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The compositional range of magmatic Mn-garnets in the Galway Granite, Connemara, Ireland

AN alkali-feldspar leucogranite, called the Murvey Granite, is exposed in the central and marginal zones of the early Devonian, I-type (Caledonian) Galway Granite in the west of Ireland (Fig. 1). Previous studies have shown that some aplites within the leucogranite contain garnets and that a garnet-bearing variety of the Murvey Granite (Garnetiferous Murvey Granite) is also locally developed at the edge of the batholith (Wright, 1964; Thornton, 1964; Leake, 1967; Coats and Wilson, 1971; Lawrence, 1975; Leake, 1974). Wright (1964) stated that there can be little doubt that these manganiferous garnets constitute a primary phase and are not the result of contamination. Leake (1967) presented the results of microprobe studies of the garnets hosted by the Garnetiferous Murvey Granite and the aplites, exposed at the western end of the batholith, and highlighted the presence of compositional zoning with Mn and Ca-rich centres and Fe and Mg-rich margins — see Fig. 2. Leake (1967) also reported that the garnets obviously crystallized from the granite magma and concluded that the zoning was clearly not related to metamorphic conditions, but was instead governed by the Rayleigh fractionation principle.

Our communication presents new compositional data from microprobe studies of garnets hosted by a pegmatite and an aplite exposed in a working quarry located in the centre of the non-garnetiferous Costelloe Murvey Granite (Fig. 1). The horizontal pegmatite is composed of alkali feldspar, quartz and biotite, and is up to 25 cm thick. Cherry red garnet euhdra between 2 and 5 mm in diameter are sporadically developed in the pegmatite and locally occur in clusters of up to ten crystals. The geochemistry of this pegmatite has been published by Whitworth and Feely (1989).

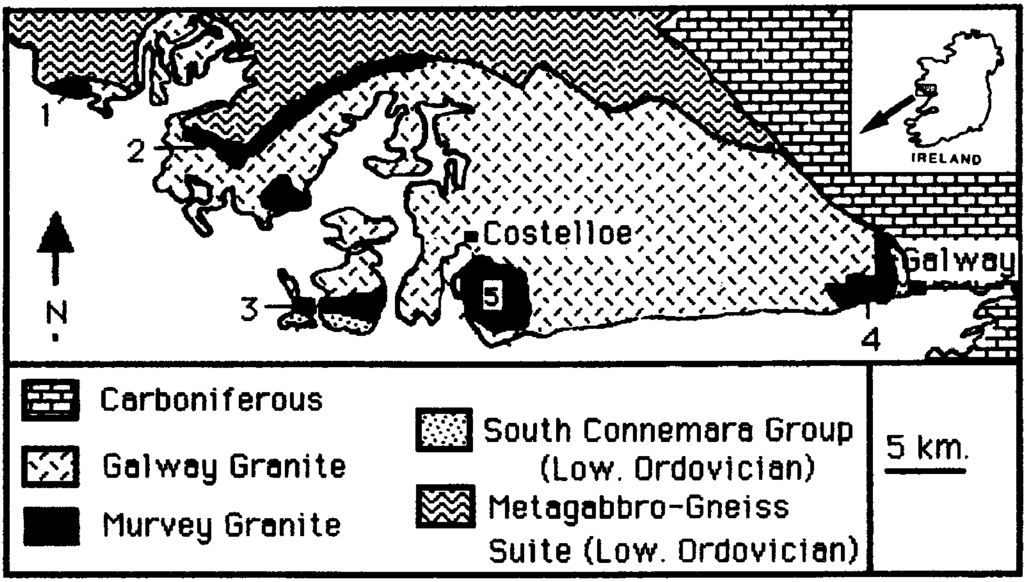

FIG. 1. A simplified geological map of the Galway Granite showing the distribution of the Murvey Granite, adapted from Max *et. al.* (1978) and Leake *et al.* (1981). The numbered localities highlight the areas where garnets have been reported from the Granite: 1, Garnetiferous Murvey Granite and aplites (Thornton, 1964; Leake, 1967); 2, Garnetiferous Murvey Granite (Wright, 1974); 4, Garnetiferous Murvey Granite (Lawrence, 1975); 4, Garnetiferous aplites (Coats and Wilson, 1971); and 5, Garnetiferous pegmatite and aplite (this study).

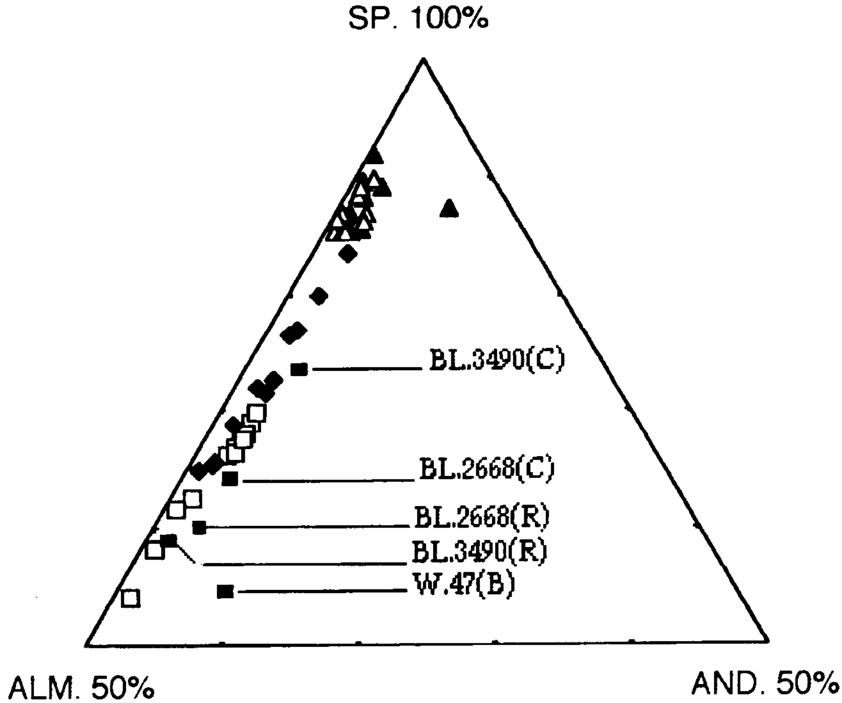

TABLE 1. Representative analyses of garnets from the pegmatite and aplite hosted by the Costelloe Murvey granite (CMG) and from the Garnetiferous Roundstone Murvey Granite (RMG).

Sample	CMG $Pegm^R$	CMG $Pegm^R$	CMG $Pegm^C$	CMG $Pegm^C$	CMG Apl	CMG Apl	RMG Gran	RMG Gran	RMG Gran
SiO_2	34.55	34.06	34.66	34.04	35.96	35.00	35.77	35.26	35.77
TiO_2	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.23	0.07
Al_2O_3	20.63	20.20	20.58	20.18	20.26	19.69	19.78	19.27	20.35
Cr_20_3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fe_2O_3	1.92	2.74	2.10	2.37	0.74	2.95	1.74	2.67	0.92
FeO	7.11	7.08	6.83	6.83	15.05	9.65	16.22	13.39	16.45
Mn0	35.30	34.84	35.50	34.36	27.39	31.71	25.71	27.76	25.82
Mgo	0.00	0.00	0.22	0.00	0.00	0.32	0.27	0.32	0.22
CaO	0.32	0.49	0.18	0.88	0.42	0.80	0.49	0.85	0.32
Y_2O_3	nd	nd	nd	1.85	0.65	0.48	nd	nd	nd
Total	99.84	99.40	100.06	100.51	100.47	100.59	100.02	99.74	99.92
				Number of ions on the basis of 24(O)					
Si IV	5.76	5.72	5.76	5.75	5.96	5.82	5.93	5.87	5.92
Al IV	0.24	0.28	0.24	0.25	0.04	0.18	0.07	0.13	0.08
Al VI	3.82	3.72	3.79	3.76	3.92	3.67	3.79	3.66	3.89
Ti VI	-	-	-	-	-	-	0.01	0.03	0.01
Cr	-	-	-	-	-	-	-	-	-
Fe^{3+}	0.24	0.35	0.26	0.30	0.09	0.37	0.22	0.33	0.11
Fe^{2+}	0.99	0.99	0.95	0.96	2.09	1.34	2.25	1.87	2.28
Mn^{2+}	4.99	4.96	5.00	4.91	3.84	4.46	3.61	3.92	3.62
Mg	0.00	0.00	0.05	-	-	0.08	0.07	0.08	0.05
Ca	0.06	0.09	0.03	0.16	0.07	0.14	0.09	0.15	0.06

nd = below detection limit

The garnet-bearing aplite vein is vertical and trends in a northerly direction. It is 40 cm thick and can be traced along strike for about 20 m. Microscopic studies reveal a grain size of < 1 mm and a mineral assemblage composed of quartz and feldspar. Sporadic euhedral to subhedral garnets (< 0.5 mm across) and ragged flakes of biotite and muscovite account for < 1% of the modal volume. The host Costelloe Murvey Granite (CMG) is a highly evolved medium grained leucogranite (Feely and Madden 1988; Whitworth and Feely 1989; Feely *et al.* 1991). It contains quartz, perthite and albite together with ragged heavily chloritized biotite accounting for < 5% of the modal volume. Accessory minerals include apatite, zircon, uraninite and thorite (Feely, *et al.* 1989). No garnets have ben observed in the CMG.

Forty nine analyses of garnets were performed using a Cambridge instruments Geoscan IV electron microprobe operating in ED mode with a livetime of 100 seconds and an accelerating voltage of 15 kV. Data were automatically reduced using the ZAF4 FLS+ Link Analytical Systems

FIG. 2. Ternary plot of mol.% of almandine (ALM), spessartine (SP) and andradite (And) for the garnets of the Galway Granite. The data represented by BL. 3490 and BL. 2668 are from Leake (1967) while W.47 is from Wright (1964); core, rim and bulk analyses are represented on the diagram as (C), (R) and (B) respectively. The rest of the data points are from this study: open squares = Garnetiferous Murvey Granite; filled diamonds = CMG aplite; filled triangles = CMG pegmatite (core analyses); and open triangles = CMG pegmatite (rim analyses).

software. In order to cross-check our results with those of the previous workers we also analysed garnets in a sample of Garnetiferous Murvey Granite exposed at the western end of the batholith taken from the same quarry as sample BL.2668 (Thornton, 1964; Leake, 1967; see Fig. 2).

Results

The results obtained are summarized in Table 1 and Fig. 2. Garnets from the CMG aplite contain 64–83 mol.% spessartine and < 5 mol.% andradite, the balance being almandine. Garnets hosted by the CMG pegmatite have a narrow compositional range unlike those from the aplite and contain significantly more of the spessartine component at the expense of almandine. The spessartine contents vary between 85 and 91 mol.% and are significantly higher than all other published values for garnets from the Galway Granite. The andradite content is < 5 mol.%, apart from one core analysis with a composition $Sp_{87}Alm_4And_9$. Core and rim analyses of the pegmatite garnets revealed the absence of any significant compositional zoning. The garnets hosted by the Garnetiferous Murvey Granite contain between 54 and 76 mol.% spessartine and include the compositional range published by Leake (1967) for BL.2668; see Fig. 2. Furthermore their compositional range partially overlaps that of the garnets from BL.3490 (an aplite) and the CMG aplite. These in turn bridge the compositional gap between the garnets from the Garnetiferous Murvey Granite and the spessartine-rich garnets from the CMG pegmatite. There is an overall trend of increasing spessartine content in garnets from the Garnetiferous Murvey Granite through the garnets from both the BL.3490 and the CMG aplites to the garnets from the CMG pegmatite. A limited number of spot analyses revealed the presence of appreciable Y levels in the garnets from the CMG aplite and pegmatite i.e. Y_2O_3 = 0.48 to 1.85 wt.% see Table 1. The highest level recorded comes from the core of a pegmatite garnet.

Discussion

In the Galway Granite a granite evolutionary sequence has been recognized by Leake (1974), starting with an adamellite (Errisbeg Townland Granite: ETG) which passes outwards to the Murvey Granite and then to the more evolved Garnetiferous Murvey Granite and aplites at the margins of the batholith. Whole-rock compositions in terms of atomic proportions of Fe, Mg and Mn presented in Fig. 3, and representing the petrochemical sequence above, show that the

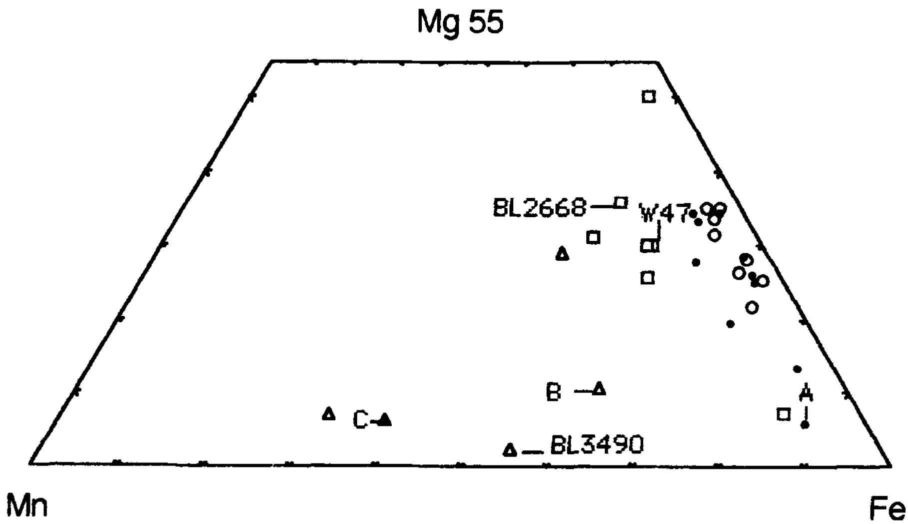

FIG. 3. Composition of granites in terms of atomic proportions of Fe, Mg and Mn. ETG (open circles); Murvey Granite (filled circles); Garnetiferous Murvey Granite (open squares); Garnetiferous aplites (open triangles); Garnetiferous pegmatite (filled triangle). A = CMG, B = CMG aplite and C = CMG pegmatite. The rock compositions of BL.2668, BL.3490 and W47 are also shown. Data from Thornton (1964), Wright (1964), Leake (1974), Lawrence (1975) and Whitworth and Feely (1989). The CMG aplite was analysed during this study (MgO = 0.06 wt.%, MnO = 0.13 wt.% and Fe_2O_3 ($Fe_{tot.}$) = 0.61 wt.%).

highest Mn/(Fe+Mg) ratios correlate with the evolved garnet-bearing lithologies especially those from the Roundstone and Costelloe areas. Leake (1967) noted that analyses of single aplites, containing garnetiferous and non-garnetiferous zones along their length, are marked by high Mn contents whenever garnet is present. According to Leake (1967), once the garnet had nucleated, it proceeded to concentrate Mn from the magma, thereby depleting the magma so much that in adjoining parts of the same aplite biotite forms instead. Miller and Stoddard (1981) showed from rock and mineral chemistry that, like the Galway Granite, the Mn/(Fe + Mg) ratio increased with differentiation and is highest in garnet-bearing rocks. Furthermore these authors concluded that most garnets in granitic rocks precipitated from an evolved Mn-rich (relative to Fe and Mg) liquid. Whitworth (1992) showed that, in the Leinster Granite, garnets from aplites contain ~60% spessartine in comparison to ~72% in garnets from the Li-pegmatites; he asserted that the aplites were not as chemically evolved as the pegmatites. This assertion that increasing chemical evlution produces increasingly Mn-enriched garnets is also supported by Baldwin and von Knorrig (1983) who showed that garnets in less fractioned marginal zones of pegmatites were Mn-poor relative to those in the central more fractionated zones. The Y analyses reflect the geochemical association that exists between Mn and Y, highlighted for example by Deer *et al.* (1992) who state that yttrian spessartines exist which may contain >2% Y_2O_3. Garnetiferous aplites in the Galway Granite are enriched in Y (~ 46 ppm) — reflection of Y substituting for Mn in garnet (Coats and Wilson, 1971). Feely and Madden (1988) showed however, that in the Galway Granite Y enrichment in evolved leucogranites (i.e. the CMG) does not necessarily mean that garnets are present.

Conclusions

This study shows that pegmatite-hosted garnets from the CMG are more enriched in Mn relative to garnets from the Garnetiferous Murvey Granite and aplites in the Galway Granite. Furthermore garnets hosted by the pegmatite and aplite in the CMG exhibit appreciable Y levels due to that element substituting for Mn in the structure. The difference in Mn contents of the garnets from the aplite and pegmatite in the CMG quarry may reflect a difference in the degree of chemical evolution between the aplite and the pegmatite. The sparsity of garnets within the batholith as a whole suggests that these pockets of extreme Mn enrichment were relatively uncommon, as evidenced by the low rock concentrations of MnO in the granites (<0.1 wt.%). Hildreth (1981) proposed a mechanism whereby the occurrence of garnet in silica-rich magma chambers could be explained by hydroxyl complexing of Mn in an ascending fluid phase producing small discrete zones of Mn enrichment in the roof of the magma chamber. Thus aqueous fluid released during the evolution of the CMG may have complexed some or most of the available Mn and transported it to the nucleation site, allowing locally high concentrations of Mn to be present in the upper parts of the intrusion and hence low-pressure crystallization of spessartine rich garnets.

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KEYWORDS: Galway granite, garnets, manganese, yttrium, compositional variation.

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Manganese ferro-ferri-winchite from Harstigen, Filipstad, central Sweden

THE small, abandoned Fe–Mn mine at Harstigen (Lat. 59°47′, Long. 14°19′), Filipstad district, is the host of more than 100 different mineral species. The ore, which is of early Proterozoic age, consists of magnetite, hematite, and hausmannite in a dolomitic host rock which is surrounded by potassic meta-rhyolites. The ore may be classified as Långban-type. In this note we report on an unusually manganese-rich ferro-ferri-winchite which has been found on the mine dumps. Other Mn-rich amphiboles are known from Harstigen and Långban under the name richterite, and have been studied by Sundius (1945) and by Holtstam (1992). These may, however, easily be distinguished from the present sample by their colour, high Mg-content and also by the associated minerals.

The winchite phase occurs fairly abundantly in a restricted association, consisting of a dark green clinopyroxene intergrown with fine-grained hematite and yellowish-brown andradite. This matrix is cut by distinctly later veinlets of rhodonite, occurring as euhedral crystals embedded in fibrous to radiating ferro-ferri-winchite (Fig. 1), and minor baryte, galena, and calcite. The veinlets are structurally perpendicular to a foliation present in the skarn matrix. If the calcite is removed by HCl the amphibole is revealed as spherical aggregates up to 5 mm in size. It shows a distinct pleochroism in thin section, with greenish