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A COMPARATIVE STUDY OF COMPOSITIONAL ZONATION IN GREENSCHIST AND GRANULITE FACIES ALMANDINE GARNETS

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Abstract: Almandine garnets in greenschist (Loch Lomond, Scotland) and granulite (Sri Lanka) facies pelitic rocks are studied with the electron microprobe analyser. Greenschist facies garnets show strong compositional zonation. MnO has its highest value at the centre of the garnet and it decreases towards the margin. FeO shows antipathetic variation to MnO. CaO and MgO exhibit less marked variation but their trend is similar to that of MnO and FeO respectively. In contrast zonation in granulite facies garnets is displayed only by CaO and MgO. Furthermore, this zonation is weak and it is confined to the margin of the garnets. The contrasting pattern of zonation is the consequence of difference in temperature of formation of the two rock groups. Models explaining the formation of compositional zonation in garnets of low to medium grade rocks are discussed. The weak zonation in the granulite facies garnets cannot be interpreted as due to cation exchange between garnets and the matrix minerals, in response to a retrograde cooling phase since biotite and plagioclase are absent in the studied rocks. Consistent with the petrographic evidence, it is suggested that the garnet rim grew with falling temperature.

1. Introduction

Since the introduction of electron microprobe analyser in the late 1960's, compositional variation in metamorphic and igneous minerals is studied widely and one of the minerals studied extensively is garnet. Microprobe studies have shown spectacular compositional variations in garnets of low to medium grade pelitic rocks and a considerable number of theoretical models dealing with the development and preservation of zoning have been proposed.[1,4,5,13] Relatively few such studies have been reported on garnets of granulite facies rocks probably because of the presumption that these garnets would show a slight or no compositional zoning and might not provide much information due to the fact that very high temperature is involved in granulite facies metamorphism. No such studies have been reported in garnets of Sri Lankan rocks. This paper presents a detailed microprobe study of almandine garnets in pelitic granulite facies of Sri Lanka and greenschist facies pelitic rocks of Loch Lomond area, Scotland.

2. Sample Locations

A belt of rocks containing abundant albite porphyroblasts occurs in the biotite and garnet Barrovian metamorphic zones of south-west Scotland and north-east Ireland. This belt is referred to as albite porphyroblast belt and the rocks containing abundant albite porphyroblast is known as albite schists.[6] The greenschist facies samples for the present study is from the albite porphyroblast belt. The samples were collected in the garnet zone, around Crianlarich, Scotland (Figure 1a).

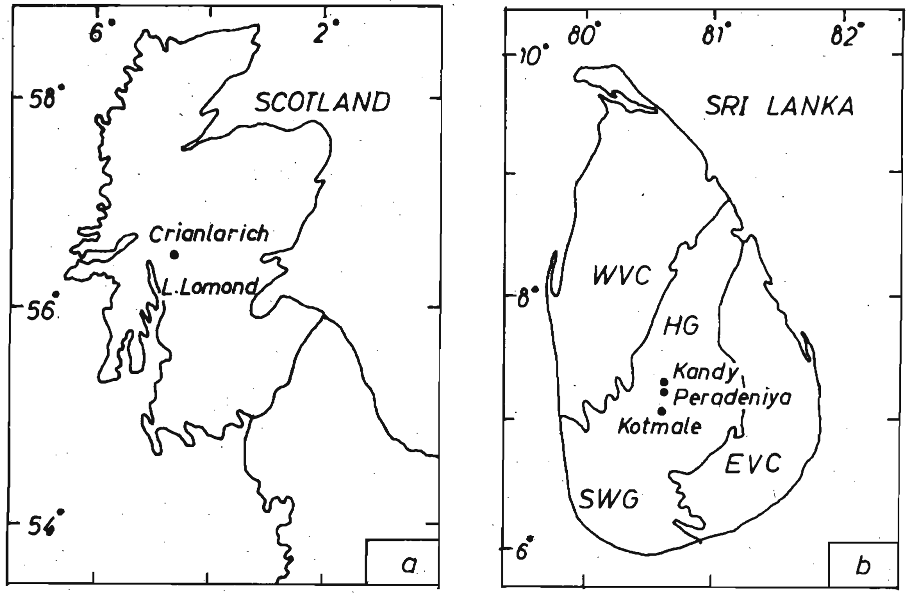

Figure 1. (a) Map of Scotland showing the sample locations.
(b) Simplified geological map of Sri Lanka and the sample locations.

Garnet-sillimanite schists (khondalites) are typically found in the granulite facies Highland Group of Sri Lanka. They are closely associated with charnockites and metasediments.[3] This rock type is easily recognised in the field by the presence of abundant porphyroblastic garnets. Garnet-sillimanite schist samples for the present study were collected from Peradeniya (lat. $7^0 15'$N, long. $80^0 36'$E), Kandy (lat. $7^0 17'$N, long. $80^0 37'$E) and Kotmale (lat. $7^0 04'$N, long. $80^0 38'$E) (Figure 1b).

3. Petrography

The albite schist samples are fine dark grey rocks with abundant white microporphyroblast and they show well developed schistosity defined by the phyllosilicates. Microscopic study shows that the schistosity is formed by chlorite, muscovite, biotite and quartz and the S—surface is microfolded (Figure 2a). Albite microporphyroblasts are randomly distributed and they contain numerous minute oriented inclusions. A few euhedral to subhedral porphyroblastic garnets are scattered throughout the rock and some of these are partially altered to chlorite. The order of abundance of the minerals is muscovite, albite, chlorite, quartz, biotite and garnet. It is shown that the porphyroblastic garnets in the albite schists have grown during the static period between D_2 and D_3 deformation phases, by studying a much larger area.[9]

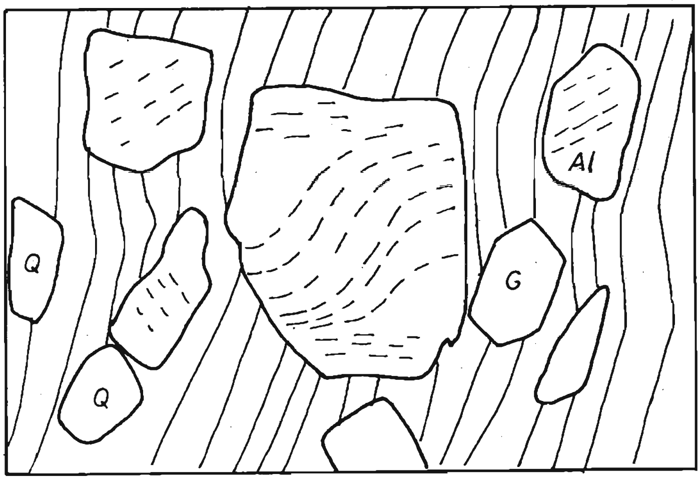

Figure 2a. Albite microporphyroblasts containing numerous oriented inclusions. Note the crenulation of the S-surface, Al-albite, G-garnet, Q-quartz. Phyllosilicates form the S-surface.

In hand specimen, the garnet-sillimanite schists are white porphyroblastic rocks containing abundant, large (up to a cm), subrounded to irregular dark red garnets. The schistosity is indistinctly defined by sillimanite needles and lenticular quartz. Patch aggregates of graphite or Fe-Ti oxides may be present. Thin section studies reveal that the garnets enclose numerous fine grains of quartz, sillimanite and ore. Quartz is the dominant included mineral and it is characteristically oval to elongate in shape. The enclosed minerals are generally concentrated at the core of the garnet crystals and thus defining a large inclusion-rich core and a narrow inclusion-free rim (Figure 2b). Moreover, the included minerals are dimensionally oriented in some garnets but not in others. Sillimanite needles are dimensionally oriented in the matrix and they abut or flow around the garnets. The relative age relations between the growth of garnet and the deformation phases were not established in the present study. However, it is generally considered that the major period of mineral growth in the granulite facies rocks of Sri Lanka is coeval with the major deformation phase, either D_1 or D_2.[2] Microperthites are smaller than quartz. Plagioclase and biotite are absent in the studied samples. The order of abundance of the minerals is garnet, quartz, microperthite and sillimanite. Graphite, zircon and Fe-Ti oxides are always present as accessories.

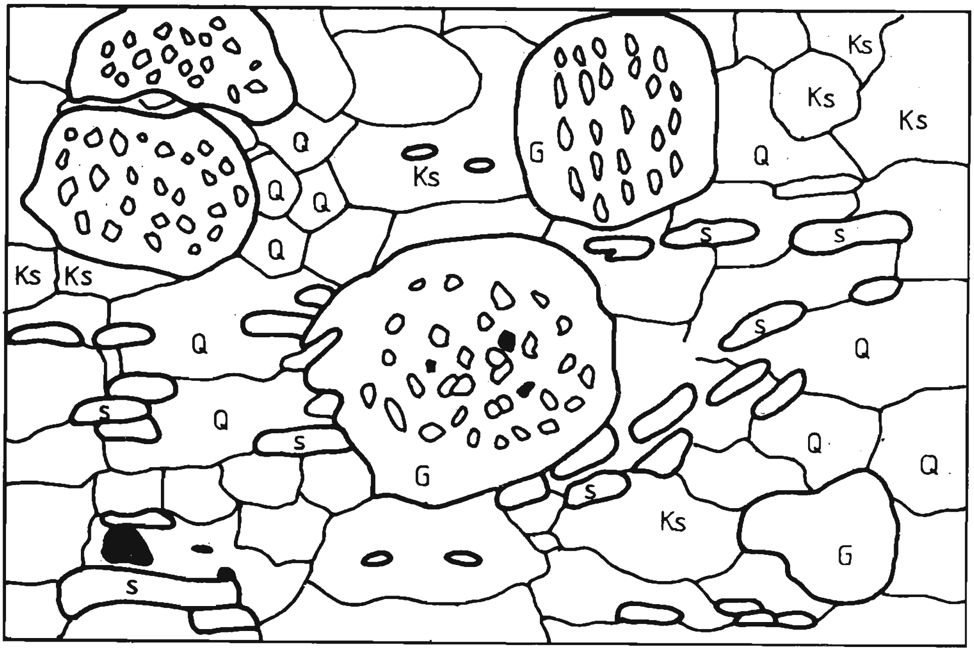

Figure 2b. Subrounded garnets containing a large inclusion-rich core and a narrow inclusion-free rim (garnet-sillimanite schist) KS-microperthite, Q-quartz, S-sillimanite.

4. Microprobe Analysis of Garnets

Several garnets in four samples from Crianlarich were probed from rim to rim and all these D_2-D_3 garnets showed similar compositional profiles. Compositional profiles of a representative garnet are shown in Figure 3a and the rim-core analyses are given in Table 1. More than four garnets in each of the three samples from Peradeniya, Kandy and Kotmale were analysed and the compositional profiles of the analysed garnets were similar. Figure 3b shows the compositional profiles of one of these garnets and the analyses are presented in Table 1. Garnets in both rock types are dominantly almandine.

Table 1. Analyses of garnets

	Albite Schist Rim	Garnet Core	Garnet-sillimanite schist garnet Rim		Core	
	x=5	x=700	x=100	x=1000	x=1400	x=1600
SiO_2	37.50	36.20	38.05	38.03	38.10	39.08
Al_2O_3	21.38	20.79	20.99	21.01	21.13	20.92
FeO	30.66	24.56	30.30	30.26	30.53	30.75
MgO	1.37	0.60	7.70	7.71	7.96	8.02
CaO	8.58	9.23	0.81	1.16	1.17	1.19
MnO	1.37	6.94	0.28	0.27	0.35	0.35
Total	100.82	98.33	98.15	98.46	99.26	100.32
Molecular proportions						
Almandine	67.49	55.12	66.79	66.12	65.52	65.75
Pyrope	5.24	2.42	30.25	30.00	30.46	30.48
Spessartine	3.04	15.83	0.64	0.60	0.76	0.77
Grossular	24.04	26.59	2.30	3.26	3.24	2.99

x - distance (in μm) from the rim.

The porphyroblastic garnets in the albite schists show strong symmetrical variations in MnO and FeO. MnO has its maximum value at the centre of the garnet and it decreases towards the rim (Figure 3a). FeO shows antipathetic variation to MnO. Though CaO and MgO, show lessmarked variation, the trend is similar to that of MnO and FeO respectively. This type of compositional zonation in garnet is referred to as normal zoning.[5] In contrast, garnets in garnet-sillimanite schists display weak zonation and it is confined to the margins of the crystals (Figure 3b). MnO is almost uniformly distributed from rim to rim. CaO and MgO are evenly distributed in the central portion of the crystals while they show normal zoning at the rims, CaO decreases and MgO increases. This zonation is similar to the pattern in garnets of pyroxene granulites from Moldanubian zone, Austria (Figure 3c).[7] However, a notable difference is that zonation in garnets of garnet-sillimanite schists is shown in MgO and CaO whereas FeO and CaO exhibit the variation in the reported pyroxene granulites.

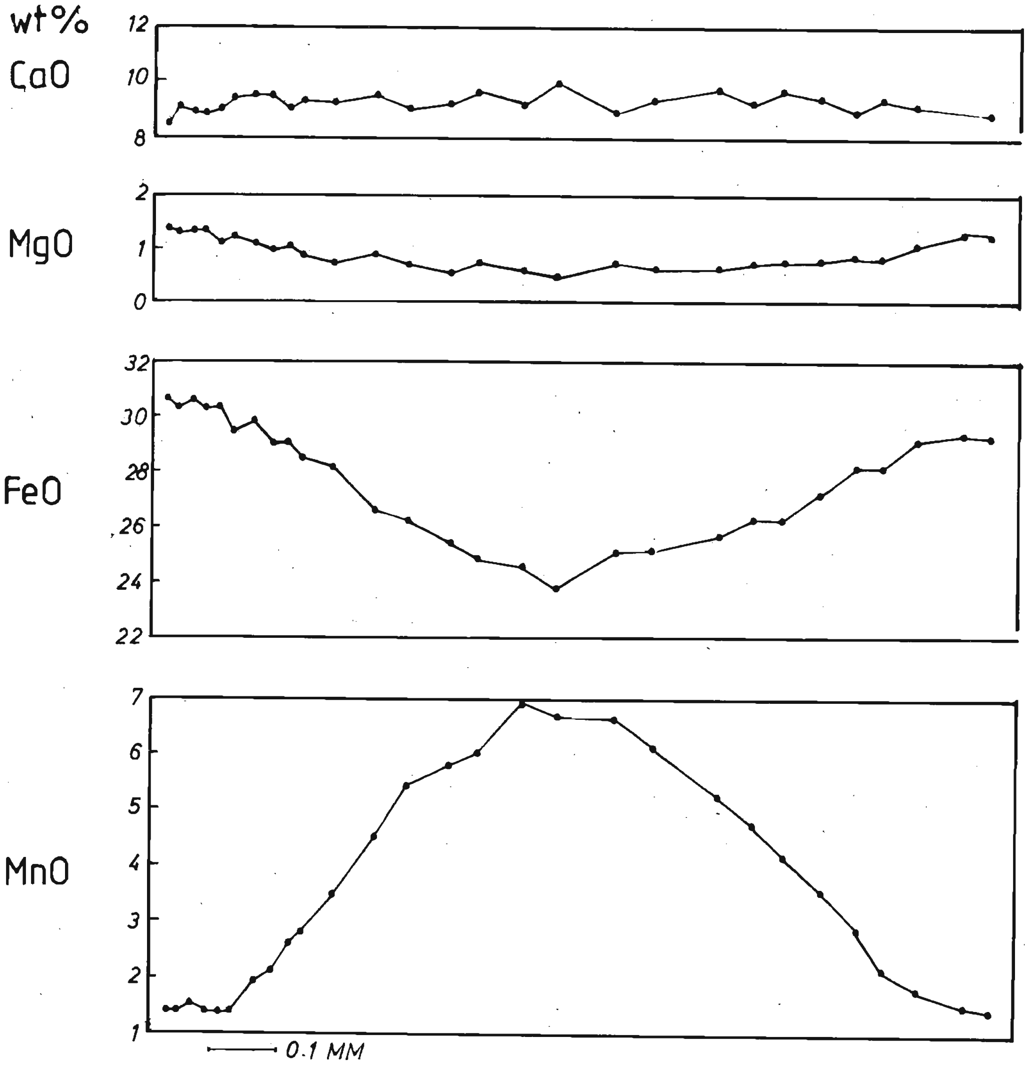

Figure 3a. Compositional profiles of a garnet in the albite schist.

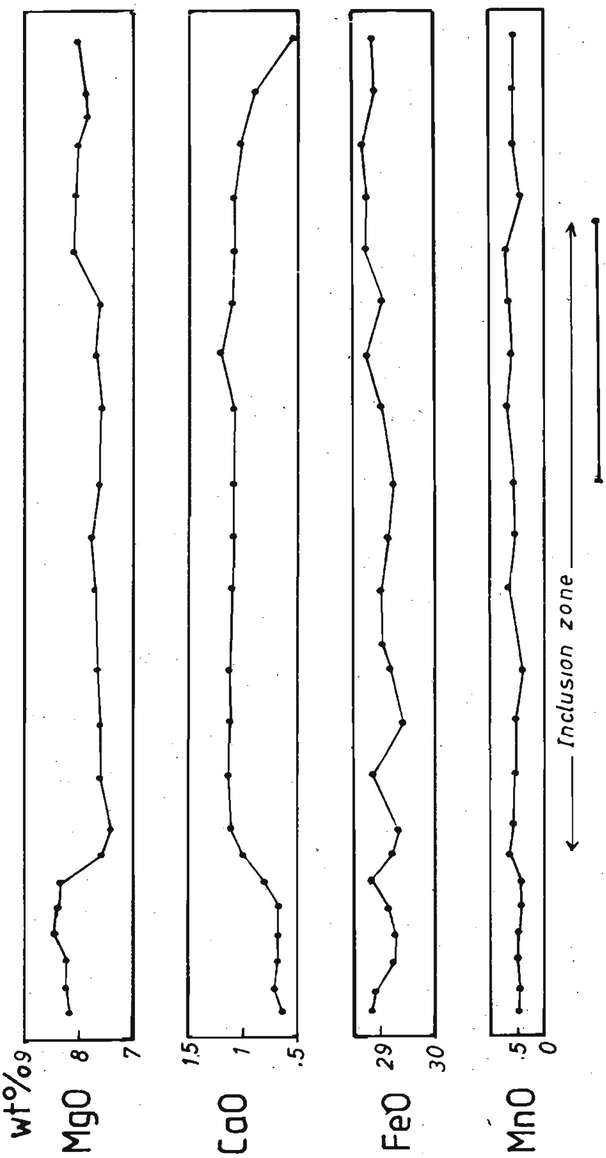

Figure 3b; Compositional profiles of a garnet in the garnet-sillimanite schist.

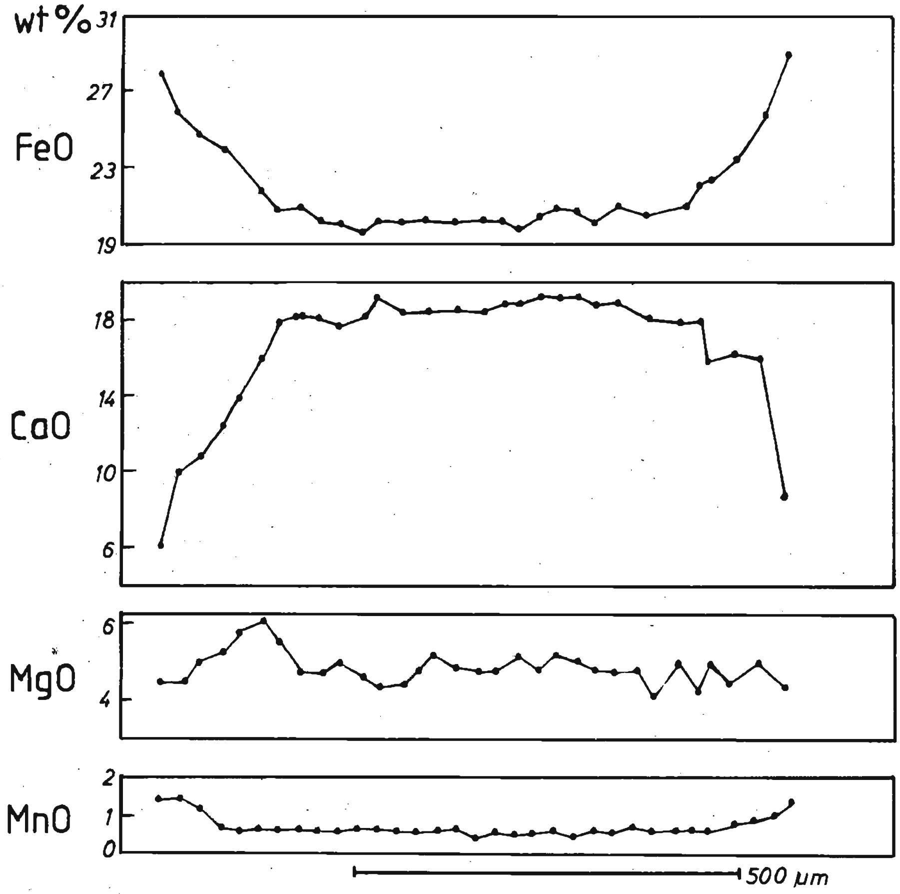

Figure 3c. Compositional profiles of a garnet in a pyroxene granulite

5. Discussion

The strong zonation exhibited by garnets in greenschist facies rocks (albite schists) conforms to the Rayleigh fractionation model proposed by Hollister.[5] The model assumes a reservoir of matrix minerals that is continuously adjusting its composition as the garnet grows. Diffusion within the garnet is assumed to be negligible with only an infinitesimal layer at the edge in equilibrium with the matrix. MnO is preferentially incorporated in the garnet crystal. With depletion of MnO in the matrix, the amount of MnO in the garnet decreases and FeO shows an antipathetic increase. Atherton[1] presented a similar model based on a treatment of zone refining developed by Pfann.[10]

Fractionation models explaining garnet zoning have provoked criticism by petrologists who prefer a more specific mechanism oriented model that may be called tho reaction partitioning model.[12] The reaction partitioning model suggests that the garnet grows while its surface composition is controled by multivariant equilibrium with one or more reactants. On the basis of mineralogy and composition, it is inferred that the porphyroblastic garnets in the albite schists were produced by the following reaction.[9]

$$\text{Chlorite}_1 + \text{Celadonitic muscovite} + \text{Quartz} + \text{Calcite} \longrightarrow \text{Garnet} + \text{Chlorite}_2 + \text{Celadonitic poor muscovite} + H_2O + CO_2 \pm \text{biotite.}$$

As garnet remains refractory and does not re-equilibrate, it records and preserves its equilibrium composition for each step of growth and thus zonation results.

MnO and FeO are uniformly distributed in the garnets of granulite facies (garnet-sillimanite schists) rocks. This implies the volume diffusion of Mn and Fe exceeds the growth rate of garnet at the high temperature involved during granulite facies metamorphism. CaO and MgO profiles are flat at the central portion of the garnets. However, they show a weak but consistent variation at the margin. This weak zonation cannot be explained on the basis of cation exchange between garnet and adjacent matrix minerals in response to falling temperature during a retrograde cooling phase since the possible minerals that might have participated in such cation exchange, namely plagioclase and biotite are absent in the studied rocks.[8] Also, it is unlikely that garnet edge grew at an elevated temperature because this precludes the preservation of zonation by the increased mobility of Ca and Mg ions. A more likely explanation is that the garnet edge grew with falling temperature. Inclusion pattern observed in the garnets support the above suggestion. The boundary between the large inclusion-rich and narrow inclusion-free zone coincides with the compositional zonal boundary (Figure 3b) and indicates a physicochemical change in the rock system. It is possible that the inclusion-rich core may have grown rapidly at high temperature preventing the garnets freeing themselves from the inclusions while a slower rate of growth of garnet rim at a lower temperature enable the garnets to brush aside the foreign matter.[11]

This study and similar microprobe studies suggest that the compositional zonation in almandine garnets of granulite facies rocks though weak and variable, the zonation provides much information on crystal growth and metamorphic process.

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