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Zoning in garnets from the mainland Lewisian

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ABSTRACT. Two types of zoning are found in garnets from Lewisian rocks. One is due to retrogression of an earlier homogeneous garnet while the other results from growth (or equilibration) during falling temperatures. Both zoning patterns result from metamorphism during or after the Dionard tectonic phase of the Laxfordian event.

ZONING in garnets is a common phenomenon (Hollister, 1969; Edmunds and Atherton, 1971 and many others) and has been reported in garnets from some Lewisian rocks (Josey and Shaw, 1974; Wood, 1975). The pattern described by the latter authors is a two-stage growth model with early Mg-rich garnet cores giving way to late marginal increases in Fe and Ca. This zoning pattern differs from what has been termed 'normal' zoning where Mn is enriched in the garnet centre relative to the rims, and with Fe and Mg showing a reverse tendency. However, variations of, and deviations from, this 'normal' pattern are common. This is particularly true of garnets from rocks which have been subjected to polymetamorphism, or other P–T regimes, or are lithologically different from the pelitic assemblages that are usually studied. The garnetiferous rocks of the Lewisian complex are therefore significant since they differ on all points. Garnets, occurring in a variety of structural settings and environments of metamorphic mineral growth, were collected and analysed for zoning using a Cambridge Instrument Geoscan microanalyser. Analytical procedure was that described by Smellie (1972).

Geological setting

The crystalline rocks of the Kylesku–Loch Inchard area consist of pyroxene granulites of the Kylesku group to the south (Khoury, 1968; Bowes and Hopgood, 1973) and amphibolite-facies gneiss of the Rhiconich group to the north (Dash, 1969; Chowdhary and Bowes, 1972). The former were metamorphosed in the Badcallian (= early Scourian) event, about 2700 Ma (Moorbath *et al.*, 1969), while isochrons of 2850 Ma (Lyon and Bowes, 1977), obtained from the latter area, suggest that it is of equivalent age. Common in the area are numerous NW-trending tholeiitic dykes which are considered by many workers (Sutton and Watson, 1951*a*; Tarney, 1963; Park, 1970; Evans and Lambert, 1974) to represent a single intrusive event (2200–1900 Ma). This time marker can therefore be used to differentiate pre- from post-dyke episodes. The dykes are considered to have intruded hot country rock in the waning stages of the Inverian (= late Scourian) event, about 2400–2200 Ma.

Much of the area has been subjected to extensive tectonic overprinting and metamorphism. Rocks of the Rhiconich group display widespread evidence of the post-dyke Laxfordian event, 1850 Ma (Lambert and Holland, 1972) while the Kylesku group rocks are cut locally by small discontinuous monoclinal shear zones of both Inverian and Laxfordian age (Beach, 1973). At the junction with the Rhiconich group, the pyroxene granulites are retrogressed in a wide zone of highly deformed and steeply dipping rocks. The age of this 'steep belt' structure is problematical (Davies, 1976, 1978; Lyon *et al.*, 1975; Evans and Lambert, 1974) but within it evidence of the Inverian and Laxfordian events is widespread (Park, 1970).

Description of samples

Specimens from the Kylesku group granulites. Petrographic studies (Kerr, 1974; O'Hara, 1977, 1978) indicate that garnet in the granulites shows a complex history of initial growth, absorption at high pressures and temperatures *within* the granulite facies and subsequent regrowth. Garnets corresponding to each of these events were analysed and no zoning was found. This was not unexpected and consistent with results in the literature (Hollister, 1969; Anderson and Buckley, 1971; Woodsworth, 1977). Faint zoning was found in one garnet type from Kylesku-group rocks. These occur as veins of cracked and broken crystals or groups of crystals, up to 6 mm in extent, which cut the flat-lying Badcallian foliation at high angles (NC 145437). Their exact time relationship to the above growth sequence is unknown; but from core chemical compositions (Kerr, 1974) and textural relations, it is highly probable that they are late-Badcallian in age. Further, the garnets are cut by carbonate and quartz veins and later microjoints along which there is much evidence of fluid movement. Alteration to biotite and chlorite is common as is granulation of the garnet edges.

Specimens from the tholeiitic dyke suite. Garnet is common in unsheared dyke margins (O'Hara, 1961) and one of these was sampled (NC 145438). A relict igneous texture persists in the rock and is defined by plagioclase laths (An_{38}) with dusted and clouded cores surrounded by clear margins. The crystals are bent and strained. Clinopyroxene is rare, the mafic mineral being strongly pleochroic amphibole. The garnet occurs as large irregular and fractured porphyroblasts with inclusions of altered plagioclase and amphibole. The indistinct and altered margins of the garnet suggest that it is breaking down. Garnet in the 'type' Scourie dyke (NC 146458) occurs in horizontal veinlets (Sutton and Watson, 1951*b*; Tarney, 1973; Dickinson and Watson, 1976). The groundmass of the dolerite retains an igneous texture with relict clinopyroxene cores mantled by green amphibole and ore. Plagioclase (An_{36}) is quite fresh although commonly bent. Within the veinlet this igneous texture is absent, being replaced by patches of shapeless fragmented garnet with inclusions of biotite, amphibole, and clinopyroxene. These garnets are set in a fine-grained groundmass of quartz, biotite, amphibole, ore, carbonate, and serpentine. Many of these phases appear to be breakdown products after garnet.

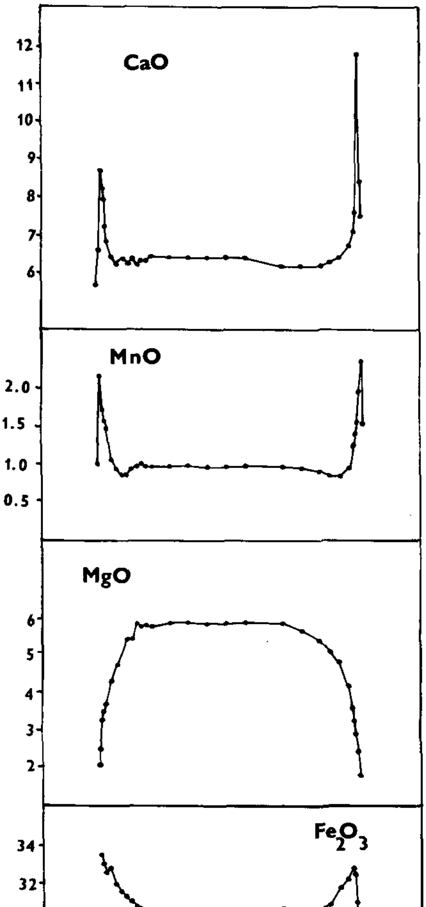

FIG. 1. Best-developed example of zoning in garnets from south of Laxford front (specimen from 'steep belt').

Specimens from the 'steep belt'. Only one sample (NC 204469) from the 'steep belt' contained zoned garnets. It was collected from a pre-Badcallian layered basic to ultrabasic igneous body (Davies, 1976). Although the rock retains a granulite-facies polygonal texture, it exhibits amphibolite-facies mineralogy pseudomorphing the original assemblage (Evans and Lambert, 1974; Beach and Tarney, 1978). The matrix consists of plagioclase (An_{38}) which is frequently zoned (normal), strained and shows marginal alteration to sericite close to garnet. Hornblende occurs as clusters of small bladed grains in which rare relict clinopyroxene cores persist. Orthopyroxene is not present. The garnet is xenoblastic, contains altered plagioclase, hornblende, and clinopyroxene. It is cut by numerous thin veins, many containing hornblende. Petrographic work together with field evidence (Sutton and Watson, 1951*a*; Kerr, 1974; Dickinson and Watson, 1976; Davies and Watson, 1977) have shown that this lithology is a partially retrogressed equivalent of the garnetiferous basic granulite near Scourie and that the garnets are relict granulite facies grains (Beach, 1973).

Specimens from the Rhiconich group. Two samples of garnetiferous amphibolite (cf. Davies and Watson op. cit.) were obtained from the Hunterian museum, University of Glasgow (NC 217534 and NC 213541). Both show identical mineralogy with bright-green hornblende, containing ore and feldspar inclusions, as the dominant mafic phase. Pale-green diopside shows marginal alteration to hornblende. Plagioclase (An_{42}) is often zoned and sericitized next to garnet. The latter is xenoblastic and contains inclusions, mainly of quartz but also of hornblende, clinopyroxene, rutile, and plagioclase. These inclusions generally increase in size and amount towards the garnet margin indicating syn- to post-tectonic growth of garnet. Textural relationships between the garnet margins and the other phases favour the latter interpretation i.e. growth under static metamorphic conditions.

Zoning patterns

Two distinct zoning patterns are found in Lewisian garnets. Zoned garnets from south of the Laxford front (Beach *et al.*, 1973) have Mg-rich cores with Fe, Mn, and Ca increasing within the last 200–300 μm of the crystal margins (fig. 1). In contrast garnets from the Rhiconich group have Ca-rich cores with the other elements behaving antipathetically (fig. 2).

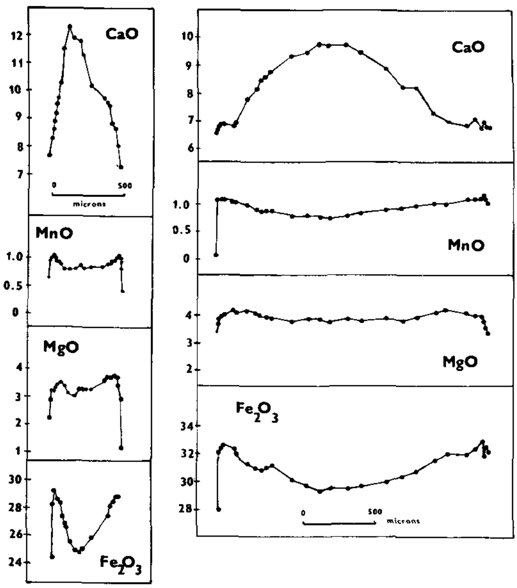

FIG. 2. Zoning in garnets of Laxfordian age from Rhiconich group. (*a*) left and (*b*) right.

Discussion

Despite the fact that they come from a variety of structural environments, garnets with Mg-rich cores show a consistency in that garnet, in each case, is a disappearing phase. The extent of breakdown varies from slight to extensive and this can be directly correlated with the degree of zoning. Also, the profiles display a marked similarity for Fe, Mg, and Mn to those described by Grant and Weiblen (1971) for resorption of an initially homogeneous garnet during retrogression. Garnets from basic granulite of the Kylesku group are unzoned and it can be shown that two of the above zoned garnets are related to such garnets. It is not known, however, whether the garnets from the Scourie dyke suite were initially homogeneous, but it is suggested from several lines of evidence that this is highly probable. The zoning in these garnets is confined to the marginal 50–100 μm of a total crystal width of 1500 μm. Also it has been suggested that *P–T* conditions during dyke intrusion were considerably greater than 500–600 °C and 7 kb (Dickinson and Watson, 1976). It would be expected that garnets formed under these conditions would be unzoned (Tracy *et al.*, 1976; Woodsworth, 1977). Therefore it is suggested that all the zoned garnets from south of the Laxford front display a double growth history, with initially homogeneous garnet becoming zoned during later resorption as suggested by Grant and Weiblen (op. cit.). However, the profiles given by the latter authors and Amit (1976) differ from the present data in that their garnets not only do not display the strong marginal enrichment of CaO seen in the Lewisian garnets, but show a slight tendency towards higher Ca cores. In the present study the degree of Ca enrichment can be directly related to degree of retrogression. Also it is well documented that Ca profiles of zoned garnets frequently show no relationship to those of the other elements, often being controlled by a separate garnet–plagioclase equilibrium (Crawford, 1974, 1977). Further, Beach (1973) and Beach and Tarney (1978) have shown that Ca was highly mobile during retrogression of these rocks.

The second zoning pattern with high core values of CaO is found in rocks north of the Laxford front where garnet was growing and the higher grade clinopyroxene–plagioclase assemblage being replaced by a garnet–amphibole–quartz one. Similar zoning profiles, reported by Kurat and Scharbert (1972), were ascribed to continuous garnet growth or equilibration with falling temperature, and this conclusion would be consistent with the present results. Several garnets in each sample were analysed and while core values differed (? cut effect) all displayed the same zoning pattern.

Thus both zoning patterns originated with decreasing temperature. In the context of Lewisian mineral chronology it is difficult to prove when these patterns developed. Nevertheless enough time relationships are known and some circumstantial evidence can be used to suggest that both patterns are related to the same metamorphic event.

All the garnets displaying Mg-rich cores initially grew at different times. However, if one accepts a single dyke suite and since garnets in the latter are affected, the retrogressive event must be Laxfordian in age. Also, garnets from dyke margins are usually destroyed in the narrow Laxfordian shear belts (O'Hara, 1961; Park, 1970; Beach, 1973); and, since the zoning pattern is best developed in the garnet from the 'steep belt', where these narrow shear belts coalesce, and show greatest intensity, it appears that the retrogression leading to zoning, in the garnets, is due to this event (Dearnley, 1962, 1963; Park, op. cit.). Thus proximity to one of the shear zones, or the 'steep belt', is the controlling factor in the degree of development of the style of zoning. Beach *et al.* (1973) defined this post-dyke event in the Kylesku group as the F2 deformation, which Dickinson and Watson (op. cit.) correlated with the Dionard (F3) phase of large NW–SE asymmetrical folds in the Rhiconich group (Bowes and Hopgood, 1973). During the final parts of F3 and post-dating this tectonic phase, granites and pegmatites were intruded into the axial zones of these folds, and caused an influx of heat into the northern region (Dash, 1969; Lyon and Bowes, 1977). It is suggested that garnet growth in the Rhiconich amphibolites occurred at the peak and towards the close of this event. This would explain the relationship of garnet-bearing assemblages with these structures (Dickinson and Watson, op. cit., p. 371) and the static nature of the garnet growth. Further it is in agreement with the known Laxfordian mineral chronology of the area whereby later events show little new mineral growth (Lyon and Bowes, op. cit.).

Thus it appears that the garnets with Mg-rich cores were retrogressed early in the Dionard tectonic and metamorphic event and their Ca rim values increased as the garnets equilibrated to the new physical and chemical conditions. About this time, in response to elevated temperatures, garnet began to grow in Rhiconich amphibolites with high-Ca core values. It is suggested that although both groups of zoned garnets attempted to equilibrate to similar metamorphic conditions, the retrogressed garnets subsequently broke down as shearing and metasomatism increased in intensity in the shear zones; while garnets with high-Ca core values continued to grow, or equilibrate, to a slowly cooling environment.

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