The significance of almandine garnets in the Lundy and Dartmoor granites

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Abstract

Almandine garnets in the cordierite-bearing granite of Sweltor Quarry, Dartmoor, contain < 10 mol. % of the spessartine end-member, whilst those in the Lundy granite have *c.* 10 mol. % spessartine. Experimental work indicates that such compositions can grow in equilibrium with siliceous melts at depths of 18–25 km. This evidence, reaction rims, lack of marked zoning and comparison with garnets in other siliceous calc-alkaline siliceous rocks point to a genesis involving partial melting of the 'local' lower crust. A restite origin rather than direct crystallization from magma is favoured but the evidence is equivocal. The Dartmoor granite (Hercynian) is a typical peraluminous late- to post-tectonic S-type granite. The S-type character of the Lundy (Tertiary) granite is revealed by the occurrence of garnet and topaz together with biotite enriched in Rb, Cs and F, despite its close association with Tertiary basic magmatism in an anorogenic setting.

KEYWORDS: almandine, garnet, granite, Dartmoor, Lundy.

Introduction

THIS paper contains the results of microprobe analyses of garnet, biotite and cordierite from the granite at Sweltor Quarry, Dartmoor (GR SX559733), and garnet and biotite from granite on the small island of Lundy, situated off the north coast of Devon *c.* 18 km NNW of Hartland Point. It also discusses the significance of these garnets in the light of experimental work and its uncommon but widespread occurrence in silicic calc-alkaline igneous rocks ranging from diorite to granite and aplite/pegmatite. For the rocks considered here the significance is heightened by the widely different ages and tectonic settings of the Dartmoor (Hercynian) and Lundy (Tertiary) granites. The most recent age determination for Dartmoor is 285 Ma (Darbyshire and Shepherd, 1985) whilst that for Lundy is 52 Ma (Hampton and Taylor, 1983). The Dartmoor granite is one of several plutons that make up the mainly post-orogenic Cornubian batholith, whilst the Lundy granite is an isolated body in a region of mainly positive gravity anomalies in a marked anorogenic setting associated with Tertiary volcanism and plutonism of western Scotland and north-eastern Ireland.

Garnet is uncommon in the exposed plutons of the Cornubian batholith (Chatterjee, 1929). However, its occurrence in the Dartmoor granite was described by Brammall and Harwood (1923, 1932) who drew attention to minute garnets in the Princetown Quarry, large garnets in the Sweltor Quarry as well as garnets in aplites, aplogranites and felsites. They suggested a magmatic origin on account of graphic intergrowth between garnet and porphyritic feldspar and a chemistry different from that of garnets typical of metamorphosed pelitic rocks. Brammall and Bracewell (1936) provided analyses of garnets from Chinkwell Tor (GR SX728781) and the Sweltor Quarry (GR SX559733) together with several partial analyses (FeO and MgO) from different parts of Dartmoor that show marked variability in composition. Garnet in the biotite granites of Lundy was referred to by Dollar (1941) and briefly in the Bideford Memoir (Edmonds *et al.*, 1979).

Petrography

The garnet-bearing granite at Sweltor Quarry appears to be part of a raft-like mass of dark grey, poorly megacrystic, medium-grained (mm-grained), largely xenomorphic biotite granite within the normal poorly megacrystic granite (Edmonds *et al.*, 1968, p. 114). Cm-grained megacrysts

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of rounded quartz, anhedral perthitic K-feldspar and well-zoned, often subhedral plagioclase occur in a grey mm-grained matrix composed of these minerals together with biotite and sporadic garnet (0–2 vol. %, but typically < 1%) and cordierite. The garnet is anhedral, 2–4 mm in diameter and altered to green biotite along cracks and grain boundaries. Brammall and Harwood (1923) also described '. . . garnet-feldspar areas (that) display . . . the features . . . of micrographic intergrowth'. Garnet also includes red-brown biotite which differs chemically from that found in the matrix (Table 3). Cordierite, about 0.5 mm in diameter, shows excellent sector twinning and is commonly rimmed or almost completely replaced by pinite.

Red garnet, similar in appearance to that in the Dartmoor granite, occurs in both the Lundy granite types referred to by Dollar (1941) as G1 and G2. The grey, medium-grained (1.0 mm-grained matrix) rock (G2) from North West Point (GR SS13014818) has abundant megacrysts (0.5–2 cm) of zoned plagioclase together with perthitic K-feldspar and large quartz grains that provide evidence of late-stage growth by replacement of feldspars. Red–brown biotite and topaz are also prominent. Anhedral garnet (< 1–4 vol. %, including altered rims), up to 2 mm in size, has no marginal intergrowths, but is traversed by cracks filled with green mica. The coarse-grained granite (G1) from the V.C. quarry on the eastern side of the island (GR SS13904537) is composed of white K-feldspars (1–2 cm) containing numerous inclusions of plagioclase (up to 2 mm) together with biotite, quartz, muscovite, topaz and some plagioclase in the matrix. Garnet, up to 6 mm in diameter, is rimmed and veined by green biotite like that in the Sweltor garnet. A 'reaction rim' of quartz and mica separates garnet from adjacent feldspar grains.

Chemistry

New analyses of Dartmoor and Lundy garnets are given in Table 1, where they are compared with earlier garnet analyses from Chinkwell Tor and Sweltor Quarry, Dartmoor (Brammall and Bracewell, 1936). Each new analysis is the mean of several points counted on one or more grains. End-member compositions calculated directly from formulae differ insignificantly from those obtained according to the method outlined by Rickwood (1968). All iron is recorded as FeO so that the andradite end-member does not appear, but excess Al in the octahedral site suggests that the andradite component is small or absent.

Table 1. Dartmoor and Lundy Garnets

	1	2	3	4	5	6
Weight %						
SiO_2	37.34	37.28	35.85	36.26	37.23	36.45
Al_2O_3	21.27	21.29	21.05	21.41	20.66	21.01
tFeO	34.85	35.30	35.82	36.59	30.88	34.80
MnO	3.33	3.61	4.23	4.51	7.30	3.45
MgO	2.52	2.54	0.83	1.10	2.00	0.95
CaO	1.46	1.43	2.33	1.28	1.31	2.43
Total	100.77	101.45	100.11	101.15	99.38	99.78*
Formulae based on 12 oxygen atoms						
Si	3.000	2.980	2.941	2.944	3.031	2.994
Al	2.011	2.007	2.035	2.049	1.983	2.034
tFe^{2+}	2.338	2.361	2.458	2.485	2.103	2.390
Mn	0.226	0.244	0.294	0.310	0.503	0.240
Mg	0.301	0.303	0.101	0.133	0.243	0.117
Ca	0.126	0.123	0.205	0.112	0.114	0.214
End members (%)						
Alm	78.2	77.9	80.4	81.7	71.0	80.7
Sp	7.6	8.1	9.6	10.2	17.0	8.1
Pyr	10.1	10.0	3.3	4.4	8.2	4.0
Gro	4.2	4.1	6.7	3.7	3.8	7.2

1. Specimen 0574GT, Sweltor Quarry, Dartmoor.
2. Specimen 0575GT, Sweltor Quarry, Dartmoor.
3. Specimen 0770GT, North West Point, Lundy.
4. Specimen 0761GT, VC Quarry, Lundy.
5 & 6. Garnets from Chinkwell Tor and Sweltor Quarry (Brammall and Bracewell, 1936).
tFeO and tFe^{2+} refer to total iron as FeO and Fe^{2+} respectively.
* Includes 0.69 wt.% TiO_2.

The new Dartmoor garnet analyses (Table 1, cols 1 and 2) are similar to one another, compare closely with the earlier analysis from the Sweltor Quarry (col. 6) but differ from the earlier analysis of garnet from Chinkwell Tor (col. 5) in containing markedly less MnO. This may reflect the variability in garnet compositions referred to by Brammall and Bracewell (1936), be a real 'regional' difference or the result of different analytical techniques. Indeed, an earlier analysis of the Chinkwell Tor garnet (Brammall and Harwood, 1923) contains considerably more (9%) MnO and suggests serious uncertainty in its determination. Green (1977) also refers to rare garnets in cordierite-bearing granite from Dartmoor having spessartine contents (in mol. %) of 11.2 (core) to 14.6 (rim), somewhat higher than the values recorded in this paper. No clear zoning of this type was observed in the specimens examined here, although the anhedral shape and evidence for reaction indicate removal of the original crystal margins.

The Lundy garnets (Table 1, cols 3 and 4) contain significantly higher MnO and lower MgO than the Dartmoor garnets (revealed statistically using *t*-tests and analysis of variance on all the points analysed). Consequently, the Lundy garnets are richer in spessartine and much poorer in pyrope than the Dartmoor garnets. There is a

Table 2. Sweltor Cordierite

	A	B	Av	CV	Formula	
SiO_2	47.32	47.35	47.33	1.0	Si	4.977
Al_2O_3	32.70	32.65	32.68	0.8	Al(4)	1.023
tFeO	12.64	12.76	12.70	3.2	Z	6.000
MnO	0.63	0.67	0.65	20.0	Al(6)	3.028
MgO	4.42	4.53	4.48	7.8	tFe^{2+}	1.117
Na_2O	0.85	1.00	0.93	17.2	Mn	0.058
Cs_2O	0.05	0.03	0.04	57.0	Mg	0.702
F	0.02	0.02	0.02	--	Na	0.189
					Cs	0.002
					Y	2.096

A and B are mean analyses of 3 points on each of two euhedral cyclic twins in specimen MS0575. Av is average of all 6 points and CV is the coefficient of variation. The formula is based upon 18 oxygen atoms. Al(4) and Al(6) are tetrahedral and octahedral Al respectively. tFeO and tFe as Table 1.

significant difference between the calcium contents of the two Lundy samples. Zoning from core to margin is not marked, although a small increase in almandine and decrease in spessartine and grossular are apparent in some microprobe traverses.

Data for cordierite (Table 2) also show high octahedral Al, i.e. Al(6), and a high sum of divalent and univalent cations, although some of the latter are likely to be occluded ions. Zoning is slight and inconsistent in the two grains analysed. The analysis given by Brammall and Harwood (1932) differs in having higher total iron, higher MgO, lower Al_2O_3 and a small amount of TiO_2. Analyses of adjacent sector twins reveal no differences in composition between sectors, such as that found by Brammall and Rama Rao (1936) on the basis of differences in 2V between (but not within) sectors.

Analyses of biotite coexisting with the garnets (Table 3, cols 1–7) show several significant features. First, all (including a Lundy biotite from a sample without garnet, col. 8) show generally high F, Rb and Cs, suggesting perhaps some common link between the trioctahedral micas of the Cornubian batholith (Stone *et al.*, 1988) and those in the Lundy granite. The principal differences between Lundy and Dartmoor biotites lie in the lower Ti, Mg and Cl, higher Mn, F and marginally higher Rb, Cs and Fe of the former compared with the latter: the (Fe + Mn)/(Fe + Mn + Mg) ratio is much higher in the Lundy biotites. Second, despite marked chemical differences, biotite inclusions in both Dartmoor and Lundy garnets are richer in Mg and poorer in Ti than biotite in the matrix. Third, green biotite (col. 5) occurs in cracks in the garnet and must have replaced it. The absence of Ti reflects its absence in the host garnet.

Garnets in silicic igneous rocks

The following brief review of garnets in silicic magmatic rocks and relevant experimental work provides a petrogenetic framework to the study of Dartmoor and Lundy garnets. Garnets in silicic calc–alkaline volcanic and plutonic rocks are typically almandine- and/or spessartine-rich, although the pyrope end-member is sometimes significant and may reach *c.* 30 mol. %.

Experimental work by Green and Ringwood (1968*a*, *b*) showed that almandine garnets occur as a liquidus or near-liquidus phase in dacite and andesite compositions at pressures above 9 kbar (with $P(H_2O) < P(\text{load})$). They considered that such melts could have been derived by partial melting of deep crust and/or upper mantle at depths greater than 25 km and also pointed out that resorbed garnet phenocrysts in some calc–alkaline rocks may provide evidence for a deep origin of their magmas. Liquids produced experimentally by the partial melting of glass of pelitic composition have compositions close to those of S-type granites (Green, 1976) with residual phases that include cordierite (unstable above 10 kbar) and garnet (unstable below 4 kbar) in the temperature range 780–1150 °C. Green (op. cit.) suggested that the presence of cordierite indicates generation at depths less than *c.* 25 km, and that higher MnO in the parental pelite may allow garnet formation at lower pressures. Using both glass of pelitic composition and natural cordierite- and garnet-bearing granites, Green (1977) showed that Mn will stabilize garnet to shallower depths. It was estimated, for example, that 20–25 mol. % spessartine will stabilize almandine-rich garnets at pressures corresponding with depths of 12 km or less, but that almandines with < 10 mol. % spessartine, like those in the silicic volcanic and plutonic rocks of Eastern Australia, crystallized at depths of 18 km or more (Green, 1977).

Many volcanic garnets are believed to have crystallized from partial melts generated close to the crust–mantle boundary. The subsequent rapid ascent of such melts to the surface is considered to have prevented reaction and preserved euhedral shape. Such garnets contain few or no inclusions and have low spessartine contents (< 10 mol. %) compatible with a deep-seated crustal origin (Fitton, 1972; Wood, 1974). Spessartine-poor almandines in granites from New South Wales are also considered to be the products of deep-seated crystallization from dry magmas (Green and Ringwood, 1968*a*). Other granites with presumed primary cordierite (euhedral and inclusion-free), like the Sweltor (Dartmoor) granite, are believed to have crystallized from relatively hydrous magmas at shallower depths (Flood and Shaw, 1975).

Some garnets occur in xenolithic facies of the granite host and/or have compositions close to those of adjacent pelitic hornfelses. These have clearly resulted from *in situ* contamination (Vennum and Meyer, 1979; Allan and Clarke, 1981). 'Contamination' at source in the form of restite garnet is found in cordierite-bearing dacites (Zeck, 1970) that contain abundant gneiss enclaves, many with almandine and also 'monocrystal' inclusions of euhedral almandine like that in the gneiss inclusions. 'Restite' garnets having abundant inclusions and Fe+Mn enriched rims suggesting final growth with falling temperature were described by Birch and Gleadow (1974).

Mn-rich almandine (> 10 mol. % spessartine) in leucogranite and aplite from the more differentiated parts of granitoid sequences are commonly euhedral and lack reaction rims, features suggesting they are neither xenocrysts nor high-pressure phenocrysts, but the products of magmatic crystallization more or less *in situ* after emplacement at moderate to high crustal levels. Some of these garnets are almandine-rich spessartines with up to 70% or more of the spessartine end-member (Hall, 1965; Leake, 1968; Manning, 1983). An antipathetic relation between Mn-rich magmatic garnet and biotite (Allan and Clarke, 1981; Hall, 1965; Kistler *et al.*, 1981; Leake, 1968; Miller and Stoddard, 1981) is explained by the inability of micas to accommodate much Mn, with a consequent marked increase in the Mn/(Mg+Fe) ratio with differentiation and the stabilization of Mn-rich almandines at high to intermediate crustal levels.

Origin of garnet in the granites of Dartmoor and Lundy

From the foregoing account, it is apparent that almandine-rich garnets occur in several well-defined groups of peraluminous rocks, namely, siliceous volcanic rocks, highly differentiated leucocratic granites and aplites and some more typical S-type biotite granites and granodiorites. Textural relations and geochemistry support experimental work in distinguishing magmatic 'high-level' almandine garnets rich in spessartine from relatively spessartine-poor (< 10 mol. %) garnets from deeper sources, a distinction made earlier by Miyashiro (1955).

Both the Dartmoor and Lundy granites are quite highly evolved biotite granites (Exley *et al.*, 1983, and unpublished data) whose garnets more closely resemble those from the deeper-seated granites than the Mn-rich almandines from higher-level differentiates. Garnets from both plutons contain some spessartine (< 10% spessartine end-member) but they are not spessartine-rich almandines. This characteristic, together with their anhedral shape and the presence of reaction rims, suggest a deep-seated crustal origin. Evidence for contamination from adjacent source rocks at the present level of exposure is lacking.

Data for garnets from siliceous calc-alkaline rocks taken from the literature together with those from Dartmoor and Lundy are plotted on an Almandine-Pyrope-Spessartine diagram (Fig. 1). Despite the paucity of data, the diagram broadly separates the Mn-richer garnets of the granites from the Mn-poorer garnets of the siliceous volcanic rocks, although some granitic garnets plot amongst the volcanics in the 3-8% spessartine region. The similarity in composition between garnets from rhyodacites and granites in S.E. Australia is striking and suggests a common origin. Dartmoor and Lundy garnets plot between the regions of siliceous volcanic garnets and the more manganiferous garnets of the leucogranite suite. They are slightly more manganiferous than the deep-seated garnets from S.E. Australian rocks (Green and Ringwood, 1968*a*), a characteristic which, together with the occurrence of coexisting cordierite in the Dartmoor granite, indicates growth at lower pressures (< 25 km).

Most of the volcanic garnets shown in Fig. 1 reveal zoning that involves depletion in Mg and enrichment in Fe towards the margins of grains, whilst in granitic rocks enrichment in Mn at the expense of Fe (and Mg) is common. Zoning in garnets showing enrichment of Mn towards the margins is taken by some petrologists to indicate crystal growth with falling temperature and pressure as the magma rose to higher crustal levels. The insignificant zoning observed in the incomplete Dartmoor and Lundy garnets suggests growth at depth with subsequent partial resorption producing anhedral rounded shapes and reaction rims as magma moved to higher levels. It is difficult to determine whether the Dartmoor and Lundy garnets have crystallized directly from a partial melt or represent true 'restite' material, although the latter is favoured here. Even though experimental work indicates that lower crustal silicic calc-alkaline melts can crystallize garnet and cordierite

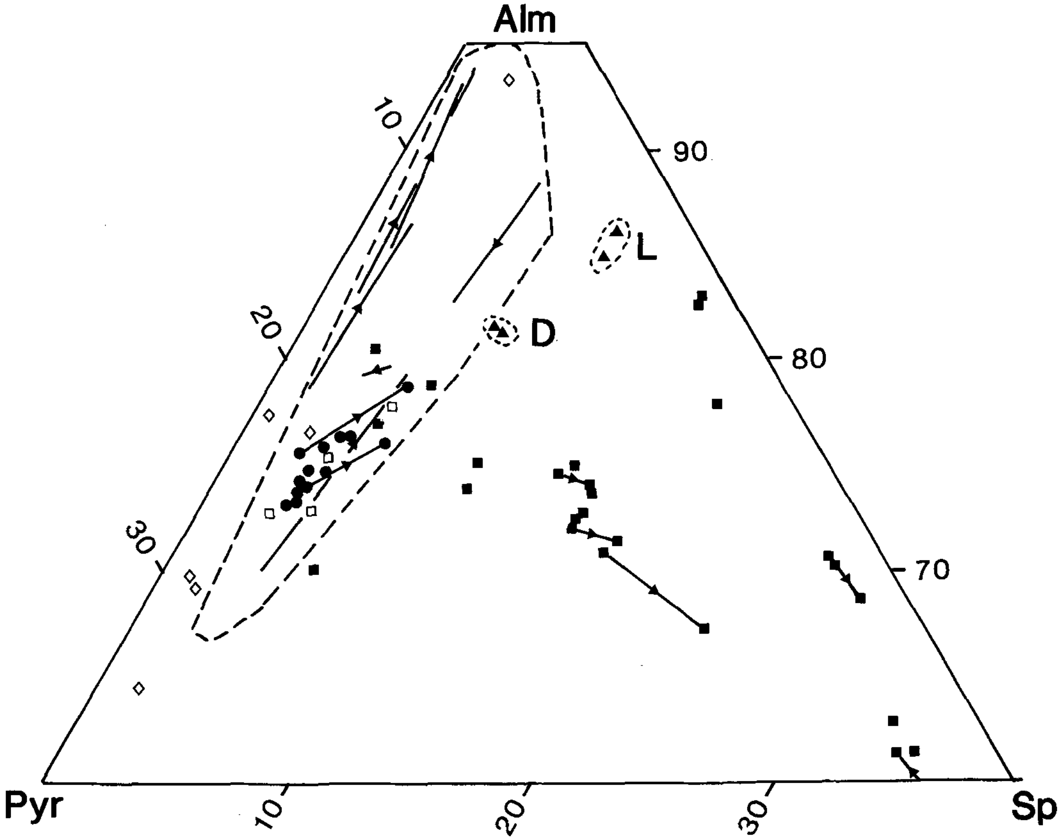

FIG. 1. Almandine (Alm)-Pyrope (Pyr)-Spessartine (Sp) diagram; end-members compositions in mol. %. The composition field of 46 garnets from volcanic rocks is enclosed by the long-dashed line. Symbols: filled circles—composition points of garnets in rhyodacites from S.E. Australia and open squares—granites and granodiorites from S.E. Australia (Green and Ringwood, 1968*a*); filled squares—garnets from other granites (including leucogranites and associated aplites); filled triangles—Dartmoor (D) and Lundy (L) garnets; open diamonds—experimentally produced garnets (Green and Ringwood, 1968*b*). Most garnets from leucogranite, aplite and pegmatite, including those cited by Hall (1965), Leake (1968), Miller and Stoddard (1981), and Manning (1983), plot below the bottom right hand corner of the diagram, i.e. at spessartine-richer compositions. Arrows on solid lines show trend of zoning from core of garnet to rim.

(Green, 1976, 1977), partial melting experiments suggest that small degrees of melting leave much plagioclase, biotite and other mafic minerals as 'restite' (Winkler, 1976; Green, 1976). Some 30% partial melting, as suggested by Charoy (1986) for the genesis of the Carnmenellis granite, is a commonly accepted crude maximum for the extent of melting in the lower crust. Such melting of high-grade lower crust beneath South West England would be expected to leave a plagioclase + biotite + oxide + cordierite + andalusite (or sillimanite) + garnet residuum and incorporate some of this as the solid component of a magma moving upwards from its source. The amount of true restite would be expected to decrease as the magma evolved and rose in the crust.

Biotite inclusions in the garnets are richer in Mg than biotite in the rock matrix. This trend, in both Dartmoor and Lundy examples is illustrated in Fig. 2, in which data points for both garnets and coexisting biotites are plotted. In each case, the trend with time is from more magnesian to more iron-rich micas, a relation indicating that earlier-formed or derived 'restite' biotite, now included in garnet, was more magnesian and hence, perhaps, closer in composition to biotite in the source rocks. The marked differences in position and orientation of the tie lines reflect the very low

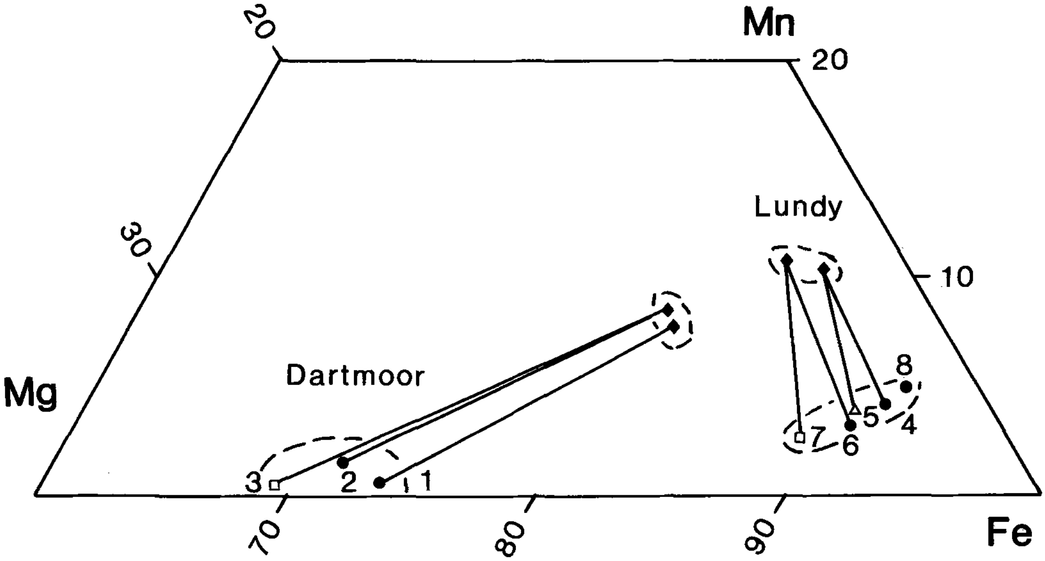

FIG. 2. Mn–Mg–Fe (atom %) diagram showing compositions of coexisting garnets (filled diamonds) and biotites (other symbols) in the Lundy and Dartmoor granites. Composition points for biotites are numbered as in Table 3. Symbols: open squares—biotite inclusions in garnet; filled circles—matrix biotites; open triangle—green biotite lining fractures in garnet.

magnesium content of Lundy biotites (Table 3) and host rocks compared with those of Dartmoor (and the whole Cornubian batholith) and the very different major element chemistry and tectonic setting of these two bodies. As pointed out above, reaction rims round garnets indicate reaction in response to decreasing pressure of earlier-formed garnet as magma rose in the crust and partial re-equilibration with evolving magma. Alteration of garnet to green micas along cracks may also point to similar re-equilibration, but marked differences between the green and matrix biotites suggest that the former were produced by later reaction between garnet and late-magmatic or post-magmatic aqueous fluids as indicated by the high F, Rb and Cs of green biotite (Table 3), an interpretation supported by experimental hydrothermal replacement of garnet by green biotite at high temperatures at or near the beginning of melting (Schneider, 1975).

Evidence for a predominantly lower crustal origin for the mainly post-tectonic granites of the Cornubian batholith is summarized by Exley and Stone (1982), Exley *et al.* (1983), and Stone and Exley (1986). The relative paucity of garnets in the other plutons of the Cornubian batholith (Chatterjee, 1929) may point to different source rocks from Dartmoor, crystallization from more evolved and 'gravity-cleansed' magma or a deeper origin for the Dartmoor magma. Genesis of the Dartmoor magma at depths of 18–25 km is consistent with low-spessartine almandine coexisting with cordierite (see also Birch and Gleadow, 1974). Mg/Fe distribution coefficients between homogeneous garnet core and matrix biotite ($K_D = (\mathrm{Mg/Fe})_{\mathrm{garnet}}/(\mathrm{Mg/Fe})_{\mathrm{biotite}}$) for the Dartmoor samples are 0.363 and 0.340. These values fall within the range of plutonic granitoids and well above the values of high-grade metamorphic rocks compiled by Lyons and Morse (1970). The geothermometric calibration of Thompson (1976) gives temperatures of 790 and 770 °C, respectively, for these K_D values and that of Ferry and Spear (1978), corrected for deviations from ideality by Al(6) and Ti in biotite and Ca and Mn in garnet (Indares and Matignole, 1985), gives temperatures of 796 and 739 °C, respectively. It is likely that at such temperatures these minerals coexisted with a partial melt. On the other hand, the higher temperature of 830 °C given by the garnet-cordierite K_D may indicate melt-crystal equilibrium while the lower temperatures of the garnet-biotite K_Ds may reflect slight late or post-magmatic ion-exchange in biotite.

The higher Mn content of the Lundy garnets compared with those from Dartmoor may be attributable to magma generation at slightly shallower depth, perhaps nearer 18 km, or it may reflect the apparently more highly evolved chemistry of the Lundy biotites (Table 3) and rocks (unpub-

Table 3. Biotites associated with Dartmoor and Lundy Garnets

Weight %	1	2	3	4	5	6	7	8
SiO_2	36.78	35.30	35.55	33.22	35.25	34.81	34.69	35.76
TiO_2	2.87	4.25	3.57	1.83	n.d.	1.88	n.d.	1.24
Al_2O_3	19.54	18.11	17.68	20.82	21.14	21.17	21.84	22.40
tFeO	21.58	23.02	24.51	26.25	25.25	25.21	25.61	22.98
MnO	0.15	0.44	0.08	1.13	1.05	0.89	0.73	1.20
MgO	4.29	4.88	6.03	0.66	0.86	0.89	1.28	0.41
CaO	n.d.	n.d.	n.d.	0.06	n.d.	n.d.	0.07	n.d.
Na_2O	n.d.	n.d.	0.37	0.11	0.14	0.74	n.d.	0.09
K_2O	9.41	9.30	9.24	9.24	9.08	9.33	9.26	9.29
Rb_2O	0.25	0.16	0.04	0.23	0.33	0.19	0.27	0.40
Cs_2O	0.03	0.04	0.03	0.05	0.02	0.07	0.04	0.09
F	1.19	2.12	2.26	2.68	3.38	2.56	2.73	3.14
Cl	0.26	0.42	0.38	n.d.	n.d.	0.10	n.d.	n.d.
Total	96.35	98.04	99.74	96.28	96.50	97.84	96.52	97.00
Formulae based on 22 oxygen atoms								
Si	5.655	5.472	5.448	5.371	5.652	5.506	5.529	5.619
Al(4)	2.345	2.528	2.552	2.629	2.348	2.494	2.471	2.381
Al(6)	1.197	0.783	0.642	1.338	1.647	1.454	1.632	1.768
Ti	0.332	0.495	0.411	0.223	---	0.223	---	0.147
tFe^{2+}	2.775	2.986	3.141	3.552	3.338	3.323	3.415	3.021
Mn	0.019	0.058	0.011	0.154	0.143	0.119	0.099	0.160
Mg	0.983	1.126	1.378	0.161	0.206	0.211	0.305	0.097
Y	5.306	5.448	5.583	5.428	5.348	5.330	5.451	5.193
Na	---	---	0.111	0.034	0.044	0.227	---	---
K	1.847	1.840	1.807	1.907	1.858	1.883	1.883	1.862
Rb	0.025	0.016	0.004	0.025	0.034	0.020	0.028	0.040
Cs	0.002	0.003	0.002	0.003	0.002	0.006	0.003	0.006
X	1.874	1.859	1.924	1.935	1.894	1.909	1.914	1.908
F	0.579	1.041	1.096	1.396	1.715	1.281	1.379	1.561
Cl	0.068	0.110	0.098	---	---	0.027	---	---

1 & 2. Matrix biotites from specimens 0574 and 0575, Dartmoor.
3. Biotite inclusion in garnet from specimen 0575, Dartmoor.
4 & 6. Brown biotites from 0770 and 0761 respectively, Lundy.
5. Green biotite lining cracks in garnet, specimen 0770, Lundy.
7. Biotite inclusion in garnet, specimen 0761, Lundy.
8. Brown biotite in matrix of specimen 0772.
tFeO, tFe^{2+} Al(4) and Al(6) as in Tables 1 and 2. n.d. = not detected.

lished data). The very low Mg content of Lundy biotites (and hence low Mg/Fe) results in extremely high garnet-biotite K_Ds and therefore precludes their use in simple geothermometry. Gravity work by Bott *et al.* (1958) indicates that the Lundy granite may be underlain by basic rock below a depth of about 2 km, perhaps suggesting a mantle source for the granite. However, 'plumbotectonics' and Sr isotope data (Hampton and Taylor, 1983) point to a crustal origin for the Lundy granite, a conclusion consistent with the evidence provided by the garnets and biotites. The occurrences of garnet and topaz and the trace-alkali element and F enrichment of its biotite point to the Lundy granite being an S-type granite (Chappell and White, 1974), like its Hercynian neighbour, the Dartmoor granite. However, it is Tertiary and is cut by Tertiary basic and intermediate dykes. Its close association with these and the adjacent and probably underlying basic rocks imply activation of crustal anatexis by mantle processes which, in turn, were related to tectonism associated with the widening of the Atlantic Ocean. This will be discussed further in a future paper dealing with the general geochemistry and petrology of the Lundy granite.

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