CHEMICALLY SECTOR-ZONED GARNETS IN THE METAPELITIC ROCKS OF THE SILGARÁ FORMATION IN THE CENTRAL SANTANDER MASSIF, COLOMBIAN ANDES: OCCURRENCE AND GROWTH HISTORY

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ABSTRACT

Almandine-rich garnet in the Silgará Formation metapelitic rocks in the central Santander Massif usually shows concentric normal chemical zoning. However, different types of garnet zoning have been reported, including chemically sector-zoned garnet, which is described here. Recent studies reveal additional discoveries of this type of zoning in different localities. Textural sector-zoned garnets have been observed in the staurolite-kyanite metamorphic zone of the Silgará Formation. They are generally fine-grained (0.25-2.00 mm in diameter), and occur in quartz-rich bands with other textural types of garnet (skeletal and poikiloblastic). The study of the chemically sector-zoned garnet indicates that it has grown in the latest stage of the Silgará Formation metamorphism. Studies on garnet from the Silgará Formation pelitic rocks have shown the importance of this as a key piece for interpretation of the tectono-metamorphic history of this metamorphic unit.
Keywords: Silgará Formation; Santander Massif; chemical sector-zoned; garnet; metamorphism.

OCCURRENCE OF SECTOR-ZONED GARNET

Garnet occurs as porphyroblasts with idioblastic to xenoblastic character (0.25 mm to 20 mm in diameter). It is also possible to difference two type of garnets according to their texture: poikiloblastic and sector zoning garnets. According to Castellanos (2001), sector-zoning garnet growth can be interpreted as a non-equilibrium stage of progressive metamorphism, followed by late poikiloblastic garnet growth. Garnet sometimes shows a trail pattern of inclusions of quartz, graphite and opaque minerals, which define a S_{int} almost perpendicular to the S_{ext} of the rock and most of them are partially included in staurolite porphyroblasts.

Some garnets are sub rounded to rounded and show a rotational trail of inclusions of quartz or S-shaped spiral structure. Inclusions in the poikiloblastic garnets are mainly quartz, opaque minerals and plagioclase, which exhibit randomly distribution and orientation. In addition, poikiloblastic garnets in some samples show a elongated shape suggesting a dendritic character due to high rate of growth. Sector zoning garnets are usually sub rounded, and show very different types in the distribution of quartz inclusions. This unusual zoning shows in general terms a radial character. It is possible to observe asymmetrical pressure shadows consisting mainly of quartz and mica, and it is also common to find garnet with rims corroded by quartz.

A common characteristic in many of the textural sector-zoned garnets is the presence of arcuate concentrations of graphite (or rarely other minerals) in a textural zone (often very thin) lying immediately outside the sector-zoned region (Figures 1b, 2). According to Anderson (1984), within sector-zoned garnets two types of inclusions can be identified.

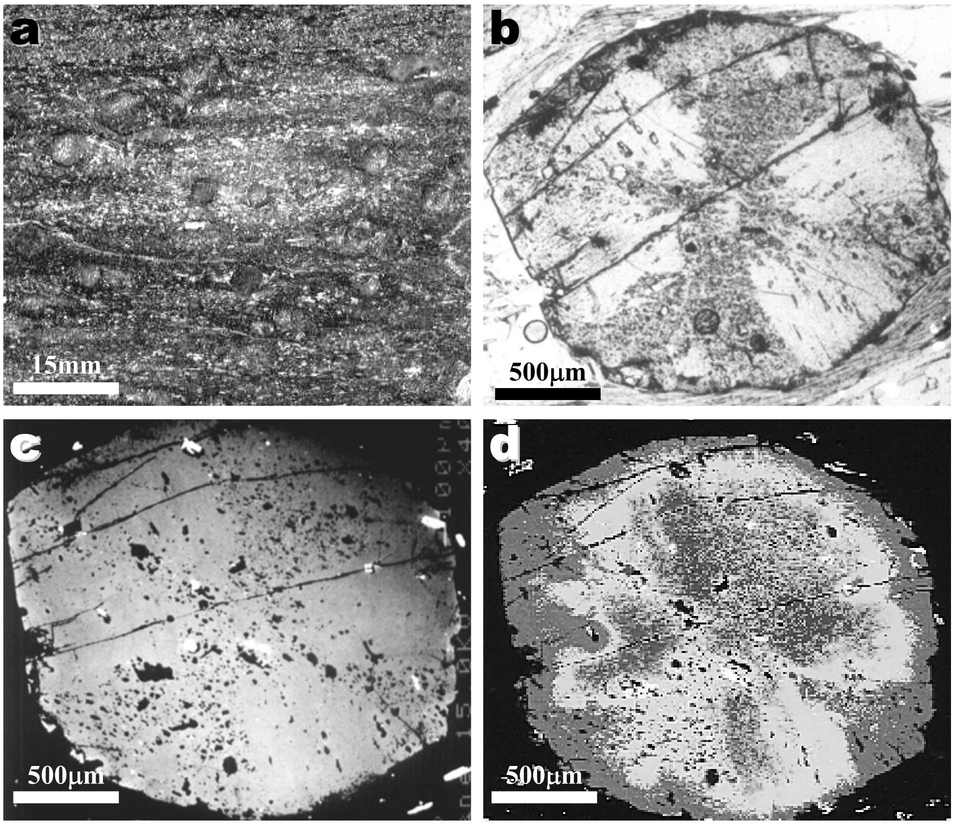

Figure 1. Textural and chemical features of sector-zoned garnet in sample PCM-618. (1) Photograph of host rock of the sector-zoned garnet. (b) Photomicrograph of a garnet displaying optical sector zoning. (c) Back-scattered electron image showing sector zoning. (d) X-ray map of Ca distribution within garnet. The light grey areas correspond to the highest Ca content and the dark grey areas, to the lowest.

Type 1 "blobby" inclusions of quartz, Fe-Ti oxides and graphite are found prefentially along the pyramid interfaces and were derived from the matrix. Type 2 "tubular" inclusions (or more properly "intergrowths" according to Burton (1986)) consist of slender inclusions of quartz which are not relics of the matrix, but have formed simutaneously with garnet. These types of inclusions have been observed in sample PCM-618 (Figures 2a, b), in which type 2 inclusions of abundant fine trails of equidimensional and tubular grains of quartz and graphite form an angle of 30^o with the pyramid interfaces, where inclusions of quartz, Fe-Ti oxides and graphite occur, and approximately 90^o with the base of the pyramid within which they formed. Locally, domal accumulations of graphite are observed at the end of the type 2 intergrowths on garnet {110} crystal faces (Figure 2b).

Chemical sector-zoning, such as in sample PCM-618 (Figure 2c, d), is characterized by growth pyramids of different crystal habit have marginally different chemical compositions. Kochi et al. (1983) describe some mechanisms to account for chemical sectoring, based on: (1) properties relating to the ion exchange taking place at the crystal face; (2) variations in the atomic configuration of the crystal structure or adsorption layer at different faces; (3) systematic variations in growth rates at different faces and relative diffusion rates of cations in melts; (4) element partition coefficients and the roughness of crystal faces.

MINERAL CHEMISTRY

Garnet is almandine-rich (X_{Fe} = 0.69-0.93) with minor pyrope (X_{Mg} = 0.06-0.15), spesartine (X_{Mn} = 0.00-0.16), and grossular (X_{Ca} = 0.00-0.11).
Castellanos (2001) reported normal, reversal and sector zoning in pelitic garnet of the Silgará Formation in the central Santander Massif. Garnet usually shows a normal zoning pattern indicating prograde growth: a strongly modified bell-shaped spessartine profile, and increasing almandine and pyrope, from core to rim. There is also an overall gradual decrease in Fe/(Mg+Fe) from core to rim.
The chemical zoning from garnets can be summarized as follows:
Type I garnet (PCM-700), which is almost almandine end member, with very low content of Mg, Mn and Ca. In addition, only a slight increase of Mn at the core was observed.
Type II garnet (PCM-651, PCM-701, PCM-971), which exhibit a normal zoning with increasing of Mg and Fe component from core to rim and decreasing of Mn and Ca component also from core to rim suggesting a prograde stage of metamorphism.
Type III garnet (PCM-47, PCM-953), which exhibit a normal zoning until the inner rim, but in the outer rim the chemical zoning is inverse, reflecting effects of a retrograde stage of metamorphism.
Type IV garnet (PCM-618), which exhibits a sector-zoning with very different models of zoning even in thin section-scale, and, in some cases, distribution of elements follows a radial trend, but in other cases distribution follows a patch trend.

DISCUSSION

In the analyzed sample of garnet pelitic schist there is not a clear textural interrelationship between the development of textural sector-zoning and the presence of matrix displacement, and is difficult to precise the occurrence of cleavage domes, except by a local development of dome shaped solid graphite accumulations. An explanation for this is that in sector-zoned garnets formed in regionally metamorphism terranes, such as the Silgará Formation metapelitic sequence, post-displacement stresses may have destroyed any cleavage domes which formed in the sense of Rice & Mitchell (1991). According to them, there is a relationship between the presence of graphite within rocks, the formation of textural sector-zoning in porphyroblasts of garnet, the development of lineage structures and/or type 2 intergrowths and the displacement of insoluble matrix grains (typically the graphite). Although textural, chemical and twin sector zoning are thought to be related, they have not been observed in conjunction in the metapelitic sequence of the Silgará Formation in the central Santander Massif.
The presence of graphite or carbonaceous material in nearly all rocks containing texturally sector-zoned garnets appears to be more significant and has been mentioned by several authors (e.g., Burton, 1986; Hollister, 1970), and this is proved in sector-zoned garnets of the Silgará Formation pelitic schists.
However, the significance of graphite should be treated with some caution; syntectonic spiral garnets have been reported from graphitic schists in many areas, some of them adjacent to areas with texturally sector-zoned garnets (e.g., MacQueen & Powell, 1977), reflecting the dependence of the development of all these textures on the presence of a hydrostatic stress field.

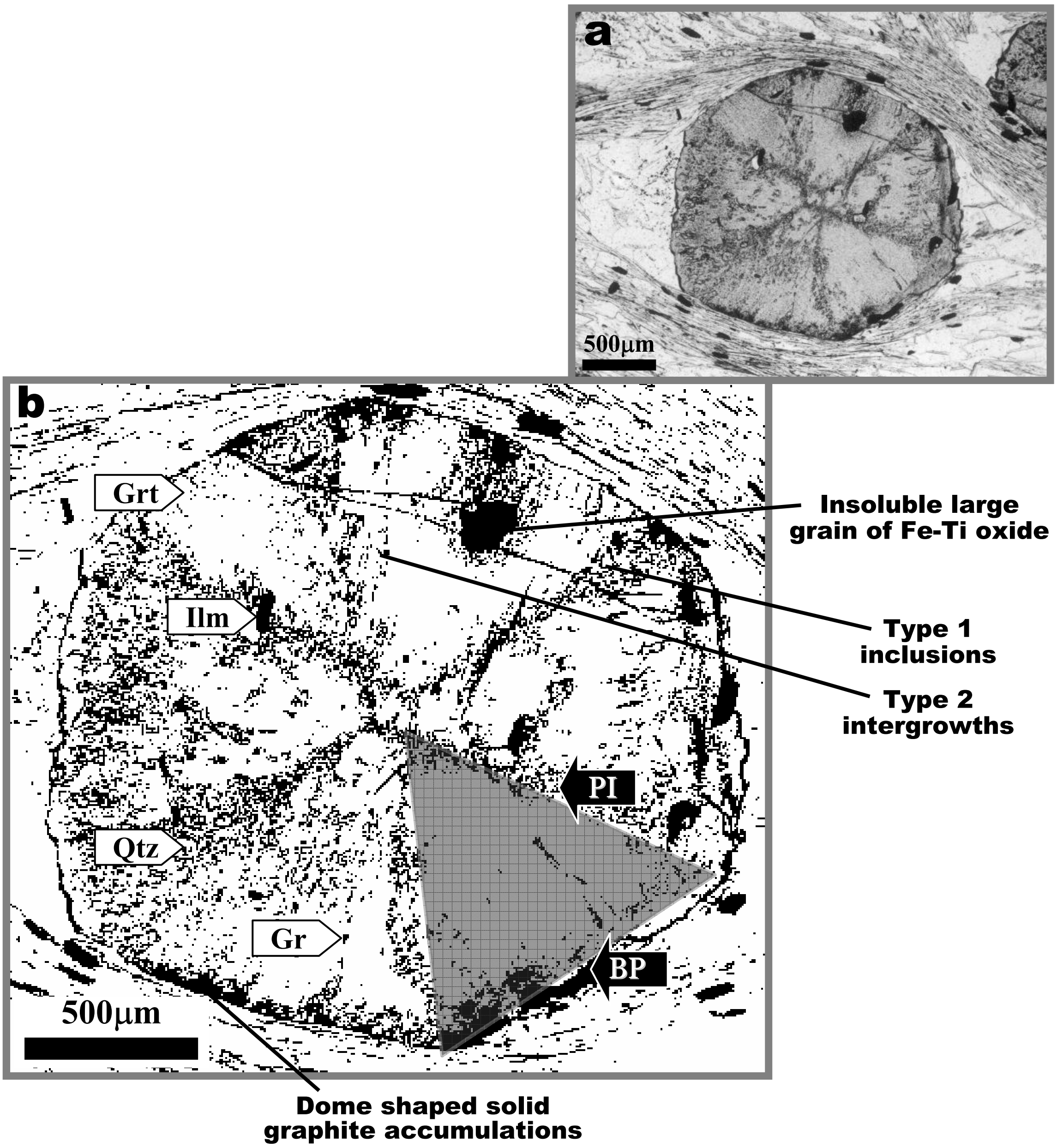

Figure 2. (a) Photomicrograph of a garnet displaying textural sector zoning (sample PCM-618) from the Silgará Formation pelitic rocks in the central Santander Massif. (b) Skech of sector-zoned garnet in (a), showing well developed type 1 inclusions of quartz, graphite and plagioclase and type 2 intergrowths of quartz and graphite. Note the local development od cleavage domes on {110} garnet crystal faces. Shadow area displays a pyramid as well as the base of the pyramid and the pyramid interface. PI: Pyramid interface; BP: Base of the Pyramid.

Cleavage domes and growth sector zoning have been interpreted as the result of growth in local stress fields developed under bulk hydrostatic conditions (Ferguson et al. 1980). However, textural observations coupled with the style of deformation in adjacent rocks, suggest that these garnets grew under active deformation (wraps and dislocations) rather than hydrostatic conditions (http://pcwww.liv.ac.uk/microstr/aziz.html).

Based in textural features and chemical zoning, two differents types of garnets were recognized for sample PCM-618; sector-zoning garnet and poikiloblastic garnet, which in some cases exhibit also a slightly zoning. These facts suggests the following growth history for garnet: Growing processes for

sector-zoning garnet can be interpreted as a non-equilibrium stage of progressive metamorphism, follows by the growing of poikiloblastic garnet at the last stage of this event.
In the study area, the Orthogneiss Formation exhibit concordant relationships with the middle- to high-grade metamorphic rocks, including the Silgará Formation pelitic schists, and may be interpreted as syn-tectonic intrusives emplaced at close to the peak metamorphism. We suggest that the emplacement of orthogneiss masses produced a local and abrupt heating of the pelitic schists of the Silgará Formation, which led to a rapid nucleation of sector-zoned garnets during disequilibrium growth conditions. Therefore, the development of sector-zoned garnets would be related with the emplacement of orthogneiss masses.

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