Petrogenetic implications of garnets associated with lithium pegmatites from SE Ireland

MARTIN P. WHITWORTH*

Department of Geology, Imperial College, London SW7 2BP, U.K.

Abstract

Spodumene pegmatites, aplites and schists from the Aclare Li prospect of SE Ireland host sporadically developed, small, red, euhedral garnets. Chemical data indicate that the pegmatite- and aplite-hosted garnets are rich in spessartine and are similar to garnets in many African Li-rich pegmatites. Partial melting as a source of the garnets is unlikely due to the large spessartine component, the abundance of inclusions within the garnets and the general *P–T–X* evolution of the pegmatite body. It is suggested that an aqueous fluid was exsolved during pegmatite crystallisation and complexed available Mn. Movement of this fluid to the intermediate zone of the pegmatite body produced areas of high Mn concentrations which permitted the crystallisation of spessartine-rich garnets at low pressures (<3 kbar).

KEYWORDS: garnets, lithium pegmatites, manganese, Aclare, Ireland.

Introduction

GARNETS are common in many metamorphic rocks, particularly those of pelitic composition, and skarns, but are not abundant in igneous rocks. They are rarely found in volcanic or mafic rocks but often occur as accessories in peraluminous granites (e.g. Sutherland, 1982), aplites (e.g. Miller and Stoddard, 1981; du Bray, 1988; Harrison, 1989), syenites (e.g. Sutherland, 1982), aplites (e.g. Whitworth and Feely, 1989) and granitic pegmatites (e.g. Černy and Hawthorne, 1982; Manning, 1983; Baldwin and von Knorring, 1983).

The origin of garnets in granitic rocks has long been a subject of debate and was recently reviewed briefly by Stone (1988). Essentially, three modes of origin have been proposed; assimilation of pelitic material (Green and Ringwood, 1968; Allan and Clarke, 1981), high-pressure phenocrysts or xenocrysts transported to higher levels (Green and Ringwood, 1968; Green, 1977) and crystallisation at low pressure from a peraluminous fluid (Miller and Stoddard, 1981). Furthermore, changes in the chemistry of garnets reflect the chemical evolution of the phase from which they crystallised and hence have led to a deeper insight into the origin and evolution of some granitic complexes (e.g. du Bray, 1988; Stone, 1988; Harrison, 1988). The presence and relative proportions of various garnet end-members permit conclusions to be drawn about possible petrogeneses of granitic magma and also the approximate depth of formation. In general, almandine-rich garnets are associated with less well-evolved granitic rocks, possibly generated at greater depths than more evolved granites which contain high-spessartine garnets. This information, combined with stable isotope and fluid inclusion data, may give further insights into the petrogenesis of Li pegmatite magmas. Accordingly, this paper documents the occurrence, distribution and chemistry of garnets hosted by spodumene pegmatites, aplites and schists from the Aclare Li pegmatite prospect, SE Ireland (Fig. 1). Fifty five analyses of garnet were performed on a Cambridge Instruments GeoScan IV microprobe operating in ED mode using an accelerating voltage of 15 kV with a livetime of 100 seconds. Data were automatically reduced using the ZAF4 FLS+ software of Link Analytical Systems. Representative analyses of garnets found in rocks at Aclare are presented in Table 1, along with their formulae calculated on the basis of 24 oxygens. Textural and chemical data are integrated with the results of previous experimental, laboratory and field studies in order to further

---

*Present address: Primary Processes Department, Process Development Group, British Steel Technical, Teesside Laboratories, Middlesbrough TS6 6UB, UK

Mineralogical Magazine, March 1992, Vol. 56, pp. 75–83

Table 1. Representative analyses of garnets from schists (samples 080, 081 and 082), aplites (123 and 124) and garnetiferous spodumene pegmatites (129, 130, 349 and 091). Oxides in wt%, formulae normalised 24 oxygens. Endmember abbreviations: alm = almandine, sp = spessartine, py = pyrope, and = andradite, gr = grossular.

Sample	080	081	082	123	124	129	130	349	091
SiO_2	36.18	36.33	36.43	35.30	34.94	35.53	35.49	35.81	35.60
TiO_2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Al_2O_3	20.54	20.73	20.84	20.14	20.18	20.26	20.43	20.50	20.50
Cr_2O_3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fe_2O_3	nd	nd	nd	nd	nd	nd	nd	nd	nd
FeO	35.62	33.92	34.05	17.39	17.41	11.45	11.09	11.76	12.25
MnO	4.70	5.64	5.59	26.60	25.90	32.19	32.67	31.34	31.24
MgO	2.06	1.96	2.22	0.00	0.00	0.00	0.00	0.27	0.20
CaO	0.73	0.91	1.05	0.37	0.35	0.41	0.25	0.38	0.21
Total	**99.83**	**99.49**	**100.18**	**99.80**	**99.78**	**99.84**	**99.93**	**100.06**	**100.00**
	Number of ions on the basis of 24(O)								
Si IV	5.94	5.96	5.93	5.90	5.89	5.92	5.90	5.93	5.91
Al IV	0.06	0.04	0.07	0.10	0.11	0.08	0.10	0.07	0.09
Al VI	3.91	3.96	3.93	3.86	3.90	3.89	3.91	3.92	3.92
Ti VI	–	–	–	–	–	–	–	–	–
Cr	–	–	–	–	–	–	–	–	–
Fe^{+3}	–	–	–	–	–	–	–	–	–
Fe^{+2}	4.89	4.65	4.64	2.43	2.45	1.59	1.54	1.63	1.70
Mn^{+2}	0.65	0.78	0.77	3.76	3.70	4.54	4.60	4.39	4.39
Mg	0.50	0.48	0.54	–	–	–	–	0.07	0.05
Ca	0.13	0.16	0.18	0.07	0.06	0.07	0.04	0.07	0.04
No anal	7	6	5	5	3	15	3	6	5
Alm%	79.20	76.59	75.64	38.82	39.49	25.68	24.92	26.45	27.52
Sp%	10.58	12.90	12.58	60.13	59.51	73.14	74.36	71.40	71.08
Py%	8.15	7.88	8.80	–	–	–	–	1.07	0.80
And+Gr%	2.07	2.63	2.99	1.05	1.00	1.18	0.72	1.08	0.60

constrain the petrogenesis and *P–T–X* evolution of the Aclare Li deposit as described by Whitworth and Rankin (1989), Whitworth *et al.* (1989), and McArdle and Kennan (1987).

Geological setting

The Leinster Granite is the largest granitic batholith in the British Isles and covers an area >1500 km^2. It is a poorly mineralised granite–granodiorite intrusion comprising five separate plutons, usually termed units (Brindley, 1973), intruded *en echelon* into complexly deformed Lower Palaeozoic metasedimentary and metavolcanic rocks (Brindley, 1973; Brück, 1974; Brück *et al.*, 1979). The Northern Unit was dated at 405 ± 2 Ma by the U–Pb method (O'Connor *et al.*, 1989). Geochemical and isotopic data of Brück and O'Connor (1977) and Davies (1983) have been interpreted as representing fractional crystallisation of a calc–alkaline parent magma. However, Sweetman (1988) considered that partial melting of a Lower Palaeozoic, immature, sedimentary source produced a parental granitic melt which crystallised without further differentiation to form the northern end of the Blackstairs Unit. At the southern end of this Unit, the remaining melt partially crystallised to form a sequence of intrusions with slightly differing SiO_2 contents. A similar petrogenesis was envisaged for the whole of the Leinster Granite (Sweetman, 1988). Five bedrock occurrences of lithium pegmatites are spatially and temporally associated with the Granite and minor tonalite–granodiorite sheets (Steiger and von Knorring, 1974; Scoon, 1978; Luecke, 1981; Whitworth, 1989).

Host rocks comprise complexly deformed Ordovician–Silurian quartz arenites, greywackes, turbidites and volcanics (Brück *et al.*, 1979) which represent the transition from trough to shelf sedimentation followed by repeated turbidite incursions into the trough (McArdle, 1981). A single penetrative fabric is commonplace in the Lower Palaeozoic rocks of SE Ireland but is cut by later, non-penetrative fabrics (McArdle and Kennedy, 1985). Structural patterns now seen in the rocks reflect polyphase deformation determined during the initial D1 and D2 phases. Shearing characterised the D2 phase, as manifested by the activation of the East Carlow Deformation Zone (ECDZ), a major shear zone on the south-eastern

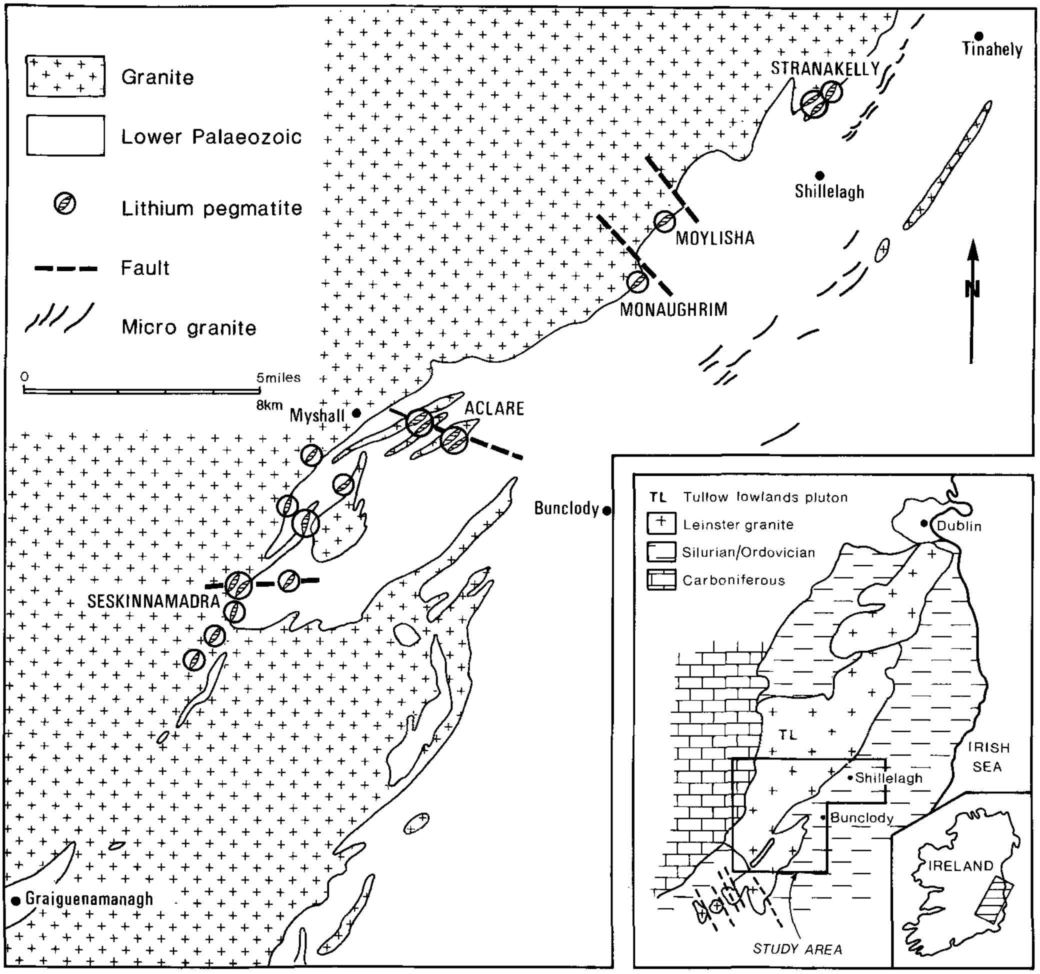

FIG. 1. Geological map of the Leinster lithium pegmatite belt, SE Ireland, showing the five bedrock occurrences of lithium pegmatites (after Brindley, 1973; Brück, 1974; Steiger and von Knorring, 1974; Whitworth and Rankin, 1989).

margin of the Tullow Lowlands Unit of the Leinster Granite (Fig. 1). Within the aureole of the Leinster Granite, the development of the ECDZ is characterised by amphibolite-grade metamorphism, but where the ECDZ is outside the aureole a greenschist-facies regional metamorphism prevailed (McArdle, 1981; McArdle and Kennan, 1987).

Li-bearing pegmatites have been discovered at thirteen localities in SE Ireland (Kennan *et al.*, 1986), of which five are proven bedrock occurrences, namely, Aclare, Seskinnamadra, Stranakelly, Monaughrim and Moylisha (Fig. 1). The largest pegmatite dyke which occurs at Aclare, is *c.* 20 m thick, internally zoned, cut by faults and is partially discordant to the schist–granite boundary (Whitworth and Rankin, 1989). Internal mineralogical zoning is heterogeneous; the outer zones are dominated by quartz–feldspar–muscovite pegmatites which grade into spodumene-bearing lithologies and finally spodumene–quartz pegmatite, quartz–feldspar pegmatite or quartz pods in the core (Fig. 2 of Whitworth and Rankin, 1989). Dykes at the remaining four prospects are composite in nature and all the pegmatites from the belt appear to be unaffected by the East Carlow Deformation Zone (Whitworth, 1989; cf. Steiger and von Knorring, 1974, and Gallagher, 1987). Gallagher (1987) reported a Rb–Sr cooling age of 360 ± 7 Ma for pegmatite from Aclare. The Leinster pegmatites are the only significantly mineralised pegmatite bodies yet found in

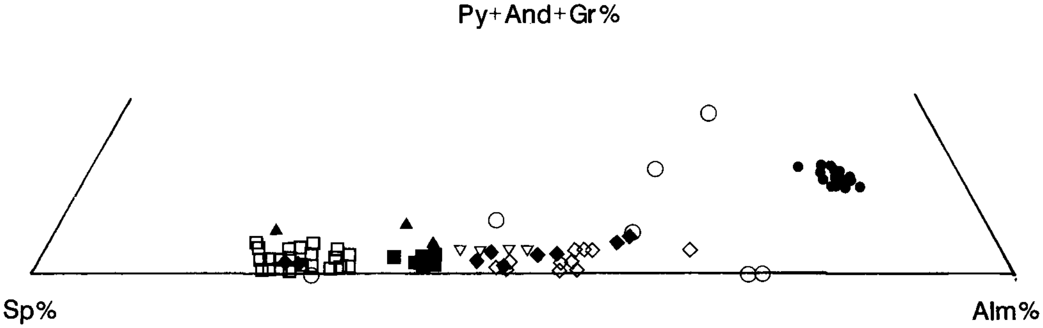

FIG. 2. Ternary plot of the mol.% of almandine (alm), spessartine (sp) and pyrope + andradite + grossular (py + and + gr) for garnets from Aclare and other granites. Aclare: garnetiferous spodumene pegmatite = open square, garnetiferous aplite = filled square, schist = filled circle. Others: Arabian granite (du Bray, 1988) = open circle, Cairngorm (Harrison, 1988) = open diamond, Galway granite and aplite (Leake, 1967) = filled triangle, Thai aplite (Manning, 1983) = filled diamond, Thai pegmatite (Manning, 1983) = inverted triangle.

Ireland (cf. Kennan *et al.*, 1986; Whitworth and Feely, 1989). Microgranite-hosted W–Sn mineralisation, in the form of scheelite with arsenopyrite and fluorite, is spatially associated with the Tullow Lowlands Unit (Gallagher, 1987, 1989) and minor vein-type Pb–Zn deposits also occur in the Northern and Lugnaquilla Units of the Granite (Williams and Kennan, 1983; Kennan *et al.*, 1986).

Garnet petrography and distribution

Garnet occurs in three lithologies at the Aclare pegmatite prospect, namely, garnetiferous spodumene pegmatite, garnetiferous aplite and garnet-bearing schist. The Aclare pegmatite was emplaced in schists which comprise fine- to medium-grained metasediments composed of quartz, muscovite, biotite, tourmaline, chlorite, staurolite, garnet and andalusite. Quartz occurs as idioblastic or angular grains up to 1 mm in diameter with patchy undulose extinction. Muscovite is ubiquitous and usually forms laths up to 3 mm long and 0.3 mm wide with inclusions, commonly of quartz. Biotite crystals are brown and some have hexagonal basal sections. Pyrite crystals up to 3 mm in size, usually in the form of poorly developed cubes, have undergone variable degrees of weathering to Fe-oxides. Poikiloblasts of staurolite with abundant quartz inclusions are common. Tourmaline occurs close (<5 m) to the pegmatite contact; it is typically acicular or lath-shaped, occasionally with rounded margins, brown and up to 5 mm in length. Hypersthene, cordierite and penninite were also noted in detailed studies of the host schists by McArdle (1981). Deep reddish-brown or black garnet porphyroblasts, 1 to 2 mm across, are subhedral to euhedral and commonly have poorly developed quartz pressure shadows. Garnet constitutes 0–6% of the Aclare schists and crystals commonly contain many quartz inclusions. Further details of the field relationships of the Aclare schists are given by McArdle and Kennan (1987).

Mineralised pegmatites (Scoon, 1978; Whitworth and Rankin, 1989) at Aclare are composed of quartz, spodumene, feldspar and muscovite with occasional garnet and accessory apatite and Ta–Nb oxides (Steiger and von Knorring, 1974; Scoon, 1978). Spodumene forms lath-shaped crystals up to 25 cm long, although it is commonly around 10 cm in size. When fresh it exhibits a pronounced cleavage, is white to light green and generally forms approximately 25% of the pegmatite. However, it is often altered to a fine-grained mass of muscovite ± albite. Quartz and albite crystals are also commonly around 10 cm in size, albite often exhibiting incipient sericitisation. Green muscovite phenocrysts up to 4 cm in diameter are subhedral to anhedral and have ragged margins. The pegmatite groundmass generally comprises a fine-grained intergrowth of quartz and feldspar. Garnets within mineralised pegmatites are sparse, but where present are red, subhedral to euhedral, measure up to 15 mm in diameter and contain abundant inclusions of quartz and feldspar. Fracturing of the garnets is ubiquitous, as is incipient alteration along the fractures. Reaction rims are absent. The garnetiferous pegmatites occur within the intermediate zone of the Aclare dyke (Whitworth, 1989; Whitworth and Rankin, 1989).

Garnetiferous aplites occur at the contact of the pegmatite body with the host schists. They comprise albite, quartz, muscovite and garnet and are dominated by lath-shaped albite crystals up to 1 mm in size. Quartz occurs as masses of anhedral crystals, each around 0.1 mm in diameter, or as discrete crystals mutually interlocked with fine-grained albite. Pale green muscovite crystals *c.* 0.5 mm in length are also common. Euhedral, red-brown garnets have diameters of 1–3 mm and make up 1–2% of the rock. Heavy fracturing is apparent in all garnets but reaction rims have not been observed.

Garnet chemistry

Garnet chemistry is, in general, very complicated when viewed as a whole (see Černy and Hawthorne, 1982, for a brief review). Members of the pyralspite series (spessartine–almandine–pyrope) are the most common garnets in granitic rocks (Miller and Stoddard, 1981; du Bray, 1988). Almandine is common in simple pegmatites but spessartine is predominant in Li-rich varieties (Baldwin and von Knorring, 1983), although this does not exclude pyrope or almandine components in many of the garnets hosted by Li-rich pegmatites. Almandine is typically found in regionally metamorphosed argillaceous sediments, along with certain members of the ugrandite series. With increasing metamorphic grade, FeO and MgO substitute for CaO and MnO in the garnet lattice i.e. the mol.% of spessartine and almandine decrease and increase respectively.

Garnets analysed from the Aclare pegmatite body belong to the almandine–spessartine solid-solution series (Table 1). They all comprise at least 88 mol.% almandine + spessartine and in many samples these two end-members make up more than 98% of the garnet (Fig. 2); pyrope constitutes up to 8.88 mol.%. Chemical zoning is absent (cf. Baldwin and von Knorring, 1983). Systematic compositional differences between garnets hosted by the schists, pegmatites and aplites at Aclare have been noted (Fig. 2). Garnets hosted by schists are rich in almandine (up to 79.2 mol.%) with subordinate spessartine, pyrope and andradite. However, garnets from the spodumene pegmatite generally contain over 70 mol.% almandine together with minor andradite; pyrope is low or absent. Aplite-hosted garnets are similar to those in the pegmatites but contain more almandine at the expense of spessartine. Plots of the Aclare garnets in terms of end-members are compared with other granite pegmatite- and aplite-hosted garnets in Fig. 2.

It is apparent that the schist-hosted garnets from Aclare contain the most almandine. Garnets from spodumene pegmatite fall in the field for Li-rich pegmatites of Baldwin and von Knorring (1983), although there is some overlap with the Li-poor pegmatite field. Garnets in the aplite have lower spessartine contents than those of Li-poor pegmatites but higher than most of the aplite- and pegmatite-hosted garnets of Manning (1983). Garnets from the Li-poor Galway Granite, Ireland (Leake, 1967), and Li-poor aplite from Thailand (Manning, 1983), have similar spessartine contents to garnets in the garnetiferous aplites from Leinster. In general, garnets from the Leinster lithium pegmatites have higher spessartine contents than those from Galway or Thailand. Garnets in peraluminous granites from Cairngorm (Harrison, 1988) and the Arabian Shield (du Bray, 1988) contain lower amounts of spessartine than the Aclare pegmatite- and aplite-hosted garnets. These data show that the chemistry of the pegmatite-hosted garnets from Aclare are typical of those in Li pegmatites (cf. Baldwin and von Knorring, 1983). However, the compositions of the Leinster garnets are similar to those found in other pegmatites and aplites which are not necessarily rich in lithium (cf. Leake, 1967; Manning, 1983).

Discussion

The origin of garnets in granitic rocks and lithium pegmatites has long been problematical since many of these rocks were not intruded at the great depths commonly believed to have been responsible for garnet nucleation. Their presence in granitic rocks has allowed some authors to constrain the petrogenesis of the host rocks by relating host rock geochemistry, field and textural relationships to garnet chemistry e.g. Green and Ringwood (1968), Fitton (1972), du Bray (1988) and Stone (1988). Until recently, this has not been the case for Li-rich pegmatites (cf. Baldwin and von Knorring 1983). The Leinster garnet data are assessed firstly in terms of the partial melting of a Li-rich protolith model favoured by McArdle and Kennan (1987 and 1988) and then in the light of the 'magmatic' model of Whitworth and Rankin (1989) and Whitworth *et al.* (1989).

Partial melting model. Pichavant *et al.* (1988) showed that Peruvian macusanite, a natural analogue of Li pegmatite magmas (London *et al.* 1988), was formed by partial melting of crystal material such as altered rhyolitic lavas or argillaceous material. High Li, B and H_2O in this magma imparted great mobility despite its high SiO_2 content. This, together with little evidence for assimilation of other material during ascent, led Pichavant *et al.* (1988) to postulate a rapid rise through the crust. Kennan *et al.* (1986) and McArdle and Kennan (1987, 1988) have proposed a similar model for the generation of the Aclare pegmatite magma. Their model involved an exhalative origin for the Li which was then concentrated by a volcanic-related hydrothermal system. Melting of this coticule/tourmalinite-bearing Lower Palaeozoic lithium-enriched metasediment (McArdle and Kennan, 1988) then gave rise to a H_2O and Li-rich magma which formed the Aclare pegmatite.

Green and Ringwood (1968) showed that almandine is present at liquidus temperatures in rocks of andesitic or dacitic composition derived by partial melting of pelitic sediments at pressures >9 kbar or depths in excess of 25 km. A mol.% of spessartine $<10\%$ indicated that garnet formed at a depth >18 km, but with an increased spessartine component of 20 to 25 mol%, almandine becomes stable at $\leqslant 12$ km depth (Green and Ringwood, 1968; Green, 1977). However, Fitton (1972) pointed out that liquidus garnets formed by partial melting of pelitic sediments are euhedral, contain few inclusions and have less than 10 mol.% spessartine (see also Green and Ringwood, 1968). These characteristics are dissimilar to those of the Aclare garnets which are euhedral, contain abundant inclusions and are *very rich* in *spessartine*, implying that they may not be the products of partial melting. Furthermore, Harrison (1988) postulated that an increased water content in the Cairngorm Granite, Scotland, may have increased garnet stability within the marginal parts of the intrusion. An aqueous phase was certainly present for much of the crystallisation of the Aclare pegmatite (Whitworth, 1989; Whitworth and Rankin, 1989) and played an important role in its development. One such role may have been the assistance of garnet growth through the transfer of material to the nucleation site (cf. Burnham and Nekvasil, 1986). Thus, it is not inconceivable that the Li pegmatites and their garnets may have been the products of crystallisation from a Li- and H_2O-rich magma derived by partial melting of the crust at a depth of around 15 to 18 km.

Garnets may also form by assimilation of material into the magma (e.g. Green and Ringwood, 1968; Allan and Clarke, 1981) but this is an unlikely origin for the Aclare garnets since there is no evidence of assimilation of schistose material in the form of xenoliths, or of disturbances in the isotopic composition of the fluids (Whitworth *et al.*, 1989).

Magmatic model. Fluid inclusion isochore modelling and stable isotope studies have shown that the Leinster Li pegmatite bodies could have been formed by isobaric cooling of a pegmatitic fluid derived from the nearby Leinster Granite at 675 °C and 2.7 kbar (Whitworth and Rankin, 1989; Whitworth *et al.*, 1989), i.e. magmatic in origin, in contrast to the model discussed above. Petrological and isotopic data indicate that the spodumene pegmatites were formed at temperatures <460 °C and at depths <8 km. Fluid-inclusion data combined with studies of the local metamorphic conditions (McArdle, 1981; McArdle and Kennan, 1987) also suggest that the pegmatitic magma could not have formed at depths >15 km (Whitworth and Rankin, 1989). These studies also agree with a previous study of the Leinster pegmatites by Scoon (1978) and with the general pressure constraints for Li pegmatites presented by Černy (1982).

Garnets formed as low-pressure precipitates from peraluminous granitic magmas have features which are very similar to those of the Leinster spodumene pegmatite- and aplite-hosted garnets, i.e. euhedral shape, lack of reaction rims, mol.% spessartine $>10\%$ and hosted by chemically evolved rocks (cf. Leake, 1967; Manning, 1983; Baldwin and von Knorring, 1983; du Bray, 1988; Harrison, 1988; Stone, 1988; Whitworth and Feely, 1989). Many spodumene-pegmatite-hosted garnets have very high spessartine (Table 1 and Fig. 2), a feature that Baldwin and von Knorring (1983) consider is only achieved in Li-rich pegmatites. However, a few garnets from the Li-poor Galway Granite and Thailand also have high spessartine contents (Leake, 1967; Manning, 1983; Fig. 2), although these garnets do not appear to be typical of the garnet populations from these intrusions as a whole. Baldwin and von Knorring (1983) also noted crystallisation temperatures as low as 550 °C for garnets in the Rosendal pegmatite, Finland. Crystallisation temperatures for pegmatite- and aplite-hosted garnets have not been determined for the Leinster samples but oxygen isotope crystallisation temperatures of 392 to 642 °C were obtained for barren pegmatites in the Leinster pegmatite belt (Whitworth *et al.*, 1989). Slightly lower temperatures are envisaged for the spodumene pegmatites (Whitworth, 1989; Whitworth *et al.*, 1989). Aplite at the contact of the Aclare pegmatite is believed to have formed at around 675 °C (Whitworth, 1989). Thus, those chemical and textural features described above, in combination with *P–T* studies, indicate that the Aclare garnets formed as a result of low-pressure crystallisation from the Li-rich pegmatitic melt.

In addition to increased garnet stability at lower pressures (Green, 1977), increased Mn concentrations in the garnet suggest a Mn-rich medium in which crystallisation occurred. The sparse development of garnet in both pegmatite and aplite indicate that the areas of Mn enrichment were relatively uncommon, a conclusion backed up by the low overall MnO contents of the Aclare pegmatites (Luecke, 1981; Whitworth, 1989). A mechanism to explain the localised presence of garnets in silica-rich magma chambers was proposed by Hildreth (1981). This model involves hydroxyl complexing of Mn in an ascending fluid phase to produce discrete areas of Mn enrichment in the roof zone of the magma chamber. This mechanism may also explain the local concentrations of spessartine since the evolution of this pegmatite body was characterised by the generation of an aqueous phase (Whitworth, 1989). This fluid promoted the coarse grain size (cf. Fenn, 1986) and allowed transport of material to the crystallisation fronts (cf. Burnham and Nekvasil, 1986). Aqueous fluid released during the evolution of the pegmatitic melt is believed to have complexed available Mn and transported it to the nucleation sites, possibly as chloride- or silica-rich complexes discussed by Burnham and Nekvasil (1986). This process locally increased the Mn content of the fluid allowing garnets to crystallise while the chemistry of the melt as a whole evolved (Whitworth, 1989). A similar model for the occurrence of garnets in the marginal portions of the Cairngorm Granite, Scotland, was proposed by Harrison (1988), who also noted that biotites coexisting with spessartine-rich almandines were Mn-rich.

According to Černy and Hawthorne (1982) and Baldwin and von Knorring (1983), increasing chemical evolution of a pegmatite fluid produced increasingly Mn enriched and Fe depleted garnets within the pegmatite. Whitworth (1989) considered that aplite at the margin of the Aclare pegmatite was the first rock to crystallise in the body. Garnets within this zone have much lower Mn than those formed during the later stages of spodumene pegmatite crystallisation (Table 1), suggesting that the aplite was not as chemically fractionated as the Li pegmatite. A similar trend was observed by Baldwin and von Knorring (1983) for African granite pegmatites where garnets in the marginal zones were Mn-poor, whereas those in the core were Mn-rich, having spessartine >90 mol.%.

Conclusions

Within the internally zoned Aclare pegmatite body, garnets are confined to garnetiferous spodumene pegmatites, garnetiferous aplite and the surrounding schists. In general, the garnets are between 5 and 15 mm in diameter, red or red-brown, euhedral and contain many inclusions, usually of quartz. They are all members of the almandine–spessartine solid-solution series. Schist-hosted garnets contain around 75 mol.% almandine, 11 mol.% spessartine, 8 mol.% pyrope and 2 mol.% andradite. Garnets in pegmatite and aplite have much higher spessartine contents, generally >60 mol.%, and lower almandine (<40 mol.%); pyrope and andradite components are negligible. The garnets are very similar in composition to those in other Li pegmatites and aplites from Africa and Thailand. The lack of reaction rims, euhedral shapes and spessartine >50 mol.% suggest that the garnets hosted by pegmatite and aplite were formed by low pressure crystallisation from a Li–H_2O-rich pegmatitic fluid.

It is suggested that exsolution of an aqueous phase from the melt complexed available Mn and transported it to the intermediate zone of the Aclare body (Whitworth and Rankin, 1989), raising the Mn concentration locally and permitting garnet crystallisation. Similar models were invoked by Hildreth (1981) and Harrison (1988) to explain the presence of Mn-rich caps to magma chambers and garnets in marginal zones of granite intrusions. These data are also compatible with the *P–T–X* model developed for the pegmatites by Whitworth (1989), Whitworth and Rankin (1989) and Whitworth *et al.* (1989). It is unlikely that the garnets were formed by localised partial melting of the crust, but it is important to note that it is still unclear as to whether the pegmatite melt itself was formed by this process and then underwent further evolution (cf. Whitworth, 1989; Whitworth, in preparation). These data are compatible with a magmatic origin for the pegmatite and aplite-hosted garnets.

Acknowledgements

I would like to thank Mr John Clifford of ENNEX International plc for permission to sample the drill-core and for encouragement throughout this project. I am also indebted to Mr Nick Royall (Imperial College) for assistance with microprobe analyses and Dr Andy Rankin for supervising the project. Dr Mike Fowler (Oxford Polytechnic) kindly reviewed an earlier draft of the manuscript. Discussions of certain aspects of this work with Drs Dave Manning (Manchester University), Dave Alderton (RHBNC), Peadar McArdle (Geological Survey of Ireland) and Padraig Kennan (University College, Dublin) are also appreciated, as are the comments of the anonymous reviewers which helped to improve the manuscript considerably. This study was performed in the Geology Department, Imperial College, University of London, during the tenure of an NERC research studentship.

References

Allan, B. D. and Clarke, D. B. (1981) Occurrence and origin of garnets in the South Mountain batholith, Nova Scotia, Canada. *Can. Mineral.* **19**, 19–24.

Baldwin, J. R. and von Knorring, O. (1983) Compositional range of Mn-garnet in zoned granitic pegmatites. Ibid. **21**, 683–8.

Brindley, J. C. (1973) The Structural setting of the Leinster granite, Ireland. *Sci. Proc. R. Dublin Soc.*, Ser. A5, 27–36.

Brück, P. M. (1974) Granite varieties and structures of the Northern and Upper Liffey Valley Units of the Leinster batholith. *Bull. Geol. Surv. Ireland*, **1**, 381–94.

—— and O'Connor, P. J. (1977) The Leinster batholith: geology and geochemistry of the northern units. Ibid. **2**, 107–42.

—— Colthurst, J. R. J., Feely, M., Gardiner, P. R. R., Penney, S. R., Reeves, T. J., Shannon, P. M., Smith, D. G., and Vanguestaine, M. (1979) Southeast Ireland: Lower Palaeozoic stratigraphy and depositional history. In *The Caledonides of the British Isles—Reviewed* (Harris, A. L., Holland, C. H., and Leake, B. E., eds). Scottish Academic Press, 533–44.

Burnham, C. W. and Nekvasil, H., (1986) Equilibrium properties of granite pegmatite melts. *Am. Mineral.* **71**, 239–63.

Černy, P. (1982) Anatomy and classification of granitic pegmatites. In *Short course in granitic pegmatites in science and industry* (Černy, P., ed), Mineralogical Association of Canada **8**, 1–40.

—— and Hawthorne, F. C. (1982) Selected peraluminous minerals. Ibid. 163–8.

Davies, G. R. (1983) *The isotope evolution of the British lithosphere.* Unpubl. Ph.D. thesis, Open University.

du Bray, E. A. (1988) Garnet compositions and their use as indicators of peraluminous granitoid petrogenesis—southeastern Arabian Shield. *Contrib. Mineral. Petrol.* **100**, 205–12.

Fenn, P. M. (1986) On the origin of graphic granite. *Am. Mineral.* **71**, 325–30.

Fitton, J. G. (1972) The genetic significance of almandine–pyrope phenocrysts in the calcalkaline Borrowdale volcanic group, Northern England. *Contrib. Mineral. Petrol.* **36**, 231–48.

Gallagher, V. (1987) *Tourmaline-bearing rocks and granite-related metallogenesis in SE Ireland.* Unpubl. Ph.D. thesis, Nat. Univ. Ireland.

—— (1989) Geological and isotope studies of microtonalite-hosted mineralization in SE Ireland. *Mineral. Deposita*, **24**, 19–28.

Green, T. H. (1977) Garnet in silicic liquids and its possible use as a *P-T* indicator. *Contrib. Mineral. Petrol.* **65**, 59–67.

—— and Ringwood, A. E. (1968) Origin of garnet phenocrysts in calc-alkaline rocks. Ibid. **18**, 163–74.

Harrison, T. N. (1988) Magmatic garnets in the Cairngorm granite, Scotland. *Mineral. Mag.* **52**, 659–68.

Hildreth, W. (1981) Gradients in silicic magma chambers: implications for lithospheric magmatism. *J. Geophys. Res.* **86**, 10153–92.

Kennan, P. S., McArdle, P., Williams, F. M., and Doyle, E. (1986) A Review of metal deposits associated with the Leinster granite, SE Ireland and a model for their genesis. In *Geology and genesis of mineral deposits in Ireland* (Andrews, C. J. *et al.*, eds), I.A.E.G., Dublin, 201–10.

Leake, B. E. (1967) Zoned garnets from the Galway granite and its aplite. *Earth Planet. Sci. Lett.* **3**, 311–6.

London, D., Hervig, R. L., and Morgan, G. B. (1988) Melt-vapour solubilities and elemental partitioning in peraluminous granite-pegmatite systems: experimental results with Macusani glass at 200 MPa. *Contrib. Mineral. Petrol.* **99**, 360–73.

Luecke, W. (1981) Lithium pegmatites in the Leinster granite (southeast Ireland). *Chem. Geol.* **34**, 195–233.

Manning, D. A. C. (1983) Chemical variation in garnets from aplites and pegmatites, peninsular Thailand. *Mineral. Mag.* **47**, 353–58.

McArdle, P. (1981) The Country rocks flanking the Leinster granite between Aughrim and Ballymurphy. *Bull. Geol. Surv. Ireland*, **3**, 85–95.

—— and Kennan, P. S. (1987) The distribution, genesis and potential of tungsten, lithium and associated metal deposits in the SE margin of the Leinster Granite. Ibid. **4**, 27–40.

—— —— (1988) Controls on the occurrence and distributions of tungsten and lithium deposits on the southeast margin of the Leinster Granite, Ireland. In *Mineral deposits of the European Community* (Boissonnas, J. and Omenetto, P. eds), Spec. Pub. No. 6, Soc. Geol. Appl. Min. Dep., Springer-Verlag, Berlin, 199–209.

—— and Kennedy, M. J. (1985) The East Carlow deformation zone and its regional implications. *Bull. Geol. Surv. Ireland*, **3**, 237–55.

Miller, C. F. and Stoddard, E. F. (1981) The role of manganese in the paragenesis of magmatic garnet: an example from the Old Woman-Piute range, California. *J. Geol.* **89**, 233–46.

O'Connor, P. J., Aftalion, M., and Kennan, P. S. (1989) Isotopic U–Pb ages of zircon and monazite from the Leinster Granite, southeast Ireland. *Geol. Mag.* **126**, 725–28.

Pichavant, M., Kontak, D. J., Briqueu, L., Valencia Herrera, J., and Clark, A. H. (1988) The Miocene–Pliocene Macusani Volcanics, SE Peru 2. Geochemistry and origin of a felsic peraluminous magma. *Contrib. Mineral. Petrol.* **100**, 325–38.

Scoon, R. N. (1978) *Lithium pegmatites in the Leinster granites of southeast Ireland.* Unpubl. M.Sc. thesis, Univ. College, Cardiff.

Steiger, R. and von Knorring, O. (1974) A lithium pegmatite belt in Ireland. *J. Earth Sci., Leeds Geol. Assoc.* **8**, 433–43.

Stone, M. (1988) The significance of almandine garnets in the Lundy and Dartmoor granites. *Mineral. Mag.* **52**, 651–8.

Sweetman, T. M. (1988) The Geochemistry of the Blackstairs Unit of the Leinster granite, Ireland. *J. Geol. Soc.* **144**, 971–84.

Sutherland, D. S. (1982) Alkaline intrusions of northwest Scotland. In *Igneous rocks of the British Isles* (Sutherland, D. S., ed.), Wiley, 203–14.

Whitworth, M. P. (1989) *Magmatic and hydrothermal processes during petrogenesis and lithium mineralisation of granite pegmatites of SE Ireland.* Unpubl. Ph.D. thesis, Imperial College, Univ. of London.

—— and Feely, M. (1989) The geochemistry of selected pegmatites and their host granites from the Galway Granite, western Ireland. *Ir. J. Earth Sci.* **10**, 89–97.

—— and Rankin, A. H. (1989) Evolution of fluid phases associated with the lithium pegmatites of SE Ireland. *Mineral. Mag.* **53**, 271–84.

—— Rankin, A. H., and Spiro, B. (1989) Diverse fluid phases associated with the crystallisation and alteration of lithium pegmatites at Moylisha and Stranakelly, SE Ireland. In *Water–Rock Interaction WRI-6, Proceedings of the Sixth International Symposium, Malvern, UK* (Miles, D. L., ed.), 769–72.

Williams, F. M. and Kennan, P. S. (1983) Stable isotope studies of sulphide mineralization on the Leinster granite margin and some observations on its relationship to coticule and tourmalinite rocks in the aureole. *Mineral. Deposita*, **18**, 399–410.

[*Manuscript received 2 April 1991; revised 10 June 1991*]