lands End, two or three units. Pervasive magmatic brecciation of these units has resulted in the regional development of breccias, in which lithic clasts, crystal aggregates and single crystals of all mineral species, are included in a fine grained quartzo-feldspathic groundmass. Granites with these characteristics have been distinguished as two-phase variants. These variants are highly variable in appearance depending on the proportion of clasts and crystals to the groundmass.

Granites with these textural features were formerly reported from South-East Asia (Cobbing *et al.*, 1986, 1992) and it is considered that these textures are likely to be widespread globally in granites of appropriate composition.

It has been established that both primary and two-phase textures are present in all the plutons and granite units except for the Blue Granite and the Foggintor-Merivale Granite of Dartmoor which are both of primary texture only. In the Carnmenellis Granite the two-phase variants are confined to the well-defined inner core and the outer granite is a primary texture granite with abundant feldspar laths. Only one primary texture granite was seen on our traverse of the Bodmin Moor Granite, which was very homogeneous in character. Some slight variation was seen in the region of Hill Tor where the megacrysts were smaller than average for this pluton and were more sparsely developed.

The primary textural features of each pluton are specific to the pluton. The Carnmenellis and Bodmin plutons have only one primary texture granite but Lands End has two and Dartmoor three. It is probable that the St Austell Granite may have more than one primary texture unit but the extreme kaolinisation in the clay pits renders investigation of that problem more difficult.

Whereas granites with both primary and two-phase textures have been identified in tin bearing granites (Hall 1974, Cobbing 1986, Cobbing *et al*., 1992) they do not seem to have been distinguished on a regional scale in other granite belts e.g. the batholiths of North and South America. They have however, been identified on a small scale in the Coastal Batholith of Peru (Cobbing 2000, Sanchez *et al*., 1995). They have also been seen by one of us (J.C.) in a number of plutons of the British Caledonides, but the scale of their development in the granites of that region is much smaller than that for the stanniferrous granites of South-West England.

The general failure to distinguish two-phase textures in granites suggests that they are probably more abundant than at present seems to be the case. It may be reasonably predicted that they would be a component of any tin granite, whether of S, I, or A-type affinity. It may also be expected that they might be a component of the ring dykes of ring complexes with these affinities. They are less likely to be a significant component of Andinotype granites, but it is possible that they might form a component of porphyry copper systems within such batholiths. Granites from these systems reported to be of seriate texture may perhaps be of this nature, however, the published information on the textures of these complexes is not good enough to form an opinion. Finally it is, fitting to draw attention to the work of Hall (1974) for his early recognition of two-phase textures in southwest England.

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