

Origin of Garnet Phenocrysts in Calc-Alkaline Rocks

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Abstract. A large number of garnet phenocrysts from Palaeozoic rhyodacites and granodiorite porphyrites from Central and Northeastern Victoria have been analyzed using the electron microprobe. These garnets, from an area of several thousand square miles, are very uniform in composition (dominantly almandine, with subordinate pyrope and minor grossular and spessartine). They show minor zoning with a very thin outer rim slightly richer in almandine and spessartine than the remainder of the phenocryst. They are surrounded by a complex intergrowth of cordierite and hypersthene forming a reaction rim. Resorbed quartz phenocrysts are typically associated with the garnet phenocrysts. The uniform composition, the conspicuous size and the subhedral-euhedral form of the garnet phenocrysts indicate that they crystallized directly from the acid calc-alkaline magma at an early stage of its crystallization. High pressure experimental work on a natural garnet-bearing rhyodacite glass demonstrates that almandine-rich garnet and quartz are near-liquidus phases at 18 and 27 kb ($P_{\text{H}_2\text{O}} < P_{\text{LOAD}}$), but garnet does not appear until well below the liquidus at 9 kb. A comparison of the composition of the experimentally crystallized garnets with the natural garnets suggests that these acid calc-alkaline magmas began to crystallize at pressures between 9 and 18 kb, i.e. at depths corresponding to the lower crust or upper mantle.

Introduction

Conspicuous almandine-rich garnet phenocrysts have been recorded in calc-alkaline rocks from Victoria, Australia (EDWARDS, 1936; RINGWOOD, 1955), New Zealand (COX, 1926), Japan (MIYASHIRO, 1955), England (OLIVER, 1956) and Russia (MAKAROV and SUPRYCHEV, 1964). Granodiorites, rhyodacites and dacites are the most common host rock-types for the garnet phenocrysts but they may also occur in rhyolites and andesites. MIYASHIRO (1955) pointed out that two garnet types are found associated with calc-alkaline rocks. These types are

- (i) garnets occurring as phenocrysts, and
- (ii) garnets occurring in cavities in lavas, or in pegmatites associated with calc-alkaline plutonic rocks.

MIYASHIRO emphasized the compositional difference between these two types viz. garnets of the first type are almandine-rich with some pyrope and are poor in spessartine, while garnets of the second type are almandine-spessartine-rich and poor in pyrope. This paper is concerned with the origin of the phenocryst garnet type.

The garnet phenocrysts reach 2 cm in size and are subhedral-euhedral in form, showing varying degrees of reaction to a cordierite-hypersthene intergrowth in the case of the Victorian garnets or to a cordierite-biotite intergrowth (MIYASHIRO, 1955), or to a plagioclase intergrowth (OLIVER, 1956). They are typically associated with resorbed quartz phenocrysts (EDWARDS, 1936; COX, 1926). Flow lines are present around some of the garnet phenocrysts (OLIVER, 1956). All these characteristic properties of the garnet phenocrysts occurring in calc-alkaline rocks point to the conclusion that the garnets initially crystallized directly from the

magma under equilibrium conditions at an early stage of crystallization, and later became unstable in their subsequent environment (EDWARDS, 1936; MIYASHIRO, 1955; OLIVER, 1956).

Recent high pressure experimental work investigating the origin of the calc-alkaline igneous rock suite has indicated a means of deriving these rocks by partial melting of quartz eclogite at 100–150 kms depth (T. H. GREEN and RINGWOOD, 1966 and 1968), or by the wet partial melting ($P_{H_2O} < P_{LOAD}$) of basalt at 30–40 kms depth (T. H. GREEN and RINGWOOD, 1968). In the course of these investigations almandine-rich garnet was found to be the liquidus or near-liquidus phase (in association with quartz) in andesite and dacite compositions. These results demonstrate pressure-temperature conditions where early, equilibrium crystallization of acid calc-alkaline magma involved garnet and quartz. At lower pressures these phases are no longer present on or near the liquidus. Thus resorbed garnet and quartz phenocrysts observed in some calc-alkaline rocks may provide evidence of a deep origin of such magmas. The magmas began crystallization at depth where garnet and quartz are the near-liquidus phases, but on rising to shallower levels these phases are no longer in equilibrium with the host magma and began resorption and reaction to different phases, in equilibrium with the magma at lower pressure.

Accordingly to verify these interpretations of the occurrence and origin of garnet phenocrysts in calc-alkaline rocks, a two-fold investigation of the problem has been undertaken. This has involved:

- (1) The determination of any characteristic compositional features of a large number of garnet phenocrysts, which may point to their igneous crystallization origin, or to an alternative hypothesis of origin (accidental inclusion of garnet xenocrysts in the calc-alkaline magma).
- (2) A high pressure and high temperature study of the crystallization of a natural garnet-bearing rhyodacite¹ from Victoria, in order to determine the pressure-temperature stability field in which almandine-rich garnet may crystallize as a liquidus or near-liquidus phase (in association with quartz) from a rhyodacite magma.

Procedure

(1) The investigation of the natural garnets has involved many analyses using an electron microprobe (Applied Research Laboratories, EMX model). In the analytical techniques adopted chemically analyzed garnets have been used as standards. Since the garnet standards approximately cover the range of compositions of the garnets analyzed, no corrections have been made for absorption, atomic number or efficiency-of-generation factor (SMITH, 1966). Dead-time corrections are unnecessary for the count-rates used and background corrections are automatically allowed for in the calibration graphs prepared from the standard garnets. Fixed specimen current counting methods have been adopted. Using these techniques an estimated relative accuracy of 5% is obtained. Six elements (Fe, Mn, Mg, Ca, Ti and Al) have been analyzed. The silica content has been calculated using the determined cation contents, and assuming ideal garnet end-member compositions.

Electron microprobe traverses across garnet phenocrysts in four different polished thin sections have been conducted to determine the degree of zoning in the crystals, and also to determine the nature of the reaction rim around the garnet. Analyses of 9 different specimens

¹ Termed rhyodacite II in this paper, to distinguish this composition from the synthetic rhyodacite I (adamellite) used in other high pressure investigations (T. H. GREEN and RINGWOOD, 1968).