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"Research Note"

THE OCCURRENCE AND ORIGIN OF ATOLL GARNET IN HORNBLENDE SCHISTS FROM THE CONTACT AUREOLE OF THE MASHHAD GRANITE, NE IRAN*

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Abstract – The formation of atoll garnet in hornblende schists from the contact aureole of Mashhad granite, NE Iran, is discussed using textural and chemical data. These data suggest the possibility of incipient replacement of pre-existing idioblastic garnet from the core. In addition, the presence of chlorite and calcite in the core of atoll garnet reveal the retrograde nature of atoll formation.

Keywords – Atoll garnet, hornblende schist, contact aureole

1. INTRODUCTION

Atoll garnet commonly consists of a complete or almost complete rim of garnet with an interior filled by any combination of biotite, muscovite, feldspar, quartz, calcite and iron oxide [1]. In several cases garnet islands can be seen inside the rims. As a general rule, atoll garnets show an idioblastic outline, which in some cases has been breached.

Studies of atoll garnet have so far resulted in disagreement about its origin [1]. Some workers [2-5] emphasized the selective replacement of the core of what used to be a complete garnet as the mechanism for atoll garnet formation. Atherton and Edmunds [6] used the uniform composition across both complete and atoll-shaped garnet from the Ben Lui schist at Pitlochry, Scotland, to argue against the selective replacement of garnet. They attributed the homogeneous nature of garnet to the rapid crystallization and suggested that the atoll rims and garnet islands had probably resulted from separated nucleation. Godard [7] favored corona or reaction rims as a mechanism for atoll garnet formation in quartz eclogites of the Hercynides. Spiess et al., [8] suggested that the atoll microstructure is controlled by multiple nucleation and coalescence.

From the preceding literature review, it is clear that there is not a general agreement on the way in which atoll garnet is formed. Here, we address the problem of atoll garnet formation by presenting textural and chemical data for atoll garnet from the contact aureole of the Mashhad granite.

2. GEOLOGICAL SETTING

The Mashhad metamorphic zone is part of the Binalood region in north-eastern Iran. The Binalood region forms a long and narrow belt which extends for several kilometres in a northwest-southeast direction. It has been considered as part of the Alborz orogenic belt in which tectonic evolution is thought to be a

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result of the northward subduction of the Paleo-Tethys and subsequent collision between the Iranian Cimmerian microcontinent and the Turan plate [9].

A 1/100000 Mashhad geological map was published by the Geological Survey of Iran [10] (Fig. 1). In the Mashhad zone, rocks are metamorphosed under low greenschist facies conditions and are intruded by granite-granodiorite plutons that have produced a distinctive thermal aureole. The contact aureole is made up of porphyroblastic rocks and characterised by thermal garnet, staurolite and andalusite normally crosscutting the regional schistosity. Majidi [11] provided Devonian-Carboniferous age for Mashhad metamorphic complex rocks. However, Alavi [9] suggested a pre-Late Triassic age for them.

Plutonic rocks, which intruded in Mashhad metamorphic complex include pegmatite, aplite, granite, granodiorite, tonalite and diorite. Alberti et al. [12] used K-Ar radiometric age on biotite and muscovite to suggest an Early Cretaceous age (120-160 Ma) for the magmatic activity. However, on the basis of field studies, Alavi [9] suggested that the intrusion of these plutonic rocks occurred prior to the Late Triassic time.

3. PETROGRAPHY OF THE HORNBLENDE SCHISTS

Garnet is a common mineral throughout the contact aureole of the Mashhad granite. However, atoll garnet exclusively can be seen in hornblende schists of the Khalaj region (Fig. 1). Hornblende schists are characterized by their dark green color and the presence of garnet porphyroblasts visible in hand specimens. In thin sections, typical rocks consist of green hornblende + garnet + quartz + muscovite + chlorite + calcite + sphene. Plagioclase and biotite are notably absent in these rocks. Hornblende occurs in elongated bladed prisms alternating with bands consisting of quartz, calcite and muscovite. Chlorite occurs as randomly orientated green flakes, occasionally crosscutting the schistosity, probably representing a late phase of growth during retrogression. Garnet appears as large and idioblastic porphyroblasts (>1.0 mm). The deflection of schistosity around some garnet porphyroblasts can be seen. Garnet usually has a clear inclusion-poor core surrounded by a dark, inclusion-rich rim (Fig. 2). Garnet core normally shows an idioblastic outline. In many examples garnet porphyroblasts contain cores of mainly calcite and occasionally chlorite or a combination of these minerals, resulting in an atoll texture (Fig. 3).

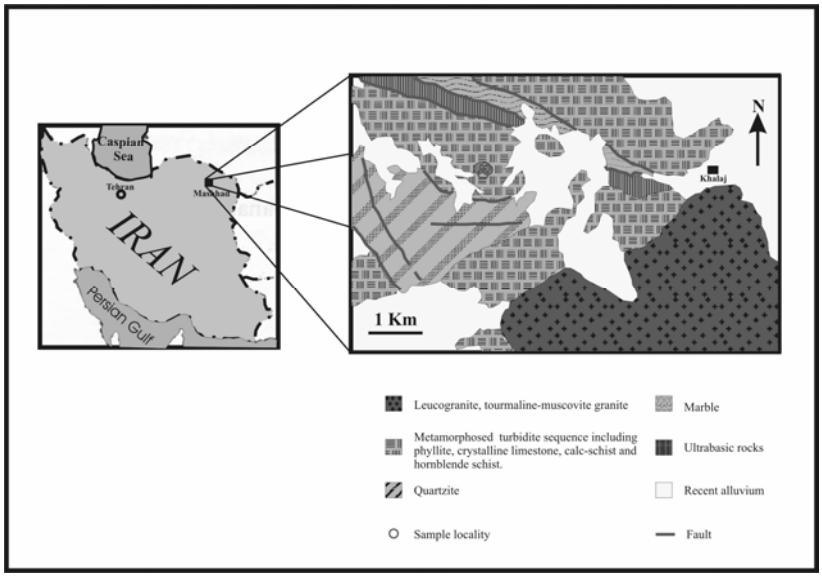

Fig. 1. Geology of the Khalaj region (modified from geological map of Mashhad [10])

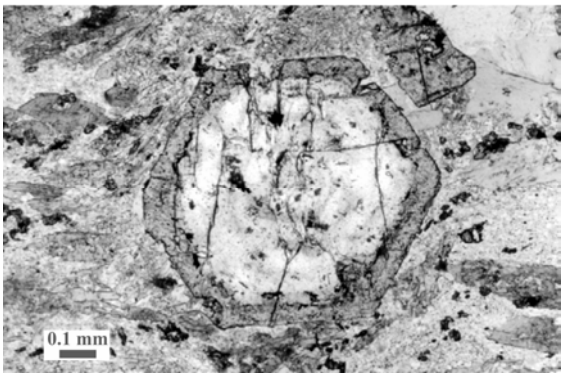

Fig. 2. Garnet porphyroblast showing a clear, inclusion-poor core surrounded by a dark, inclusion-rich rim. Note the idioblastic outline of the garnet core

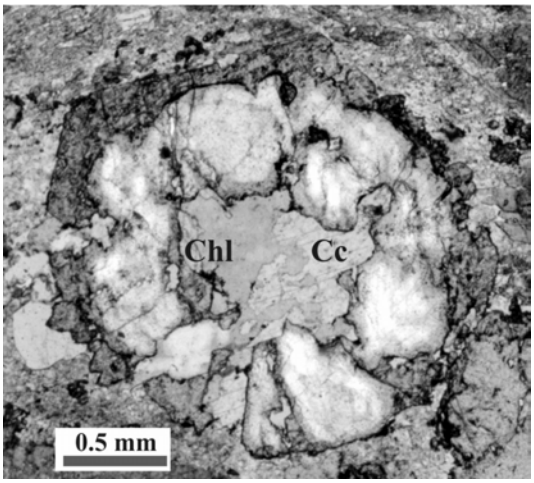

Fig. 3. Atoll garnet enclosing a core of chlorite (Chl) and calcite (Cc)

4. COMPOSITIONAL CHARACTERISTICS

Specimens prepared for scanning electron microscopy comprised 30 μm thick polished thin sections with a 20 *n*m carbon coating. Mineral data were acquired at the Department of Earth Sciences, University of Liverpool, on a Philips XL-30 Scanning Electron Microscope. The operating condition was 15-20 kV electron beam accelerating voltage. Microprobe X-ray analyses were produced with the Oxford ISIS Series 300 Microanalysis System.

Analyzed garnets have relatively high amounts of spessartine (between 0.7 and 1.6 atoms per formula unit), but small amounts of pyrope (between 0.05 and 0.17 atoms per formula unit). The amounts of almandine and grossular vary from 1.15 to 1.33 and from 0.52 to 1.3 atoms per formula unit respectively.

The presence of chemical zoning in analyzed complete garnets is evident. There is little difference in Mn, Fe and Ca across the core of complete garnet. However, Mn decreases, while Ca and Fe increase rapidly in the outermost rims (Fig. 4a).

There is an evident similarity in chemical zoning between atoll garnet and complete garnet. The values of Fe, Mn and Ca show a little difference from the internal edge of atoll garnet, where garnet is close to calcite or chlorite, towards the rim, although Mn decreases but Fe and Ca increase rapidly in the outermost rims (Fig. 4b). Interestingly, the sharp changes in chemical composition of both complete and atoll garnets are exactly coincident to border between clear, inclusion-poor cores and dark, inclusion-rich rims suggesting that these two features of garnet may belong to different generations. X-ray chemical

maps of complete garnet (Fig. 5) display that the garnet is concentrically zoned. In some examples, atoll garnet show no chemical zoning. In these cases, values of Ca and Mn are very similar to those from outermost rims, suggesting complete consumption of the core of pre-existing complete garnet to produce calcite and/or chlorite.

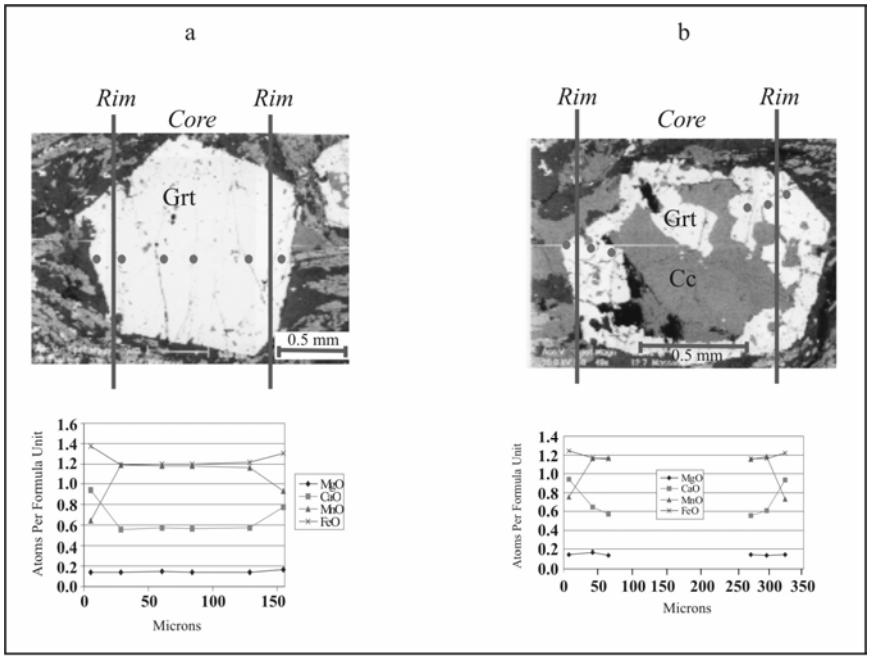

Fig. 4. Microprobe traverse across a complete (a) and an atoll garnet (b) from hornblende schists of the Khalaj region. Minerals are garnet (Grt) and calcite (Cc). Top two pictures are backscattered electron images

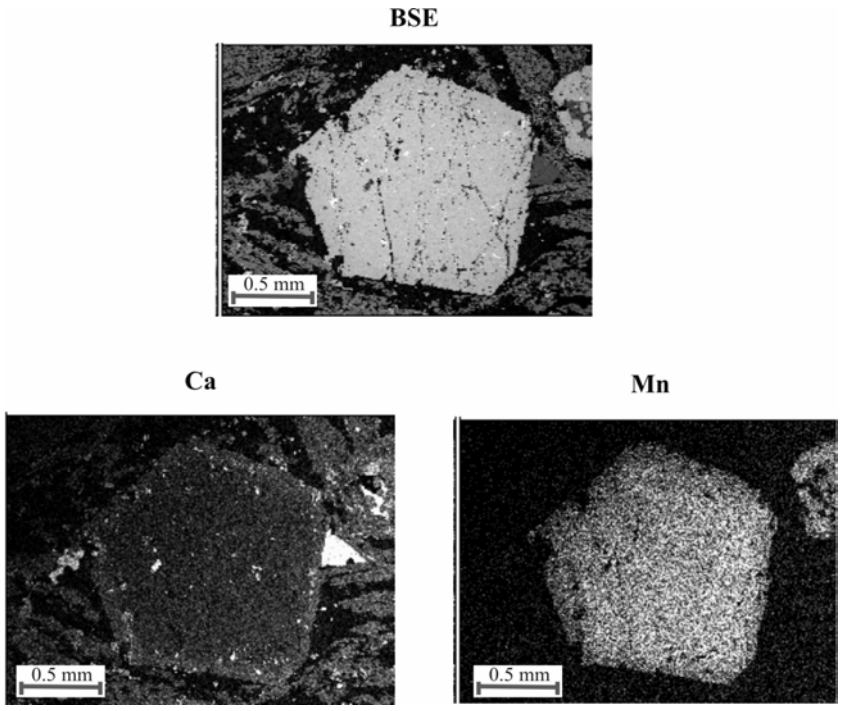

Fig. 5. X-ray maps showing the distribution of Mn and Ca in a complete garnet (correspond to that of fig 5a) from hornblende schists of the Khalaj region. Note that the garnet is concentrically zoned. BSE: Backscatter Electrons

5. DISCUSSION AND CONCLUSION

The most logical explanation for the formation of atoll garnet in hornblende schists of the contact aureole of Mashhad granite can be provided here using the textural and chemical data.

As mentioned earlier, garnets usually consist of an almost complete dark, inclusion-rich rim with a clear, inclusion-poor core with an idioblastic outline, usually filled by calcite and/or chlorite. Garnet rim always remain unaffected. The idioblastic outline of garnet core may suggest that the inner surface of the atoll garnet was in existence before calcite and chlorite started growing and that calcite and chlorite nucleated on this surface. It seems necessary to describe why calcite and chlorite nucleate on the inner surface of the atoll garnet, but never on the outer surface of the atoll. Many researchers [2-5] conclude that the core of pre-existing complete garnet was selectively replaced because the original crystal was zoned. The same suggestion can be used for the studied atoll garnets. As mentioned in section 4, garnets show an evident chemical zoning, and more interestingly, sharp changes in chemical composition are exactly coincident to border between the core and rim. It is believed that garnet core and rim have grown as a result of two different periods of metamorphism (regional and thermal metamorphism) or two different reactions during one single metamorphic event. Therefore it is suggested that the atoll garnets represent the remnant rims, while their core have been replaced by mainly calcite and sporadically by chlorite. Atoll formation occurs when the rim is mechanically breached and the unstable inner zone becomes partially or completely replaced, as dissolution-replacement is supposed to have progressed faster or more extensively upon those parts of garnet (core of garnet crystals) that had failed to change their composition. The garnet-consuming reaction could be slowed down or prohibited in any place by localized closing of diffusion channels. The breakdown of garnet most likely occurred during retrograde metamorphism as calcite and chlorite, both of which represent late phases of growth during retrogression in these rocks, and have been found in the core of atoll garnets.

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