The origin of accessory garnet in the Donegal Granite

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Summary. In the Donegal Granite garnet occurs as an accessory mineral in muscovite-granites, pegmatites, and aplites. The composition of the garnet in fourteen samples of granitic rock has been determined from the physical properties and three new chemical analyses are given. All the samples examined are intermediate in composition between almandine and spessartine. The reason for the high manganese content in garnet from granites is discussed.

GARNET is a common accessory mineral in the muscovite granites, aplites, and pegmatites of the Donegal Granite, and this study was carried out in order to determine the composition of the garnet in each of the principal types of occurrence. There are four members of the Donegal granite suite in which garnetiferous rocks are found, and their relations are shown in fig. 1. The first to be emplaced was the Older Granodiorite (Pitcher, 1953*a*), which is not itself garnetiferous although it contains numerous inclusions of grossular-bearing limestones. Intruded into it is the Rosses Ring Complex (Pitcher, 1953*b*), consisting of four ring-granites together with a swarm of early microgranite sheets and later intrusions of microgranite, pegmatite, and aplite. These later intrusions are all rich in muscovite and are frequently garnetiferous. To the south of the Rosses Ring Complex is the Trawenagh Bay Granite (Gindy, 1953), which is later than the Rosses Complex. It contains both biotite-granites and muscovite-granites, and garnet is widespread in the latter. It is especially common in pegmatitic segregations in the granite as well as in aplite and pegmatite veins. The Trawenagh Bay Granite passes eastwards into the Main Donegal Granite (Pitcher, Read, *et al.*, 1959). The latter consists mainly of biotite-granite, and garnet occurs only in aplites and pegmatites.

The specimens that have been studied include representatives of all the types of occurrence: in muscovite-granites, in pegmatitic segregations, and in aplite and pegmatite intrusions. The localities are shown in fig. 1. Garnet was the only dark mineral present in the rocks except for a minute amount of magnetite in one or two samples. None of the garnetiferous granites contain biotite or chlorite, even though some of the garnetiferous pegmatite segregations were in biotite-granites, but all the rocks contain muscovite.

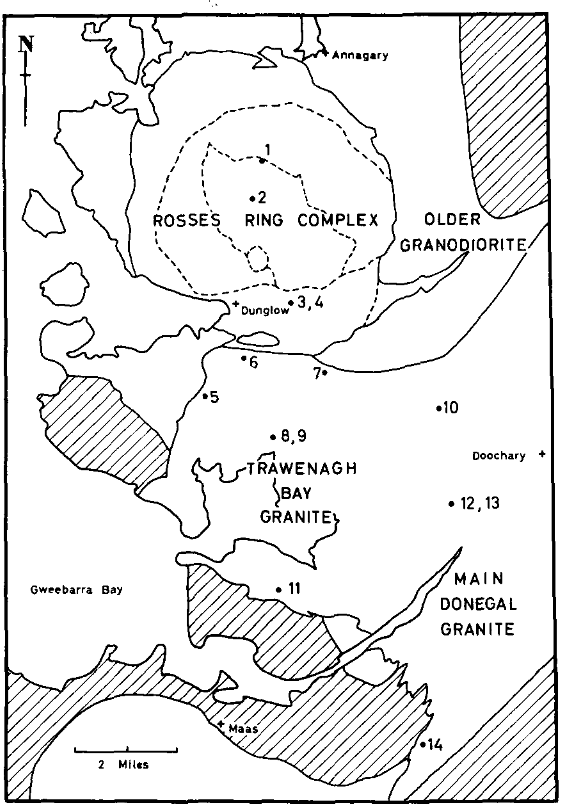

FIG. 1. Geological map of the western end of the Donegal Granite showing specimen localities. The Dalradian country rocks are shaded.

The garnets have a light reddish-brown colour when separated from the rock but are almost colourless in thin section; in specimen 14 the centres of crystals are slightly brown in thin section whereas the outer parts are colourless, possibly an indication of slight zoning. None of the garnet is at all birefringent. Crystals are sometimes euhedral against other minerals but are more often rounded; they are not intergrown with any of the neighbouring minerals and do not contain any inclusions.

Composition. Garnets were separated from fourteen samples of rock using a magnetic separator and their compositions estimated by measuring the refractive indices and unit-cell edges. The refractive indices were measured by the dispersion method, with a probable accuracy of $\pm 0{\cdot}002$. Cell edges were measured from powder photographs taken with Fe-$K\alpha$ radiation in an 11·46 cm diameter camera; several doublets in the back-reflection region were used for measurement and an accurate value obtained by extrapolation to $2\theta = 180°$; film shrinkage was corrected for and the results obtained are considered to be accurate to within 0·001 Å of the stated value. Refractive indices and cell edges of all the samples are listed in table I.

TABLE I. Refractive indices and unit-cell edges of garnets from the Donegal Granite

No.	Rock Type	Refractive index (n_D) Minimum	Maximum	Mean	a
1	Pegmatite intrusion in Rosses G3 granite	1·815	1·820	1·818	11·576 Å
2	Muscovite granite dyke in Rosses G3 granite	1·815	1·818	1·817	11·592
3	Aplite member of composite pegmatite-aplite sheet	1·812	1·817	1·814	11·595
4	Pegmatite member of composite pegmatite-aplite sheet	1·812	1·817	1·814	11·602
5	Pegmatitic segregation in biotite granite	1·813	1·817	1·815	11·606
6	Muscovite granite	1·821	1·822	1·822	11·589
7	Garnetiferous granite lining joint in biotite granite	1·814	1·817	1·816	11·602
8	Muscovite granite	1·817	1·821	1·819	11·575
9	Pegmatitic segregation in muscovite granite	1·818	1·821	1·820	11·593
10	Pegmatite in biotite granite	1·814	1·821	1·817	11·583
11	Pegmatite in biotite granite	1·815	1·820	1·818	11·606
12	Pegmatite variety of Trawenagh Bay granite	1·818	1·822	1·821	11·589
13	Aplitic variety of Trawenagh Bay granite	1·818	1·822	1·820	11·579
14	Leucogranite containing very little muscovite	1·815	1·820	1·817	11·591

It will be seen that the range of variation is very small, indicating that all the garnets have a similar composition. There is no apparent correlation between the physical properties and the type of occurrence; pegmatite garnets are similar to those from muscovite granites and aplites. Refractive index measurements on crystals from individual rocks vary over a small range, usually about 0·004, indicating that the samples may be slightly inhomogeneous or zoned.

Where sufficient material was available the garnet was further purified by centrifuging in methylene iodide and these samples were chemically analysed. Gravimetric methods were used for silicon, aluminium, calcium, and magnesium, and colorimetric methods for titanium, total iron, phosphorus, and manganese, the latter being determined separately in each of the gravimetric precipitates. Ferrous iron was determined by the modified Pratt method. Sodium and potassium were sought by flame photometry but were not found to be present. The results of the analyses are given in table II.

TABLE II. Chemical analyses of garnets from the Donegal Granite. Analyst: R. C. Tyler. TiO_2, Fe_2O_3, MgO, alkalis, and P_2O_5 absent. Specimen nos. as table I

	5		8		14	
SiO_2	35·85		35·77		35·76	
Al_2O_3	20·75		20·50		20·45	
FeO	9·37		22·74		21·66	
MnO	33·65		19·88		20·75	
CaO	0·71		1·06		1·37	
Total	100·33		99·95		99·99	
Atomic proportions on the basis of 12 *oxygens*						
Si	2·957	3·000	2·964	3·000	2·962	3·000
Al	0·043		0·036		0·038	
Al	1·974	1·974	1·967	1·967	1·959	1·959
Fe^{2+}	0·646	3·060	1·576	3·066	1·501	3·078
Mn	2·351		1·396		1·456	
Ca	0·063		0·094		0·121	
Molecular percentages of end-members						
Almandine	21·1		51·4		48·8	
Spessartine	76·9		45·5		47·3	
Grossular	2·0		3·1		3·9	
Physical properties						
n_D ($\pm$0·002)	1·815		1·819		1·817	
Cell edge (Å)	11·606		11·575		11·591	

The analyses show that samples 5, 8, and 14 contain no magnesium or ferric iron at all so that the composition can be expressed completely in terms of the almandine, spessartine, and grossular end-members, with the latter being only a minor constituent. The highest manganese content is found in no. 5, which contains 76·9 mol. % spessartine, but the other specimens are also quite rich in manganese (45·5 and 47·3 mol % spessartine). In this respect the samples are typical of garnet from granitic rocks; Wright (1938) gives the average proportion of the spessartine molecule in garnet from granites as 36·0 % and in garnet from pegmatites as 47·1 %.

The origin of the garnet. Several different explanations have been put forward for the occurrence of garnet in granitic rocks. Gindy (1956) has described occurrences in Donegal and Egypt and has suggested that garnet, together with muscovite, crystallizes as an alternative to biotite from magmas that are enriched in volatile constituents. Brammall and Harwood (1932) suggested that the garnet that is locally present in the Dartmoor granite is derived in some cases from assimilated country rocks. Garnets from granites and pegmatites usually contain a substantial amount of manganese, and Rankama and Sahama (1950) attribute the occurrence of manganese minerals in acid igneous rocks to the high proportion of manganese to iron in the later products of crystallization differentiation. However, the presence of manganese does not necessarily rule out a contamination origin, since the garnets of contact metamorphic rocks (except limestones) are also manganiferous (Tilley, 1926).

The possibility that the garnet in the Donegal granites is derived from assimilated country rocks can be eliminated because the granites that contain garnet are mostly intruded into older non-garnetiferous granites, and are free of xenoliths or other evidence of contamination. In particular the garnetiferous segregations in biotite- or muscovite-granites are completely surrounded by non-garnetiferous rock.

It is obvious from their composition that the garnets must contain most of the manganese in the rock, and the possibility arises that the rocks that contain garnet are particularly rich in manganese. However, three of the rocks have been analysed for manganese (specimens 2–4) and the highest MnO content is only 0·13 %. In view of the fact that these rocks contain nearly 10 % of muscovite it is a little surprising that this small amount of manganese is not accommodated in the muscovite. Muscovite can contain as much as 3·5 % of MnO (Hirowatari, 1957), but the muscovites from specimens 2–4, which have also been analysed, contain only 0·08, 0·09, and 0·06 % of MnO respectively. It may be predicted from Goldschmidt's Rules that the order in which octahedral ions tend to enter the muscovite structure is Al^{3+}–Fe^{3+}–Mg^{2+}–Fe^{2+}–Mn^{2+}. Therefore as the muscovite crystallized the residual magma would become enriched in manganese with respect to iron and magnesium. Christophe-Michel-Lévy (1951) has shown that at a water pressure of approximately 500–700 Kg/cm^2 and a temperature of 700° C pure almandine cannot be synthesized from its constituents, but that if the constituents of spessartine are also present a garnet can be formed. The enrichment of the magma in manganese due to its reluctance to enter the muscovite lattice therefore brings about the formation of garnet, even though the actual amount of manganese is so small that it could easily be accommodated by the muscovite.

The suggestion that muscovite and garnet form as an alternative to biotite under certain conditions is unlikely because the proportion of garnet to muscovite in the garnetiferous muscovite granites is so small that if all the garnet and muscovite were combined to form a mica the product would still have the composition of a muscovite rather than a biotite. The ratio of manganese to iron and magnesium in igneous rocks is highest in the most acid rocks, so that the more common occurrence of garnet in muscovite-granites than in biotite-granites is probably due to the greater probability of the Mn/(Fe+Mg) ratio rising to a garnet-forming level during crystallization of the magma.

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