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CHEMICAL ZONING IN GARNETS OF THE KASHABOWIE GROUP, SHEBANDOWAN, ONTARIO

DIETER BIRK
McMaster University, Hamilton, Ontario

Abstract

The Kashabowie Group sediments are progressively metamorphosed in the amphibolite facies and contain chemically zoned almanditic garnets. The mode of MnO and FeO zonation in the garnets up grade is anomalously inverse to the sense of zoning in the down grade areas. Inverse zoning is attributed to retrograde metamorphism, causing partial garnet resorption and MnO migration. CaO zonation does not show an inversion due to the larger Ca^{2+} ion radius.

Introduction

Cryptic compositional zoning in garnets has been demonstrated for a variety of mineral assemblages and metamorphic grades (see references). Chemical zoning records the physical and mineralogical environment of crystallization and its preservation indicates that diffusion within the solid garnet must have been absent or incomplete. Chemical profiles, obtained by Edmunds & Atherton (1971), suggest that even several subsequent metamorphic events may not be sufficient to homogenize the garnets.

The Kashabowie Group at Shebandowan, Ontario, provides a schist-gneiss-migmatite terrain abundant in almanditic garnet. Cryptic zonation in the garnets was investigated as part of a study of progressive metamorphism. Microprobe traverses are reported which show a marked change in the mode of chemical zonation, as samples are taken progressively up grade.

Geology of the Shebandowan Area

The study area lies north of the town of Shebandowan, 80 miles west of Thunder Bay, Ontario, and straddles an east-west trending belt of Archean metagreywackes, named the Kashabowie Group (Perdue 1938). A logging road (GLP Road 511) provides a north-south traverse (Fig. 1). The northern boundary of the metasediments is in gradational contact with a white granitoid ("granitoid" as defined by Marmo 1971) ; to the south lie metavolcanics (Morin 1972).

The lithology of the Kashabowie Group changes northward from metagreywacke to biotite schist, biotite paragneiss, and finally to migmatite. The microscopic texture grades from lepidoblastic phyllite in the south through granoblastic paragneiss in the north, with an increase in grain size of both matrix and porphyroblasts northward. Thin section studies (Birk 1971) reveal the presence of one or more metamorphic index minerals (staurolite, cummingtonite, sillimanite) in a quartzofeldspathic matrix, indicating progressive metamorphism in the amphibolite facies, from the staurolite-almandine subfacies in the south to the sillimanite-almandine-orthoclase subfacies in the north.

Pale pink porphyroblastic garnet accounts for up to 5% of rock modes. Idioblasts in phyllites and pelitic schists disappear further northward, then reappear as xenoblasts with embayments and numerous quartz inclusions. The absence of garnet corresponds with an abundance of hornblende or homoaxial intergrowth of hornblende and cummingtonite and is interpreted as due to an inappropriate bulk composition rather than any variation in metamorphic grade. The average composition of garnet rims was determined

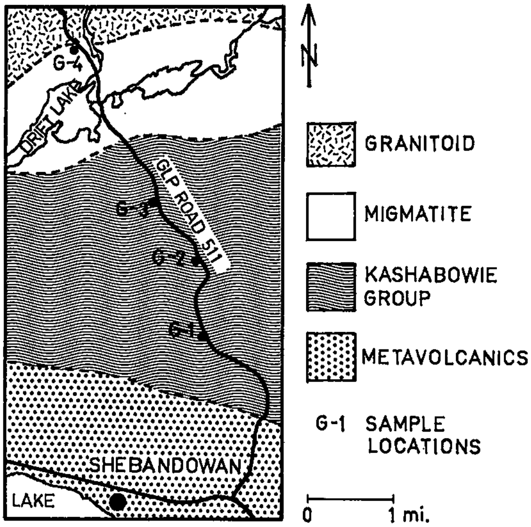


Fig. 1. Location map for garnet samples: Shebandowan is 80 miles west of Thunder Bay, Ontario, Canada. Sample numbers increase with increasing regional metamorphic grade.

to be: almandine 68.5%, grossular 6.8%, pyrope 5.2%, and spessartine 19.5%. Modal determinations (Birk 1971) suggest that the spessartine concentration varies inversely with the abundance of garnet in the host rock.

Probe analyses of six garnets from four locations along the GLP Road 511 are presented in this paper, with sample numbers increasing to the north (Fig. 1). Garnet G-1 is from metagreywacke; G-2a, G-2b, and G-3 are from biotite schist; G-4a and G-4b are from the paragneiss fraction of a lit-par-lit injection gneiss. The garnet pairs G-2a, G-2b and G-4a, G-4b are from the same polished sections, corresponding to sample locations G-2 and G-4 respectively.

ANALYTICAL PROCEDURES

An ARL Model AMX electron microprobe was used to obtain point analyses, at 25 micron intervals or less, along the diameters of garnet porphyroblasts. The largest crystals in each polished section were selected, to ensure that the traverses intersected close to centers, thus giving the greatest chemical variation. Elements were determined in pairs, with iron (treated as divalent) and calcium in one run, and magnesium and manganese in another. Care was taken to duplicate the traverses, but the best correlation should occur within these chemical pairs. Inclusions were recognized optically or by cathodoluminescence, and readings at such stations were eliminated. The data have not been corrected for absorption, atomic number, or fluorescence effects, as it was felt that the use of a garnet standard would suffice to reveal any compositional trends. The standard (S-76) is an unzoned garnet of known composition: SiO_2 = 39.0, Al_2O_3 = 22.0, Fe_2O_3 = 0.75, FeO = 21.26, MgO = 11.53, CaO = 4.20, MnO = 0.50, TiO_2 = 0.08 wt. %.

DISCUSSION

Going northward, garnets of the Kashabowie Group show a startling variation in the mode of cryptic zonation (Figs. 2, 3, 4, 5, 6, 7). The sense of MnO and FeO zoning in the northern garnets is inverse to that in the southern garnets.

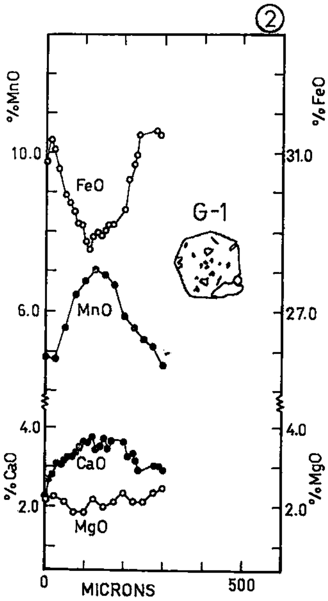
In the lowest grade garnet, G-1, MnO and CaO decrease continuously from core to rim, and FeO increases. The MgO readings give a shallow, erratic profile. These results are compatible with the simple concave-convex profiles found by Harte & Henley (1966) and others, and for the sake of this discussion, are considered the normal mode of zoning in garnets. Minor deviations are attributed to inclusions or fractures. Harte & Henley (1966) suggested that such zonation records crystal growth during rising temperatures — as metamorphic grade increases during growth, Fe^{2+} and Mg^{2+} are increasingly stabilized in the garnet structure. Alternatively, they proposed fractionation of MnO from the host rock, as MnO is depleted immediately adjacent to the growing garnet. Hollister's (1966) calculations, based on the Rayleigh fractionation model, support this hypothesis but require that, during garnet growth, the matrix be free from any compositional gradient. This dictates a growth rate sufficiently slow to allow complete diffusion of nutrients in the host rock.

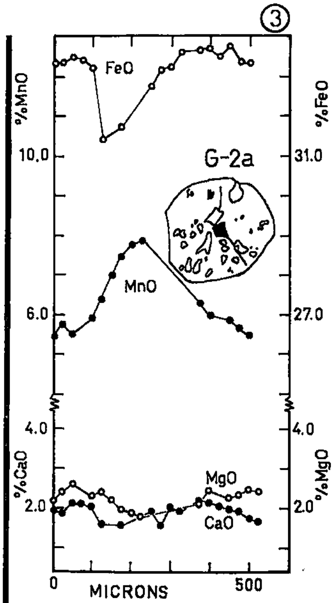
Garnets G-2a and G-2b both show the normal MnO trends near garnet cores (Figs. 3, 4) but for G-2b, MnO shows an inverse trend over the outer 75 microns. Over this same distance, FeO zoning is antipathic to MnO zoning. FeO readings near the core of G-2b give a shallow profile. CaO and MgO profiles for both G-2 garnets are shallow and erratic.

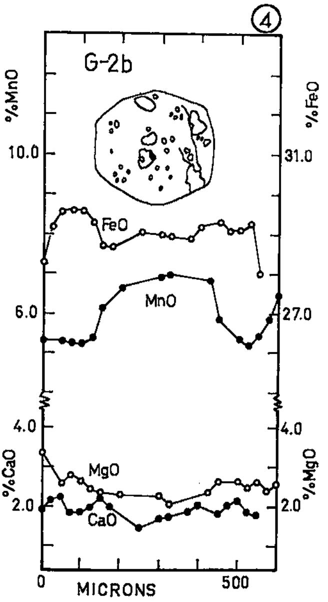
MnO enrichment, in the outer few microns, has been reported by several authors (Chinner 1962; Edmunds & Atherton 1971), generally in regional metamorphic garnets which suffered subsequent thermal metamorphism. To explain the increase in MnO, Edmunds & Atherton (1971) invoked a continuously decreasing growth rate near the termination of garnet growth. The abundance of inclusions in garnets G-2a and G-2b (see insets, Figs. 3, 4) points to rapid growth leading to rapid nutrient depletion, therefore suggesting the presence of compositional gradients immediately adjacent to the growing garnet (contrary to Hollister's 1966 model). The mechanism of decreasing growth rate would therefore have to overcome this gradient to establish the higher MnO rim concentrations. Chinner (1962) and de Béthune *et al.* (1968) suggested another alternative: garnet growth was followed by a period of resorption during which released MnO migrated inward. Such migration of MnO raises questions because the preservation of chemical zonation within garnet porphyroblasts dictates that internal diffusion be absent or incomplete. De Béthune *et al.* (1968) proposed that the garnet structure is less stable immediately ahead of the resorption front, thus permitting migration.

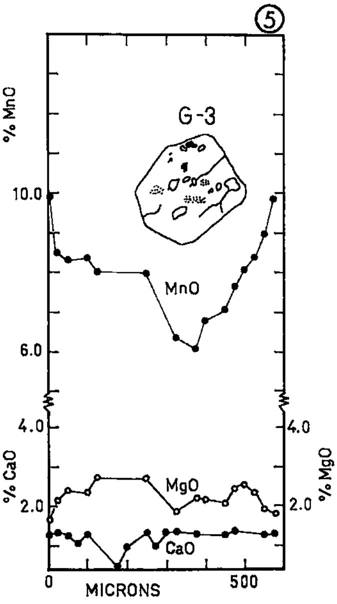
In garnets G-4a and G-4b, the inverse sense of FeO and MnO zoning persists to the cores (Figs. 6, 7). A similar trend of inverse MnO zoning exists in G-3 (Fig. 4) but unfortunately, FeO readings were lost and the author no longer has access to the equipment.

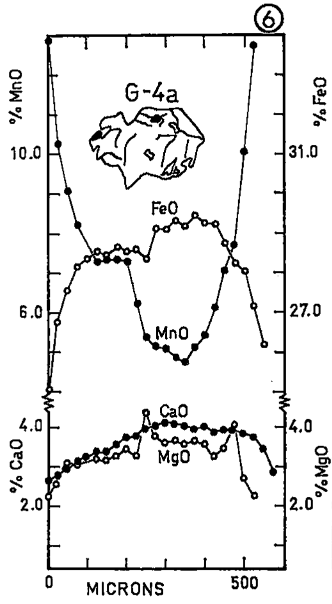
A decreasing growth rate, as postulated by Edmunds & Atherton (1971) could not have











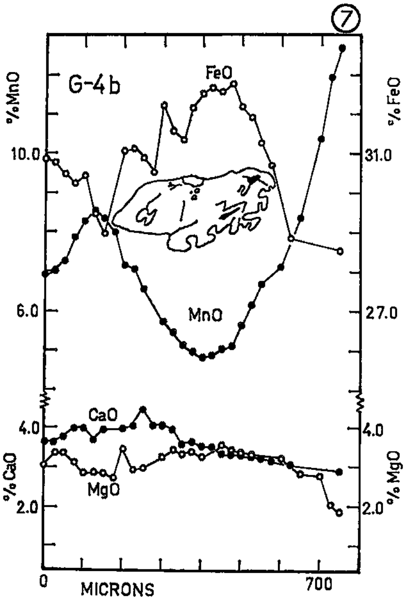


FIG. 2. Probe analyses along diameter of almanditic garnet G-1 (inset sketch) from metagreywacke, showing variation in MnO, FeO, CaO, MgO. The porphyroblast sketches for this garnet and others (Figs. 3, 4, 5, 6, 7) are drawn proportionally but may not reflect actual garnet sizes due to a cut effect: the polished sections may not have intersected garnet centers. Likewise the chemical variations may not be the maximum present. Garnet diameter can be determined from the abscissa, left to right.

FIG. 3. Probe analyses for garnet G-2a (inset sketch) from biotite schist of the Kashabowie Group.

FIG. 4. Probe analyses for garnet G-2b (inset sketch) from the same polished section as garnet G-2a.

FIG. 5. Probe analyses for garnet G-3 (inset sketch) from biotite schist of the Kashabowie Group.

FIG. 6. Probe analyses for garnet G-4a (inset sketch) from the paragneiss fraction of a lit-par-lit injection gneiss at the northern extremity of the Kashabowie Group.

FIG. 7. Probe analyses for garnet G-4b (inset sketch) from the same polished section as G-4a.

operated during the entire growth history. Likewise the profiles for G-3, G-4a, and G-4b are incompatible with a depletion mechanism for MnO. Hollister (1969) suggested that depletion could have a negative sense: the resorption of a refractory mineral in a reaction would effectively add elements to the system. However, such an accumulation of MnO in the host rock is unlikely to have occurred during the entire garnet growth period as G-3, G-4a and G-4b profiles require.

The concept of partial garnet resorption and inward migration of MnO is supported by carious rims and numerous embayments of porphyroblasts G-4a and G-4b (insets, Figs. 6, 7). Retrograde metamorphism which could account for garnet resorption in the northern portions of the Kashabowie Group is suggested by petrographic features: biotite flakes chloritized along cleavages and plagioclase highly sericitized. Information is insufficient, however, to determine the nature of the garnet resorbing reaction.

The shallow CaO composition profiles for G-1 and G-4a show that normal CaO zoning, with enrichment towards the cores, has persisted through the period of resorption. This can be accounted for by the greater ionic radius for Ca^{2+} ($Ca^{2+} = 0.99$Å, $Mn^{2+} = 0.80$Å, $Fe^{2+} = 0.74$Å) and therefore more restricted lattice mobility.

The asymetrical nature of FeO and MnO content near the rims of G-4b is an enigma. Perhaps secondary overgrowth took place on one side (Fig. 7). This correlates with the absence of embayments on that side of the garnet.

Grant & Weiblen (1971) reported inverse cryptic zonation in garnets from a migmatitic terrain in Minnesota. Profiles presented show homogenous cores with Fe and Mn increasing, and Mg decreasing outwards, over the outer 40% of the garnet radii. They attributed the homogenous cores to diffusion during high grade regional metamorphic conditions, and the marginal zoning to a retrograde metamorphic reaction consuming Mg and partly resorbing the garnets. In contrast, the Kashabowie garnets, also associated with a migmatitic terrain, show no homogenous cores. FeO zoning is antipathic to MnO zoning — not sympathic. MgO zonation is erratic and weak. That the Kashabowie garnets were not initially homogenous is suggested by the persistent normal zoning of CaO. Furthermore, the profiles for G-2b and possibly the FeO profile for G-2a, may show the transitional stage, from normal zonation patterns of the south to inverse zonation patterns in the migmatites of the north. That inversed zonation occurs up grade is significant, as retrograde metamorphism may be more effective in higher grade migmatitic terrains (Grant & Weiblen 1971) where volatiles are abundant.

CONCLUSIONS

Zonation of MnO and FeO in the Kashabowie garnets is interpreted as having a two-stage history. During regional metamorphism, garnet growth produced effective fractionation of MnO from the host rock and a progressive decrease of MnO from garnet core to rim. A subsequent period of retrograde metamorphism, in the northern high grade portions of the Kashabowie Group, caused partial resorption of the garnet porphyroblasts. As the garnets dwindled, Mn^{2+} migrated inwards, replacing Fe^{2+}. Microprobe traverses of these northern garnets therefore give composition profiles inverse to those of the southern garnets. CaO profiles, on the other hand, are identical from north to south since the larger Ca^{2+} ion has less mobility.

ACKNOWLEDGEMENTS

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