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Structural and Compositional Evolution of Cr-Spinels and Hornblends, Palma Group, Rio Grande do Sul, Brazil

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Abstract - One amphibolite facies metamorphic event is registered in chromites and hornblendes from the Palma Group serpentinites and andesites, Brazil's southernmost Rio Grande do Sul State. Metamorphism was apparently caused by syntectonic injection of voluminous Cambaí Group meta-granitoids and not by post-tectonic Jaguari Granite intrusion. Regional metamorphic hornblendes are in direct contact with magmatic pargasites, which indicates that it was the first metamorphic event in the area. Both hornblendes in Campeslre Formation and Cr-spinel in Cerro da Cruz Formation are little zoned, an indication that only one metamorphic event was of regional extent. Recrystallization to chlorite + epidote green schist facies parageneses is restricted to shear zones and volumetrically small.

Keywords - Cr-spinel, hornblende, electron microprobe, backscattered electrons

INTRODUCTION

The internal structure and chemical composition of minerals establish fundamental constraints on the origin and evolution of the rock associations in which they occur. Minerals which present extensive solid solutions are even more useful as indicators of geological processes. The zoning of chromian spinels and hornblendes is a key to the correct unravelling of complex geological histories. We made use of these characteristics in Cr-spinel and hornblende to unravel the metamorphic evolution of the Palma Group serpentinities and andesites in the Palma region south of São Gabriel, State of Rio Grande do Sul, Brazil.

Chromian spinel texture and composition are good indicators of the tectonic environment of formation of the spinels (Irvine, 1965, 1967; Dick & Bullen, 1984; Sack & Giorso, 1991). Mantelllic chromites in ophiolites display ductile deformation, whereas crystal crystals respond mostly in a brittle manner to deformation (Strieder & Nilson, 1992). The spinel solid-solution series has been much studied, due to its tectonic, petrologic, and economic importance. The chemistry of Cr-spinels is constrained by many factors, including the magmatic or metamorphic (either mantellic or crustal) setting of formation; the chemistry can be usually discriminated among magmatic, metamorphic and mantelllic compositions (see Suita & Strieder, 1996, for a review).

The spinel group of minerals, including chromite, is highly reactive in the presence of metamorphic fluids and tends to re-equilibrate or newly-crystallize as P, T, X conditions change. This has been widely applied to unravelling how the rocks are affected by progressive regional or contact metamorphism (Matthes, 1971; Oliver et al., 1972; Trommsdorf & Evans, 1972; Springer, 1974; Evans & Trommsdorf, 1974; Evans & Frost, 1975; Arai, 1975; Irving & Ashley, 1976; Evans, 1977; Hietanen, 1977; Turner, 1981; Naumann & Hartmann, 1984; Suita, 1996; Suita & Hartmann, 1997). Internal parts of crystals may be armoured by newly-deposited or recrystallized rims, and thus preserve the chemical record of older events. The central parts of thick (>10 m) massive chromitites tend to preserve older compositions better than thin chromitites, whereas disseminated grains in a silicate matrix are usually re-equilibrated by superimposed younger events. Heat and fluids from intrusive granites may cause recrystallization of spinels, making this mineral group significant for the study of contact aureoles.

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15
Calcic amphiboles are common indicators of metamorphic conditions in deformed segments of the crust. Their chemistry is sensitive to varying P, T, X conditions, e.g. actinolite indicates greenschist facies and hornblende amphibolite facies (Bucher & Fry, 1994). Calcic amphiboles in low-pressure metamorphic belts have overall lower contents of Ti and Na when compared with medium-pressure belts (Laird & Albee, 1981; Hartmann et al., 1990). When subjected to stress during crystallization, the prisms are aligned along the foliation and may generate a lineation. In low-stress or contact metamorphism, the crystals tend to become poiquiloblastic without preferential alignment. Polymetamorphism may cause diffusional zoning in amphiboles. These characteristics were used for unravelling the metamorphic evolution of volcano-clastic rocks and integrated with the Cr-spinel studies from associated serpentinites.

Disseminated Cr-spinels are common in serpentinites and olivine-talc meta-serpentinites in southern Brazil and thus are useful for the identification of tectonic and petrologic environment of formation (Hartmann & Remus, 1999). They are common in the Vila Nova Terrane of Western Rio Grande do Sul State in southern Brazil, identified by Babinski et al. (1996), Leite (1997) and Leite et al. (1998) as juvenile accretion in the Neoproterozoic. The Cerro Mantiqueiras Ophiolite has been characterized by Leite (1997) and occurs only 30 km to the SE of the study area. The NS-trending, western border of the Dom Feliciano Belt of crustal reworking (Babinski et al., 1997; Silva et al., 1999) is positioned only 55 Km to the east. On the other hand, Remus et al. (1993) identified komatitic chemistry in the ultramafic schists located 35 Km to the north. These three contrasting neighbours may indicate that the VNT contains sepa of older basement in the juvenile terrane. Therefore, the crust in the Palma region could be very complex. Hence studies of chromian spinels were carried out in association with the andesitic hornblends to determine the origin and evolution of the Palma Group.

The Palma region has been the focus of geological interest for decades (Jost, 1966; Villwock & Jost, 1966). Its evolution is related to the complex geology of southern Brazil. Current models call either for a Neoproterozoic ophiolitic crust or an Archean greenstone belt, or else a tectonic mixture of the two rock associations, invaded by voluminous syn- to post-tectonic granites. Questions that require answer are the regional or contact metamorphic nature of the serpentinites and schists and the number of geological events registered in the minerals.

Additionally, the Cr-spinels could contain structural and chemical information regarding a mantelic or crustal origin, including the possible wide aureoles of crustal contact metamorphism. How can these Cr-spinels in the serpentinites and the hornblends in the meta-andesites be used to constrain these questions?

**GEOLOGY AND SAMPLES**

The Palma region (~30 x 30 km) is situated in the riverhead of the Rio Vacacai, south of the town of São Gabriel in Brazil’s southernmost State of Rio Grande do Sul (Fig. 1). Geological mapping was undertaken by many authors for two decades (Szubert et al., 1977; Kirchner & Grazia, 1978; Szubert, 1978; García & Hartmann, 1981; Kirchner & Andriotti, 1981; Chemale, 1982; Naumann et al., 1984; Santos et al., 1990), with reviews by Hartmann & Nardi (1983), Jost & Hartmann (1984) and Chemale et al. (1995). First geological studies in...
the area were done by Leinz (1943), Goñi et al. (1962) and Jost (1966). Senior undergraduates of UFRGS (1966, 1967, 1985) and UNISINOS (1981) mapped the region at the 1:50,000 scale. More recently, UFRGS (1996) senior undergraduates mapped the area during 30 days and sampled and thin sectioned 300 ultramafic, mafic and intermediate metamorphic rocks.

The ultramafic and andesitic rocks collected for this study are located close to coordinates 30°40'S, 54°07'W (Fig. 2). The ultramafics are strongly magnesian and most have a jackstraw texture (Snoke & Calk, 1978; Nesbitt & Hartmann, 1986) of interlocking one mm-long prisms of olivine and one mm-wide triangular portions of fine-grained interlocking blades of talc (Fig. 3). The arrangement of these crystals is approximately random, as observed on different scales, including hand samples sawed in three perpendicular directions. The olivine blades are almost entirely serpentinized, but they survive in few small patches, where the elongation sign is negative, a property of metamorphic olivines (Trommsdorf & Evans, 1972; Hartmann, 1982; Hartmann et al., 1987). All samples closer than 600 m from the granite have a jackstraw-texture whereas those farther away do not. Samples between 1,500 and 5,000 m from the granite have an interlocking arrangement of fine-grained serpentine and talc (or magnesite). Radiating bundles of tremolite (identified with the optical microscope and by EDS on the electron probe) are present in the matrix of the jackstraw-textured meta-serpentinites to a distance of 600 m from the contact, but are not seen farther away.

These rocks were collected from the Cerro da Cruz Formation serpentinites of the Palma Group, which also contains metabasalts, metandesites, metapelites, metatuffites and magnesian schists (Fig. 2). The ultramafic rocks of the Palma Group are varied in composition, containing serpentinites,
ultramafic schists rich in talc, chlorite and tremolite. The studied meta-andesites are part of the Campestre Formation of this Palma Group which is in concordant contact with the Cambai Group of gneissic diorites, tonalites, and granodiorites.

The Palma Group has not been dated radiometrically, but its minimum age is 700-750 Ma, which is the conventional U-Pb zircon age of the Campestre Formation dated to the north of the study area by Machado et al. (1990) and of the Cambai Group gneisses dated in an outcrop along Br-290 about 50 km to the north by Babinski et al. (1996). The Palma Group may contain unidentified septa of older paleoproterozoic sequences. Hence here is an intriguing problem that remains to be solved in this area, and is more important due to the proximity to the westernmost border of Gondwanaland. The Palma Shear Zone (PSZ), as defined by UFRGS (1996), is a major Neoproterozoic crustal-scale discontinuity, along which a clockwise movement is imprinted on all the lithological units, under transitional upper greenschist/amphibolite facies conditions.

Intrusive granites are volumetrically abundant in the region, including the Santa Rita Monzogranite, the São Manoel Granite, and the Jaguari Granite. These granites were intruded in the Palma and Cambai Groups at ca. 590-550 Ma (Gastal et al., 1992). They cause significant contact aureoles on the older sequences, such as in the southern part of the Santa Rita Monzogranite (Naumann & Hartmann, 1984). The aureole on the Palma Group in general, and in the northern part of the Jaguari Granite in particular, is investigated in this work for the first time.

The Jaguari Granite is rounded in shape and has 20 km in diameter (Gastal et al., 1992). A large contact aureole is to be expected, for Turner (1981) illustrates that the thermal effect of the igneous body tends to extend to a distance comparable to the diameter of the intrusion. The intensity of recrystallization of the Palma Group is expected to be attenuated by the low amphibolite facies parageneses already present before the intrusion of the granite.

Regional metamorphism was superposed in the Palma Group by the intense contact metamorphism of the postectonic granites; this makes very difficult the discrimination of the two metamorphic events, regional and contact. The regional metamorphism occurred in the greenschist to amphibolite facies transition, and is characterized in this investigation as M1. Greenschist facies M2 metamorphism is observed along shear zones. Although the large volume of intrusive granites makes the Palma and Cambai Groups resemble a mega-xenolith in which the contact metamorphic effects blur the evidence of regional metamorphism in places, it is seen that the highest grade of regional metamorphism corresponds to syn- to posttectonic metamorphism related to intrusion and deformation of syntectonic granite bodies such as the Sanga do Jobim Granitoids. A metamorphic overprint M3 in the low amphibolite facies is observed in some samples. This investigation concentrates on the M1 event, because it is the most intense in the region.

METHODOLOGY

Twenty serpentine samples were thinned-sectioned for petrography; each sample had a one-inch wide thick polished mount prepared for reflected light studies. Of these, eight were selected for electron microprobe analyses and imaging because they cover a fairly large distance away from the granite contact and have well developed Cr-spinel grains. Samples extend from 100 m near the contact of the Jaguari Granite to 5,000 m north of it. Six samples of meta-andesites from the Campestre Formation were selected for further studies out of 100 thin-sectioned, because they are located at increasing distances from the Jaguari Granite contact. This was done in order to test the hypothesis of contact metamorphism caused by intrusion of the Jaguari Granite into the Campestre Formation.

The Cr-spinels and hornblendes were investigated in the CAMECA SX-50 electron microprobe laboratory of Centro de Estudos em Petrologia e Geoquimica, Instituto de Geociencias, Universidade Federal do Rio Grande do Sul. Ten Cr-spinel images were made in the backscattered electron (BSE) mode using Polaroid 55 film. In sequence, twelve WDS quantitative scans were performed on the Cr-spinel crystals with the electron microprobe (EPMA). Backscattered electron (BSE) images were made with the electron microprobe on Polaroid 55 film and scanned. Oxides of the following elements were analysed with 10% accuracy and precision: Mg, Al, Cr, Mn, Ti, Fe, Si; ferrous and ferric iron were calculated by charge balance. Several spots were analysed on each studied hornblende crystal in the six samples; accuracy and precision are within 10%. Analytical data were retrieved in an electronic file and treated with
Microca! Origin 4.0 and CorelDraw 8. The analytical data were calculated and plotted with MinPet 2.0.

**EVOLUTION OF Cr-SPINELS**

The Cr-spinel crystals (Fig. 3) are euhedral to subhedral, 1-2 mm large and equant, and some are bordered by small grains of chromian magnetite, which are also abundant in seams in the crystal or dispersed in its matrix. Mg-chlorite occurs as rare 0.5 mm-large crystals in a few of the samples.

The BSE images (Figs. 4 and 5) reveal rather homogeneous crystals, without significant variations in average atomic numbers in the same grain. Nevertheless, some variation is present in Figs. 4a, 4c, 5c, 5d and 5e as darker and brighter areas. Brighter bands cut across the grains along fractures (e.g. Figs. 4a, 4e, 5d and 5e) and rims, and bright small grains are also present at the matrix.

Twelve traverses were made on the eleven studied Cr-spinels. Position of chemical traverses on the crystals are displayed in Figs. 4 and 5. Graphs in Figs. 6 and 7 and Table I demonstrate the rather homogeneous composition of the Cr-spinels. They are mostly chromites (35 wt% Cr2O3), but samples 7 and 8 (Figs. 4c and 4d) correspond to Cr-magnetites. Chemical zoning is very weak or absent, and only present in the rims, which trend towards slightly more iron-rich compositions. MgO and Al2O3 remain below 10 wt%. Contents of TiO2 are extremely low, except in Cr-magnetites.

Inhomogeneous parts of crystals are located mostly along fractures, as observed in the BSE images, and are invariably impoverished in Cr2O3 and enriched in Fe2O3. Sample 5 (Fig. 5d) is an exception, because Al2O3 may reach 42 wt% in parts of the crystal.

Optical and BSE observations show no evidence of ductile deformation – such as subgrains, dynamically-recrystallized smaller grains, or crystal stretching – more common in grains of crustal derivation. The mineral chemistry, particularly the low TiO2 content, might indicate mafic composition, but Figure 8 confirms that the crystals are not mantle-derived, for they plot entirely outside the ophiolitic field. They also plot outside the mafic field, and therefore this possibility is rejected.

A solid-state crustal origin is indicated by the chemistry of the crystals, because all compositions fall in the metamorphic field. The grade of metamorphism shown by the composition of the spinels (Fig. 8) varies from upper greenschist to lower amphibolite facies. No regular chemical variation is observed with distance from the Jaguari Granite contact, as can be seen by comparing field location (Fig. 2) with composition of crystal (Figs. 4, 5, 6 and 7). This is due to thorough recrystallization of the spinels in the regional metamorphic event, before intrusion of the granite. The thermal effect was only observed in the formation of picotite and radiating bundles of tremolite in the matrix of serpentinites very close to the granite contact; recrystallization of the Cr-spinels to Cr-magnetite along fractures may also be due to this event.

**HORNBLENDES**

Rock types are rather varied in the Palma Group, but the Campestre Formation meta-volcaniclastics are abundant and contain the studied hornblendes. The low amphibolite facies metamorphism and deformation were intense, but the dominant quartz-feldspar-amphibole mineralogy of the meta-andesites (Fig. 9, Table 2) makes them massive and weakly banded S and L tectonites, in general. Amphiboles are very common. An igneous amphibole (Table 2) is present regionally in the Palma Group in peridotites, pyroxenites, gabbros, anorhositcs, basalts and andesites. In all these rock types, the amphibole is of late-igneous crystallization, brown to reddish brown in color, large 2V (§), extinction angle = 30°. These amphiboles are descriptively classified as basaltic hornblendes (Deer et al., 1966), and were correctly considered pargasites by Garcia & Hartmann (1981), Chemale (1982) and Oliveira (1982). Amphiboles from the Campestre Formation were studied in this project in ca. 100 thin-sections, and in additional 300 thin-sections from previous studies (Garcia & Hartmann, 1981; Chemale, 1982; Oliveira, 1982).

Calcic amphiboles with appreciable Al content may be called hornblendes, according to Deer et al. (1992, p. 226) and these are the predominant amphiboles in the Campestre Formation. They are light green under the microscope and tend to be optically unzoned, indicating that only one metamorphic event occurred in the region or two events in very similar metamorphic conditions. Some are partially to completely altered to either chlorite or epidote, but some thin-sections both alteration minerals are present.

Chemical analyses of the amphiboles (Table 3, Figs. 10 and 11) are of calcic amphiboles with predominance of tschermakitic hornblendes. Most
Figure 4 - Backscattered electron images of Palma Group Cr-spinels. EPMA scans indicated by white lines.
Figure 5 - Backscattered electron images of Palma Group Cr-spinels. EPMA scans indicated by white lines.
Figure 6 - Distance-composition diagrams of several Cr-spinel crystals have very little zoning.

Figure 7 - Distance-composition diagram of several Cr-spinel crystals show little zoning; fractures are sealed by Cr-magnetite (e.g. e and f). Al₂O₃ content of sample 5 is low about 10%, but some high-aluminum portions reach about 40%.
Table 1 - Representative electron microprobe chemical analyses (wt %) of studied Cr-spinels. One spot analysis selected from homogeneous crystals, two spot analyses from zoned crystals. - below detection limit.

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
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<tbody>
<tr>
<td>SiO₂</td>
<td>0.42</td>
<td>1.29</td>
<td>0.28</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>TiO₂</td>
<td>7.93</td>
<td>4.69</td>
<td>3.27</td>
<td>4.49</td>
<td>1.78</td>
<td>6.38</td>
<td>9.11</td>
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<td>53.18</td>
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<td>3.54</td>
<td>4.09</td>
<td>1.28</td>
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<td>MgO</td>
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<td>6.87</td>
<td>5.74</td>
<td>2.95</td>
<td>5.30</td>
<td>5.28</td>
<td>2.27</td>
<td>9.93</td>
<td>2.84</td>
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<td>0.64</td>
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<td>0.79</td>
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<td>Total</td>
<td>99.03</td>
<td>99.33</td>
<td>98.78</td>
<td>98.13</td>
<td>98.81</td>
<td>98.21</td>
<td>97.16</td>
<td>95.74</td>
<td>98.06</td>
</tr>
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</table>

Figure 8 - Selected compositions of six analysed crystals plotted on discriminant diagram (Irving, 1965). All samples plot in the upper greenschist/low amphibolite facies (UG/LAF) field; a few of the sample 5 compositions plot in the upper amphibolite/granulite facies (UA/GF) field. None of the samples plots in the ophiolite/upper mantle (OPH) or igneous stratiform (STR) fields. Retrogressive Cr-magnetite compositions in the lower greenschist facies (LGF) were not plotted for clarity.

Figure 9. Scanned thin-sections of andesites (samples 1-6) used in this investigation. Metamorphic foliation indicated by black lines.
Table 2 - Rock and hornblende characteristics in studied meta-andesites from the Campestre Formation, Palma Group.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Mineralogy</th>
<th>Texture</th>
<th>M1 hb pleochroism</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ig = plag, qz, M1 = bio, gar, epi, tit, hb, M2 = carb, chlo, epi</td>
<td>M1 matrix weakly granoblastic; porphyroblastic M2 Nematoblastic</td>
<td>Ng = bluish green, Nm = intense green, Np = light yellow</td>
</tr>
<tr>
<td>2</td>
<td>Ig = plag, qz, M1 = hb, zo, bio, op, M2 = chlo</td>
<td>M1 matrix weakly granoblastic; porphyroblastic M2 Lepidoblastic</td>
<td>Ng = bluish green, Nm = intense green, Np = pale yellowish green</td>
</tr>
<tr>
<td>3</td>
<td>Ig = plag, qz, kf, op, zir, tit, M1 = bio, anf, M2 = chlo, carb</td>
<td>Matrix weakly granoblastic M1 porphyroblastic M2 granoblastic decussate</td>
<td>Ng = intense green, Nm = intense green, Np = pale yellow</td>
</tr>
<tr>
<td>4</td>
<td>Ig = plag, qz, M1 = hb, epi, op, carb, M2 = chlo</td>
<td>M1 matrix granoblastic M2 weakly nematoblastic M3 granoblastic decussate</td>
<td>Ng = bluish green, Nm = intense green, Np = golden yellow</td>
</tr>
<tr>
<td>5</td>
<td>Ig = plag, qz, M1 = epi, hb, op, M2 = epi, ser</td>
<td>M1 incipient granoblastic and porphyroblastic M2 incipient nematoblastic</td>
<td>Ng = green, Nm = bluish green, Np = golden yellow</td>
</tr>
<tr>
<td>6</td>
<td>Ig = plag, qz, M1 = hb, epi, carb, op, M2 = chlo</td>
<td>M1 matrix weakly granoblastic porphyroblastic M2 lepidoblastic</td>
<td>Ng = bluish green, Nm = intense green, Np = pale golden yellow</td>
</tr>
</tbody>
</table>

Obs.: plag = plagioclase, qz = quartz, bio = biotite, gar = garnet, epi = epidote, tit = titanite, hb = hornblende, carb = carbonate, chlo = chlorite, zo = zoisite, op = opaque mineral, kf = K-feldspar, zir = zircon, ser = sericite. M1 = oldest regional metamorphism, low-amphibolite facies; M2 = shear zone metamorphism, greenschist facies; M3 = latest metamorphism, low-amphibolite facies.

Figure 10 - Hornblende compositions from meta-andesites define a narrow compositional field in the Leake et al. (1997) diagram. Each symbol corresponds to analyses of hornblendes from one thin section.

Palma, and is indicative of crystallization in medium P/T metamorphic conditions (Laird & Albic, 1981; Hartmann et al., 1990). Heat flow in this island-arc sequence was therefore lower than in some of the younger volcanic environments in other parts of the world, where low P/T conditions predominate.

Observation of Figure 2 indicates that metamorphic pressures were fairly high, for there is

Figure 11 - Chemical composition of analyzed hornblendes has a tschermakitic trend. In this diagram, only the average composition of analyzed amphiboles is shown for each sample.

Figure 12 - Low-Ti content of analyzed hornblendes, as commonly observed in hornblendes from medium P/T metamorphic belts. Low P/T hornblendes from other terrains straddle the inclined line. In this diagram, only the average composition of analyzed amphiboles is shown for each sample.
Table 3 - Representative electron microprobe analyses of hornblendes from the Cambaizinho Formation. One metamorphic (low TiO₂) and one magmatic (high TiO₂) analysis in sample 7 hornblendes.

<table>
<thead>
<tr>
<th>Sample</th>
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<td>Na₂O</td>
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<td>1.33</td>
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<td>1.24</td>
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<tr>
<td>K₂O</td>
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<td>0.39</td>
<td>0.59</td>
<td>0.36</td>
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<tr>
<td>P</td>
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<td>0.00</td>
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<tr>
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<td>97.95</td>
<td>98.65</td>
<td>97.11</td>
<td>98.43</td>
<td>100.69</td>
<td>97.90</td>
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</table>

An absence of correlation between amphibole composition and distance from the Jaguary Granite contact. Figure 10 shows that there is little variation in amphibole chemistry with distance from granite contact. This shallow intrusion is therefore not the cause of the regional metamorphic event.

Because the hornblende textures are indicative of syn- to postecotic metamorphism, the source of heat may be found in the sum of the several foliated granitic intrusions in the area. The Palma Group resembles a mega-xenolith contained in the syn- to postecotic magmas. The rocks were probably subjected to intense circulation of fluids (and advecting heat) from the crystallizing granites.

The regional syn- to postecotic M1 event generated parageneses nearly in thermal equilibrium with the intruding postecotic granites; hornblendes remained stable, without generation of zoning to lower-grade amphiboles. This is the geological explanation for the textural and compositional observations on the amphiboles.

CONCLUSIONS

Cr-spinels in the northern aureole of the Jaguary Granite were formed as accessory minerals during regional metamorphism of ultramafic rocks; serpentinites and jackstraw-textured meta-serpentinites were formed during this event. Hornblendes in meta-andesites were formed in this same regional metamorphism, which is well preserved throughout the entire Palma Group. Grade of metamorphism varies from epidote-amphibolite to lower amphibolite facies, whereas the contact effect is only observed as lower grade recrystallization in the matrix of serpentinites or in fractures, the crystals modifying their chemistry accordingly from chromite to chromian magnetite; epidote and chlorite are formed in the meta-andesites. Lack of zoning of amphibole crystals indicates that the low-grade event of chlorite and epidote formation remained restricted to narrow shear zones because the amphiboles did not recrystallize during this event. This seems a low-grade shear-zone metamorphism. Older chromian spinels are mostly chromites but chromian magnetites also occur; these minerals show weak chemical zoning. Late inhomogeneities occur along fractures in the Cr-spinels where they tend to be poor in Cr₂O₃ and rich in Fe₂O₃. Low TiO₂ in studied chromites may be caused by regional crustal metamorphism, and does not seem to be related to a mantellic origin. The source of heat for metamorphism may be the nearly simultaneous intrusion of several granitic plutons, affecting the Palma basement as a mega-xenolith.

No indication is obtained from the Campestre Formation hornblendes or Cerro da Cruz Formation Cr-spinels for decreasing conditions of contact metamorphism with increasing distance from the Jaguary Granite contact. Low Ti and Na of the M₁ hornblendes characterizes the Campestre Formation as a medium P/T metamorphic belt comparable to the Cambaizinho belt 50 km to the north.

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REFERENCES


