

Magmatic garnets in the Cairngorm granite, Scotland

T. N. HARRISON

Department of Geology and Mineralogy, University of Aberdeen, Aberdeen AB9 1AS, Scotland

Abstract

Small, euhedral Mn-rich garnets (32–52 mol. % spessartine) from the Cairngorm granite, Eastern Grampian Highlands, Scotland, are considered to be of magmatic origin and have not been derived from the assimilation of metasedimentary material, despite their occurrence largely at the margins of the pluton. Similar garnets also occur in a late cross-cutting aplite sheet. The garnets in the granite crystallized early in the sequence and are thought to have formed in response to the ponding of Mn-rich fluids against the wall of the pluton. This Mn enrichment of the fluid phase continued throughout the evolution of the pluton, resulting in Mn-rich biotites and opaque oxides and the localized crystallization of Mn-rich garnets in aplite. Garnet contains up to 1.67 wt. % Y, but has not played a major role in the geochemical evolution of the Cairngorm granite, which has high SiO₂ (72–77%) and is enriched in Y and HREE. Chemical analyses of garnets, biotites and rocks are given.

KEYWORDS: magmatic garnets, spessartine-almandine, Cairngorm granite, Scotland, Mn enrichment, yttrium, biotites, fluid phase.

Introduction

GARNETS have often been recorded as accessory minerals in granites and volcanic rocks of granitic composition, and their origin has been the subject of much debate. There have been three mechanisms proposed for their origin: (1) as a product of the partial assimilation of pelitic material (e.g. Vennum and Meyer, 1979); (2) as low-pressure precipitates from a highly differentiated peraluminous magma (e.g. Miller and Stoddard, 1981); and (3) as xenocrysts or high-pressure phenocrysts transported to higher levels (e.g. Green, 1977). They are also common in granite pegmatites, which may reflect the Fe–Mg–Mn phase relations during the final stages of crystallization of these melts (Abbott, 1981).

Geological setting

The Cairngorm granite is the largest pluton (c. 365 km²) in a series of post-tectonic, broadly calc-alkaline granitoids that were emplaced into the Scottish Caledonian metamorphic belt between 435 and 390 Ma, some 55–25 Ma after the peak of regional metamorphism and deformation. The pluton is a composite body of coarse, pink por-

phyritic and non-porphyritic biotite adamellites (Fig. 1) (corresponding to monzogranite of Streckeis, 1976), which show gradational internal contacts and are cut in the west by a fine-grained porphyritic granite (Harry, 1965; Harrison, 1987*a*). The adamellites also contain numerous small bodies of porphyritic aplite (or microgranite) that appear to have developed *in situ* as residual liquids ponded and quenched in a proto-joint system developing parallel to the flat roof of the pluton (Harrison, 1987*b*). These porphyritic aplites are associated with abundant pegmatites and aplites, and are frequently drusy. Pegmatites and aplites are found throughout the pluton and are extremely abundant in places. Non-porphyritic adamellite from the northern part of the pluton has yielded a Rb–Sr whole-rock age of 408 ± 3 Ma and a Sr initial isotope ratio of 0.7062 ± 7 (Harmon *et al.*, 1984).

The pluton has a monotonous mineralogy with brown quartz, pink plagioclase, and K-feldspar comprising 95–98% of the modal mineralogy. Biotite is the only mafic silicate present, although it has locally altered to secondary muscovite. Accessories include ubiquitous apatite, Fe–Ti oxides, zircon and monazite, with minor andalusite, topaz, beryl, uraniinite, xenotime, and a number

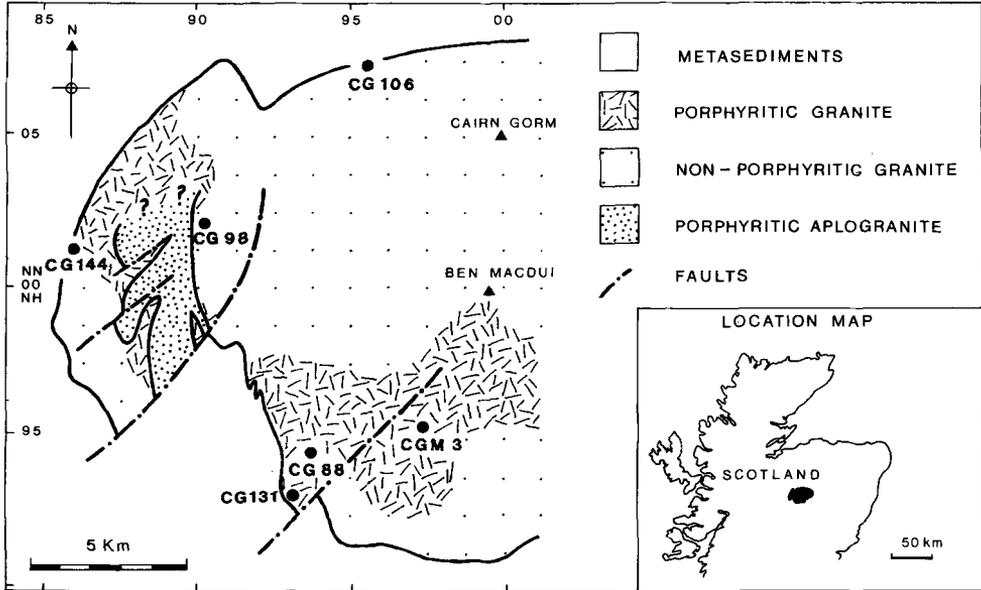


FIG. 1. The geology of the western part of the Cairngorm pluton, showing the location of garnetiferous granites. Minor intrusive bodies omitted for clarity.

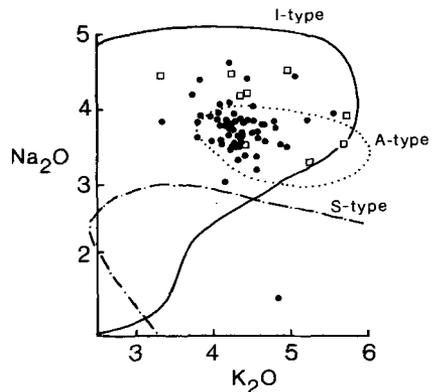
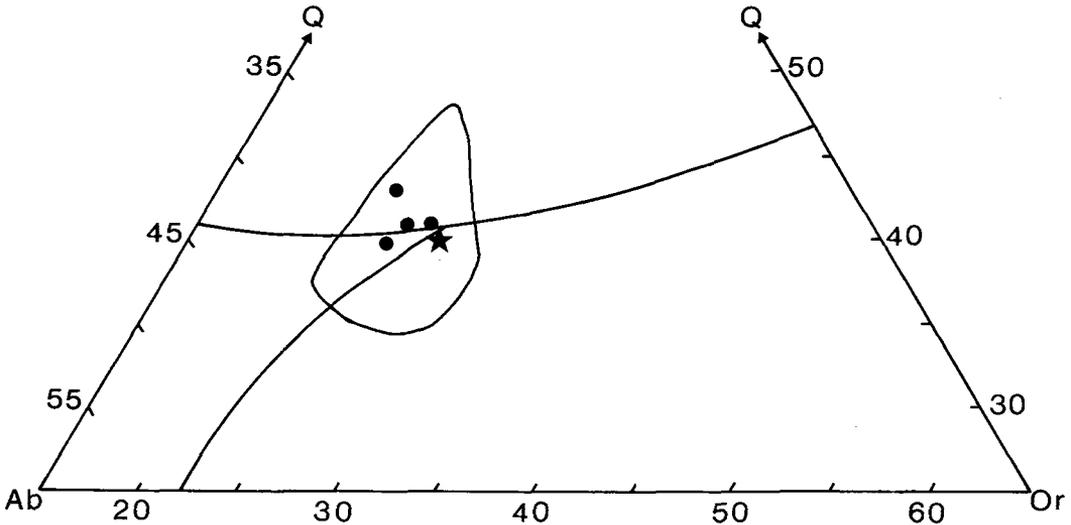


FIG. 2. (a, above) Phase relationships of the Cairngorm granite within the system Q-Ab-Or-H₂O. Cotectic line for melting at 0.5 kbar after Tuttle and Bowen (1958). Star represents 1 kbar minimum melt composition in a natural low-Ca granite system (Day and Fenn, 1982). Dots represent garnetiferous granites (from Table 1). Field encloses 51 other analyses from the granite. (b, right) Relationship between Na₂O and K₂O in the Cairngorm granites, showing the fields defined by the Australian I, S and A-type granites (after White and Chappell, 1983). Closed circles—main granites; open squares—minor intrusives.

Table 1. Major and trace element analyses of three representative, non-garnetiferous granites (CG1, CG24, CG56) and four garnetiferous granites. Total Fe as Fe_2O_3 ; n.a. - not analysed.

Sample	CG1	CG24	CG56	CG88	CG98	CG106	CG144
SiO ₂	76.62	72.54	77.24	77.61	76.76	74.42	77.19
TiO ₂	0.12	0.09	0.04	0.07	0.06	0.10	0.00
Al ₂ O ₃	13.04	15.47	12.68	12.97	12.76	13.85	13.18
Fe ₂ O ₃	1.21	1.81	0.96	1.01	0.92	1.14	0.71
MnO	0.01	0.01	0.03	0.04	0.03	0.02	0.06
MgO	0.00	0.02	0.04	0.01	0.01	0.02	0.07
CaO	0.39	0.44	0.17	0.21	0.22	0.16	0.00
Na ₂ O	3.57	3.86	3.50	3.65	3.93	3.44	3.63
K ₂ O	4.37	5.18	4.07	4.18	3.96	4.22	3.77
P ₂ O ₅	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Loss	1.77	1.46	1.10	1.19	1.38	1.30	1.27
Total	101.10	100.88	99.83	100.94	100.03	98.67	99.88
Normative compositions							
Q	38.29	29.29	40.88	39.93	38.27	37.89	41.54
Or	25.83	30.61	24.05	24.70	23.40	24.94	22.28
Ab	30.21	32.66	29.62	30.89	33.26	29.11	30.72
An	1.94	2.18	0.84	1.04	1.09	0.79	0.00
C	1.73	2.72	2.12	2.06	1.61	3.36	3.13
Molar A/CNK							
	1.15	1.21	1.21	1.19	1.15	1.32	1.31
Trace elements (ppm)							
Rb	349.9	384.5	564.9	413.3	397.6	512.4	811.4
Sr	66.9	69.2	35.5	46.4	44.9	129.0	12.0
Ba	182.1	226.4	n.a.	168.9	n.a.	n.a.	n.a.
Y	37.2	37.1	65.2	34.1	33.7	19.9	9.6
Nb	23.6	22.8	45.8	35.4	32.9	37.6	79.1
Zr	131.3	279.6	99.3	99.6	81.8	160.4	67.9
U	8.3	26.7	5.1	n.a.	6.1	17.5	13.1
Th	41.0	74.2	24.0	n.a.	15.0	26.4	8.7
Rb/Sr	5.23	5.56	15.9	8.91	8.86	3.97	67.6
K/Rb	124.9	134.7	72.0	101.1	99.6	82.4	46.5

of other rare Be, Nb and Y minerals (MacPherson and Livingstone, 1981). Garnet is only found in the western part of the pluton (Fig. 1).

All members of the pluton are moderately peraluminous, with molar $Al_2O_3/(CaO + Na_2O + K_2O)$ between 1.10 and 1.30, 1.5–4.0% normative corundum and SiO₂ between 72 and 77%. The chemistry is typical of a minimum melt granite, with low MgO, CaO, and P₂O₅ (Table 1) and compositions plotting

close to the thermal minimum in the granite system (Fig. 2a). There is no systematic difference in chemistry between the porphyritic and the non-porphyritic granites, although there is a clear intrusion sequence based on the field mapping (Harrison, 1987a). The pluton appears to be transitional between I-type granites (*sensu* Chappell and White, 1974) and A-type granites (*sensu* Collins *et al.*, 1982) since it is very restricted in its major element composition (Fig. 2b), enriched in incompatible elements such as Y, Nb, Th, U, Sn, Be, and F, yet is part of a broadly calc-alkaline suite (Stephens and Halliday, 1984). A number of chemically and mineralogically similar granites extends eastwards for 100 km although the Cairngorm granite is the most chemically evolved of this group.

The greater part of the envelope of the pluton is composed of monotonous, flat-lying psammites and biotite psammites of the Grampian Group Dalradian. The eastern contact is against graphitic schists, limestones and semipelites of the Appin Dalradian, although this contact is largely fault-bounded. Despite the size of the pluton, the thermal aureole is narrow (approximately 200 m wide) and carries andalusite, cordierite and wollastonite. *P-T* estimates for calcareous and pelitic assemblages in the aureole lie in the range $550 \pm 30^\circ C$ and 1.2–2.0 kbar (Harrison, 1987b).

It should be noted that the area described lies within the Cairngorms National Nature Reserve, and a permit is required for scientific research within the Reserve.

Occurrence and textural relationships of the garnets

Although they are of rather restricted occurrence within the pluton (Fig. 1), garnets have been noted previously by several authors (Barrow and Cunningham-Craig, 1913; Harry, 1965; Barritt, 1983) from one locality in the western lobe of the pluton at Allt Ruadh (National Grid Reference NH 860010). This locality is recorded as CG144 in this paper. All the garnetiferous rocks are coarse or medium-grained granites with the exception of CGM3 (Fig. 1) which is a cross-cutting aplite sheet. No other garnetiferous granites have been found in either the Cairngorm pluton or in the other Eastern Grampians Newer Granites (Harrison, 1987b), and the occurrence appears to be unique in the Scottish Caledonian Newer Granites. The garnetiferous granites form isolated exposures up to 50 m in length, although, due to the generally poor levels of exposure, the exact size of the occurrences is not known. Garnet is not abundant in the rocks, forming less than 5% of the modal

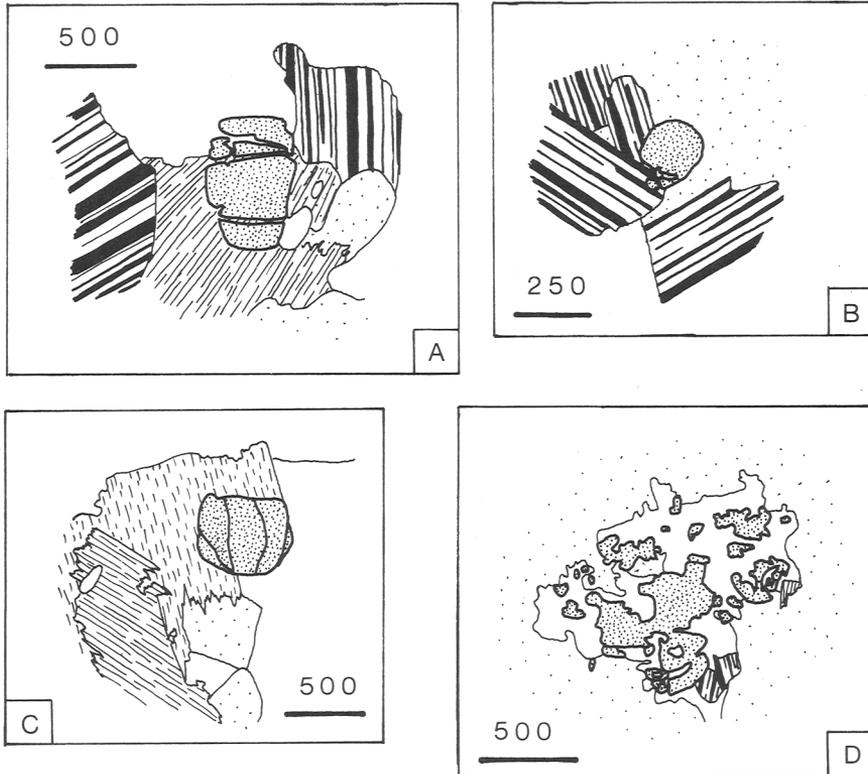


FIG. 3. Textural relationships of the garnets. All garnets are from CG144, except 3D which is from CG98. Garnet—heavy stipple; K feldspar—light stipple; plagioclase—formalized twinning; biotite—thin shading; muscovite—pecked shading; quartz—clear. Scale bar in μm .

amount and is often hard to distinguish in hand specimen from the more abundant brown quartz.

The garnets are small (< 2.5 mm) and their generally subhedral shape (Fig. 3) suggests equilibrium with the melt. However, garnet from CG98 (Fig. 3d) is ragged and surrounded by a rim of quartz which suggests that it has reacted significantly with the melt. Other textural relationships are illustrated in Fig. 3. The garnets occasionally contain inclusions of zircon, apatite and Fe-Ti oxides, and are considered to be primary magmatic phases. They are not considered to be derived from the assimilation of metasedimentary material because there are no xenoliths in the garnetiferous granites and also because the country rocks are essentially psammitic in composition. There is also no textural evidence to suggest that the garnets formed in response to a biotite-consuming reaction as documented by Allan and Clarke (1981).

Garnet coexists with biotite (\pm secondary muscovite) in all rocks except CGM3, where it is the

only mafic silicate. Biotite in the garnetiferous rocks has the distinctive pleochroic scheme $\beta = \gamma$ = foxy red-brown to pale straw-yellow, whereas all biotites in the non-garnetiferous rocks have the pleochroic scheme $\beta = \gamma$ = deep green-brown to pale straw-yellow. This difference may reflect the oxidation state of a number of cations, particularly Fe and Mn (de Pieri and Jobstraibizer, 1983).

Chemistry of the garnets

Thirteen analyses have been made of garnet (Table 2) and nine of biotite coexisting with garnet (Table 3) using a Cambridge Instruments Geoscan MK IV electron microprobe with Link Systems energy dispersive system and ZAF4 corrections. The acceleration voltage used was 15 kV with a livetime of 200 s.

The garnets are solid solutions between almandine (Fe-Al) and spessartine (Mn-Al) and have Mg contents of less than 3.0 mol. % pyrope (Fig. 4). The garnets fall well within the range of igneous

Table 2. Electron microprobe analyses of garnets from the Cairngorm pluton. Total Fe as FeO; n.a. - not analysed.

Sample	CG88		CG98	CG106		CG131			CG144		CGM3		
	10	10A	13	11	12	15	16	17	13	14	3	4	5
SiO ₂	36.67	36.27	36.53	36.94	36.45	36.40	36.46	36.25	36.60	36.84	35.31	35.09	34.98
Al ₂ O ₃	20.16	19.97	20.62	21.27	20.85	20.18	20.64	20.29	20.21	20.25	19.96	19.80	19.64
FeO	23.38	23.58	28.02	23.79	22.97	23.48	23.14	23.17	24.14	22.43	20.44	20.96	20.45
MnO	18.58	17.89	13.43	17.52	18.38	18.99	19.71	19.34	18.20	19.48	22.62	22.05	22.36
MgO	0.52	0.64	0.69	0.67	0.65	0.28	0.24	0.32	0.00	0.00	0.12	0.13	0.20
CaO	0.62	0.58	0.32	0.56	0.50	0.48	0.21	0.23	0.25	0.34	0.25	0.23	0.21
Y ₂ O ₃	n.a.	n.a.	n.a.	n.a.	n.a.	0.05	0.18	0.09	0.76	1.00	1.45	1.66	1.33
Total	99.93	98.93	99.61	100.75	99.80	99.86	100.58	99.69	99.40	99.34	100.15	99.92	99.17

Structural formulae calculated on the basis of 12 oxygens

Si	3.017	3.015	3.006	2.996	2.992	3.008	2.988	2.991	3.015	3.025	2.933	2.919	2.940
Al	1.956	1.957	2.000	2.033	2.017	1.966	1.994	1.973	1.962	1.960	1.953	1.941	1.945
Fe	1.609	1.639	1.929	1.614	1.576	1.623	1.586	1.599	1.663	1.540	1.419	1.458	1.437
Mn	1.295	1.260	0.937	1.204	1.278	1.329	1.368	1.352	1.270	1.355	1.591	1.554	1.592
Mg	0.063	0.079	0.084	0.081	0.079	0.035	0.029	0.040	0.000	0.000	0.015	0.016	0.025
Ca	0.055	0.052	0.028	0.048	0.044	0.043	0.019	0.035	0.022	0.030	0.022	0.021	0.019
Y	-	-	-	-	-	0.003	0.008	0.010	0.033	0.044	0.064	0.074	0.059

End-member compositions

Pyr	2.13	2.65	2.86	2.79	2.70	1.17	0.97	1.33	0.00	0.00	0.49	0.53	0.82
Alm	54.22	55.04	65.39	55.67	53.73	54.34	53.02	53.28	56.70	53.19	46.91	48.15	47.05
Spess	43.65	42.31	31.75	41.53	43.57	44.49	46.00	45.38	43.30	46.81	52.60	51.32	52.13

compositions recorded by Miller and Stoddard (1981). Several garnets were analysed for zoning, although none was found. However, the garnets did show highly irregular variation of less than 1 mol. % Fe and Mn. Zoning is a common feature

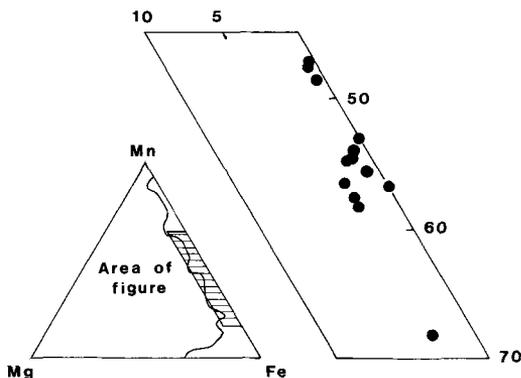


FIG. 4. Composition of the Cairngorm garnets, showing the compositional field of igneous garnets defined by Miller and Stoddard (1981).

of metamorphic garnets, and has been recorded from garnets in granitic rocks as well (e.g. Leake, 1967; Manning, 1983). In metamorphic rocks the zoning has been attributed to changing compositions of the growth medium, thereby setting up concentration gradients at the growing faces of the garnet (Yardley, 1977). Zoning of Mn-rich garnets in granitic rocks has been attributed to simple Rayleigh-type fractionation. At first sight, therefore, the absence of zoning in the garnets from the Cairngorm pluton suggests that they grew from a compositionally homogeneous liquid. However, this liquid would have to have been anomalously rich in Mn in order to sustain garnet growth. Yardley (1977) has shown that zoning in metamorphic garnets is eradicated by cation diffusion as temperature increases. He has shown that zoning is effectively eradicated in garnets of 1–2 mm diameter from sillimanite-K-feldspar gneisses that are estimated to have reached $640 \pm 30^\circ\text{C}$. Such temperatures are clearly exceeded in a granite magma, and the size of the garnets in the Cairngorm pluton compares well with those of Yardley (1977). It is suggested that the Cairn-

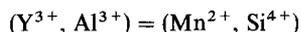
Table 3. Electron microprobe analyses of biotites coexisting with garnet. Total Fe as FeO; n.a. - not analysed.

Sample	CG88		CG98	CG106		CG131	CG131	CG144	CG144
Analysis	112	113	257	220	221	427	428	314	315
SiO ₂	35.47	36.18	35.66	36.71	36.47	36.79	35.22	38.43	39.07
TiO ₂	2.66	3.13	2.71	2.87	2.48	2.08	2.41	1.67	1.72
Al ₂ O ₃	17.56	18.02	19.39	19.33	19.65	19.16	18.81	20.92	21.16
FeO	24.92	24.25	24.03	24.10	24.31	22.93	24.57	19.51	19.43
MnO	1.32	1.39	1.29	1.53	1.22	1.67	1.73	2.21	1.87
MgO	2.98	3.18	3.21	3.24	3.16	2.75	2.61	0.54	0.53
Na ₂ O	0.39	0.20	0.52	0.56	0.44	0.21	0.42	0.15	0.33
K ₂ O	9.57	9.52	9.37	9.69	9.64	9.51	9.48	9.68	9.83
Total	94.84	95.87	96.18	98.03	97.37	95.10	95.25	93.11	93.94
Structural formulae calculated on the basis of 22 oxygens									
Si	5.504	5.616	5.511	5.568	5.563	5.714	5.541	5.966	5.994
Al	2.396	2.384	2.398	2.432	2.437	2.286	2.459	2.034	2.006
Al	0.875	0.913	1.043	1.025	1.096	1.220	1.029	1.794	1.820
Ti	0.316	0.366	0.315	0.327	0.284	0.243	0.286	0.194	0.199
Fe	3.293	3.148	3.105	3.057	3.101	2.979	3.233	2.533	2.493
Mn	0.177	0.182	0.169	0.197	0.157	0.220	0.231	0.290	0.242
Mg	0.702	0.737	0.739	0.733	0.718	0.637	0.613	0.124	0.120
Na	0.113	0.060	0.157	0.164	0.130	0.128	0.128	0.046	0.099
K	1.929	1.885	1.848	1.874	1.875	1.903	1.903	1.918	1.925
Fe/(Fe+Mg)	0.824	0.810	0.808	0.806	0.812	0.824	0.841	0.953	0.954
Al/(Al+Si)	0.368	0.370	0.391	0.383	0.388	0.380	0.386	0.391	0.389

gorm garnets never showed any significant compositional zoning.

No attempts have been made at garnet-biotite geothermometry because garnet compositions far exceed the value of $(Ca + Mn)/(Ca + Mn + Fe + Mg) < 2.0$, which Ferry and Spear (1978) cited as the limits for correction factors due to the presence of these elements.

Yttrium is often a conspicuous component of the Cairngorm garnets and shows concentrations up to 1.67 wt. % Y₂O₃ (Table 2). Y analyses are rarely presented for garnets, and the study by Jaffe (1951) is by far the most extensive work on this subject. He showed that there is a strong correlation between high Y and high Mn in garnets, and suggested that Y may enter the garnet through the substitution



due to the similar ionic radii of Mn²⁺ (0.91 Å) and Y³⁺ (0.98 Å).

Discussion

Although the occurrence of magmatic garnets has not been recorded from any other pluton of the Scottish Newer Granites, they are well known from other granitic rocks throughout the world. Miller and Stoddard (1981) have studied the development of garnet in a series of strongly peraluminous muscovite-biotite and muscovite-garnet granites from the Old Woman-Piute Range, California and have found that the development of garnet was accompanied by an increase in the molar Mn/(Fe + Mg) ratio of the rock. However, no similar differentiation sequence is seen in the Cairngorm pluton—indeed, the lack of a clear differentiation sequence in the pluton is one of its most striking features, despite the variety of granitic rock types present. Clearly, the development of the garnet must be attributed to more localized controls over the concentration of Mn in the melt. Since there is no differentiation se-

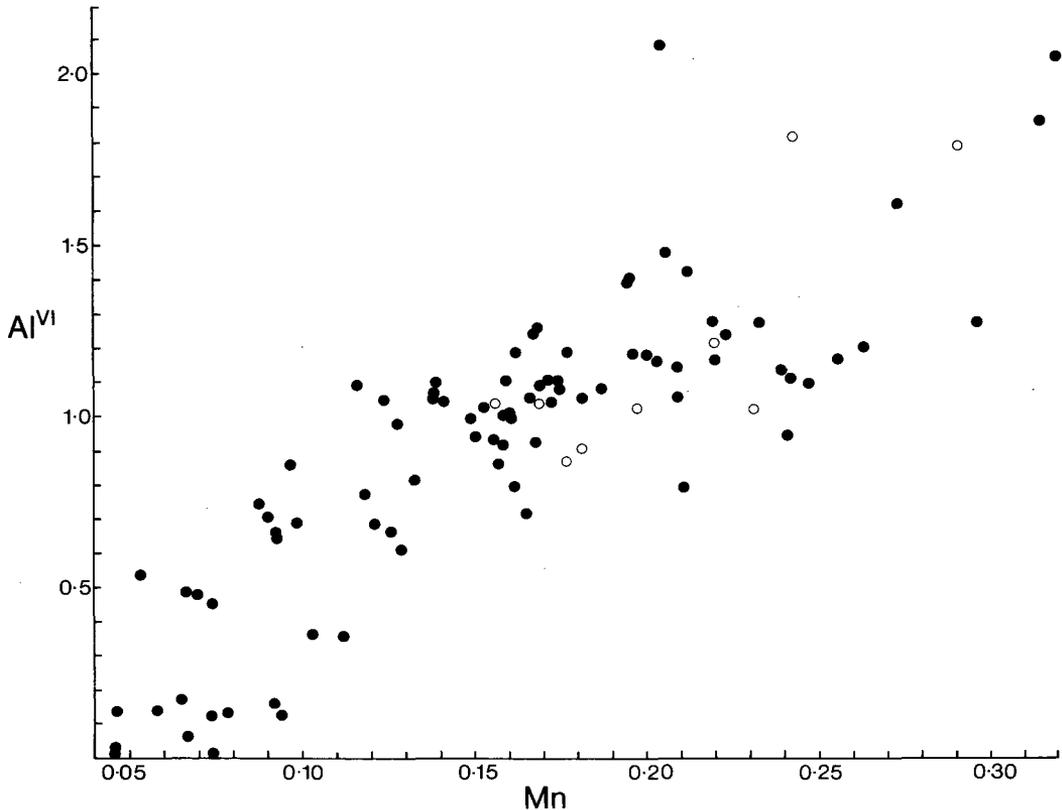


FIG. 5. Relationship between Mn and Al^{VI} in biotites from the Cairngorm pluton. Open circles are biotites coexisting with garnet.

quence in the pluton, the behaviour of Mn can be monitored through variations in the Mn content of the common mafic phases biotite and Fe-Ti oxides.

Fe-Ti oxides are not abundant in the granites. Magnetite has a virtually pure end-member composition, and ilmenite has high Mn contents (up to 7 mol. % pyrophanite). The Mn enrichment in the ilmenite and its coexistence with virtually pure magnetite suggests low-temperature, high- f_{O_2} re-equilibration of these phases with a late fluid phase (Buddington and Lindsley, 1964; Neumann, 1974). This is upheld by the extremely coarse exsolution textures.

Biotite too has been affected by this interaction with the fluid phase, and displays concomitant Al^{VI} and Mn enrichment with increasing interaction. The most Mn and Al^{VI} -rich biotites coexist with large amounts of secondary muscovite which has formed as an alteration product of the biotite during late magmatic or subsolidus conditions (Harrison, 1987*b*). This Mn enrichment is shown

in Fig. 5, and may be attributed to the absence of any significant hornblende fractionation during the evolution of the Cairngorm magma. Hornblende is absent from the granite, and due to its high K_{Mn} in silicic melts (Mahood and Hildreth, 1983) its early fractionation would have depleted the Cairngorm magma in Mn. Also, the Cairngorm pluton is underlain by large negative residual magnetic and gravity anomalies (Brown and Locke, 1979), precluding the presence of denser, hornblende-bearing rocks at depth. However, the concomitant Mn and Al^{VI} enrichment in the biotites suggests that Mn is being concentrated into the fluid phase that is interacting with the biotites, because the most Mn-rich biotites are also those which coexist with abundant secondary muscovite. Hildreth (1981) has suggested that the Mn enrichment seen in the caps of high-silica magma chambers (which formed the source of voluminous, compositionally zoned ash-flow deposits) may be due to the hydroxyl complexing of Mn in a fluid phase which had concentrated towards the roof

of the magma chamber. Indirect evidence for this is also seen in the data of Baldwin and von Knorring (1983), who show that the Mn contents of garnets from granite pegmatites increases from the contact zones towards the centres of the bodies. The presence of even more Mn-rich garnets in the centres of Li-rich pegmatites suggests that halogens may also play an important role in Mn complexing.

The observation of Hildreth (1981) may help to explain the distribution of garnetiferous granite in the Cairngorm pluton, since this rock type is generally only found at the margins of the intrusion. In the western part of the pluton (Fig. 1) several sheets of pegmatite-rich porphyritic aplogranite and pegmatite have formed along the wall of the intrusion as a result of the ponding of volatiles. Whilst none of these sheets is associated with garnetiferous granite, it is envisaged that similar processes operated during the formation of garnet in the granite, whereby local Mn 'super-enrichment' occurred as a result of the volatile complexing of Mn from the melt into these volatile-rich areas, enabling garnet to crystallize. Both Hsu (1968) and Weisbrod (1974) have demonstrated experimentally that the stability of Mn garnet is greatly increased by the presence of excess water. It is not clear why garnet was not developed at other marginal locations in the pluton, although this may reflect both the composition and degrees of concentration of these localized fluids. The garnet in the aplite CGM3 is the only mafic silicate and has crystallized in place of biotite (cf. Abbott, 1981).

The stability of garnets in granitic melts has been studied by Green (1977), who concluded that increased Mn contents in the garnets increased their stability at lower pressures. For example, garnets with 20–25 mol. % spessartine may crystallize in equilibrium with a granitic liquid at pressures of *c.* 3 kbar, and at even lower pressures with increasing spessartine content. This observation may help to explain the striking disequilibrium textures shown by the comparatively Mn-poor garnet from CG98 (Fig. 3) and may indicate greater depths of crystallization. The stability of garnets in granitic melts with varying water content is not known, but available experimental evidence and the field evidence from the Cairngorm granite suggests that high water contents favour garnet stability in the melt.

The extremes of Mn enrichment demonstrated by the biotites in the Cairngorm pluton (Fig. 5) do not correlate with the formation of garnet. Table 3 shows that, with two exceptions, all biotites coexisting with garnet have $Fe/(Fe+Mg) = 0.808 \pm 0.011$ despite the wide range in $Fe/$

$(Fe+Mg)$ for other biotites in the Cairngorm pluton (0.660–0.950). This suggests that the presence of garnets in the melt has buffered the $Fe/(Fe+Mg)$ ratios of the coexisting biotites, probably through simple Fe–Mg exchange. However, the different pleochroic schemes between the biotites in garnetiferous and non-garnetiferous granites suggest that the garnets may also have buffered the f_{O_2} at lower levels than in the non-garnetiferous melts, since the foxy red–brown biotites seen in the garnetiferous granites are typical of 'S-type' biotites (Speer, 1984) which have crystallized in a reducing environment.

The Y-enrichment demonstrated by many of the garnets (Table 2) has at first sight potentially important ramifications for the *REE* budget of the Cairngorm pluton. Y appears to behave in a similar geochemical manner to the *HREE* Ho (Felsche and Hermann, 1970). Although Jaffe (1951) does not record appreciable Ho enrichment in yttrian garnets, he does record enrichment in other *HREE*, notably Gd and Dy. Plant *et al.* (1980) have shown that the Cairngorm pluton is markedly enriched in Y and *HREE* compared with other Caledonian Newer Granites, and it may be that the Mn enrichment demonstrated by the biotites and the formation of garnets has had a concomitant enriching effect on Y and *HREE*. However, this Y and *HREE* enrichment argues directly against extensive garnet fractionation since this would have depleted the granite in Y and *HREE* (Schnetzer and Philpotts, 1970). The restricted, marginal occurrence of the garnets serves to confirm this. Table 1 illustrates a major problem with the sampling of small, sparsely distributed phases in a coarse-grained rock, since the garnetiferous samples show lower Y than the non-garnetiferous samples. It seems likely that little or no garnet may have been present in the sample analysed, despite careful homogenization of the crushed granite. Y in the non-garnetiferous granites is accommodated largely in plagioclase and apatite, although monazite and xenotime may be important hosts elsewhere in the pluton.

Conclusions

The Mn-rich garnets in the Cairngorm granite are all considered to be the products of magmatic crystallization from a Mn-enriched, volatile-rich granite. They show a very localized distribution, generally against the margins of the pluton, and this is considered to reflect localized concentrations of these volatiles ponding against the walls of the pluton. The Mn enrichment in the pluton is considered to be due to the absence of hornblende fractionation during the early stages of the evol-

ution of the melt, although both extensive garnet fractionation and garnet in the residue can also be ruled out because the Cairngorm pluton shows significant *HREE* and Y enrichment. The garnets themselves show Y enrichment.

Acknowledgements

Electron microprobe analyses were performed in the Department of Geology and Mineralogy, University of Aberdeen, by George Taylor and John Still. XRF analyses were performed with the assistance of Colin Wood. The author acknowledges the receipt of a NERC/CASE studentship in conjunction with the British Geological Survey under the supervision of Peter Brown, Doug Fettes and Ian Munro. All the fieldwork was carried out under permit from the Nature Conservancy Council. The comments of the anonymous referees, especially on an earlier manuscript, are gratefully acknowledged.

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[Manuscript received 10 December 1987;
revised 22 February 1988]