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METAKOMATIITIC AND META-ULTRAMAFIC ROCKS FROM THE RIO MANSO REGION, MINAS GERAIS: GEOLOGY, TEXTURES AND METAMORPHISM

STELAMARIS DE OLIVEIRA PINHEIRO[1] AND ARIPLINIO ANTONIO NILSON[2]

ABSTRACT The study area is located in the southwestern part of the "Quadrilátero Ferrífero", south of Serra do Curral, Minas Gerais (Brazil). Three major units occur in the area: Granite-Gneiss Complex, Nova Lima Group and intrusive bodies. The Nova Lima Group consists of metakomatiite and metakomatiitic basalt, meta-ultramafic rocks devoid of spinifex texture, rare iron formation, amphibolites and metasedimentary rocks. It comprises mainly meta-ultramafic rocks without primary igneous texture relicts and subordinate metakomatiitic rocks. Metakomatiites occur only in Morro da Onça, and display spinifex texture, especially of the random type. Thin layers interpreted as probable metacumulate parts of flows (B zone) occur locally. A structure that may correspond to a komatiite lava tube is also exposed. Metakomatiites are typically peridotitic komatiites and subordinately komatiitic metabasalts; the latter may exhibit pillow-lava structures. Progressive metamorphic evolution began with a Mg-chlorite + tremolite-actinolite paragenesis. In a second stage orthopyroxene and olivine porphyroblasts were developed in a Mg-hornblende groundmass. Progressive increase of Al in chlorite contributed to olivine and rare anthophyllite blastesis in the initial phases of the progressive metamorphism. Late metasomatism led to serpentinization and talcification. Amphibole plays an important role when the modal/textural relations of the highest-grade metamorphic parageneses are considered. Al enrichment of Ca-amphibole through tschermak and edenite replacements led to consumption of olivine to yield pyroxene and to spinel consumption through its incorporation as the aluminous component of amphibole. Thus the area consists of abundant meta-ultramafic rocks devoid of igneous texture relicts and subordinate komatiitic flows with thin cumulate zones. The former may partly correspond to an ultramafic layered sequence.

Keywords: Komatiite, spinifex, Morro da Onça, ultramafic rocks, metamorphism.

INTRODUCTION Komatiites yield important data on the thermal conditions and on the composition of the Archean mantle. They are present in virtually all Archean cratonic areas: southern Africa, Australia, India, Russia, Scandinavia, Canada, Brazil, etc. The occurrence of typical komatiites in the Rio Manso region, Minas Gerais, in the southern portion of the São Francisco Craton was initially reported by Noce *et al*. (1990). It represents a new occurrence of komatiitic lavas in the southern part of the craton, along with komatiites from Fortaleza de Minas (Brenner *et al.* 1990), Pium-hi (Schrank *et al*.1984) and Santa Bárbara (Schorcher 1978). The Rio Manso komatiites are exposed mainly in the Morro da Onça and exhibit well-preserved volcanic features. These include well-developped spinifex texture and lava tube remnants in komatiites, and pillowed flows in basaltic komatiite. These primary features are obliterated by amphibolite facies metamorphic recrystallization and superposition of greenschist facies parageneses in most of the dominantly ultramafic belt under study.

The aim of this paper is to document and interpret the geology, the volcanic structures and textures of the komatiites as well as the superposed metamorphic features, especially in the ultramafic rocks devoid of spinifex texture.

GEOLOGY The study region comprises a rectangular area of approximately 115 Km^2 located in the southwestern part of the "Quadrilátero Ferrífero" (Fig. 1), south of the Serra do Curral and approximately 100 km SW of Belo Horizonte, in the state of Minas Gerais. A metasedimentary sequence of the Minas Supergroup extending from Serra do Curral to the north intercepts an extensive greenstone belt terrain correlated to the komatiite-bearing Nova Lima Group in this region (Noce *et al.* 1990; Pinheiro and Nilson 1997, 1994, 1993; Pinheiro 1998).

Three lithostratigraphic units were identified, namely the Granite-Gneiss Complex, the Nova Lima Group and small intrusive bodies (Fig. 2). The Nova Lima Group volcano-sedimentary belt is exposed in the central portion of the study area; gneisses and intrusive rocks surround it.

Granite-Gneiss Complex The Granite-Gneiss Complex is represented mainly by white, sometimes porphyritic, granodioritic to tonalitic biotite-gneiss, consisting of quartz, plagioclase, subordinate K-feldspar and biotite. The granitic gneisses commonly exhibit alternating quartz-feldspar-rich bands and discontinuous mafic-rich bands. Fine to medium-grained granitic rocks containing quartz, K-feldspar, biotite, muscovite and sometimes garnet are exposed in the western part of the area. Small elongate N-S trending metabasite bodies and small amphibolite bodies occur in the gneisses east of the volcano-sedimentary belt.

Nova Lima Group Nova Lima Group rocks consisting of metakomatiite and komatiitic metabasalt flows and associated massive meta-ultramafic rocks and rare amphibolites outcrop along a N15E trending belt that is over 20 Km long and 500 to 3 000 m wide. This dominantly meta-ultramafic sequence contains narrow amphibolite and "ferruginous quartzite" units.

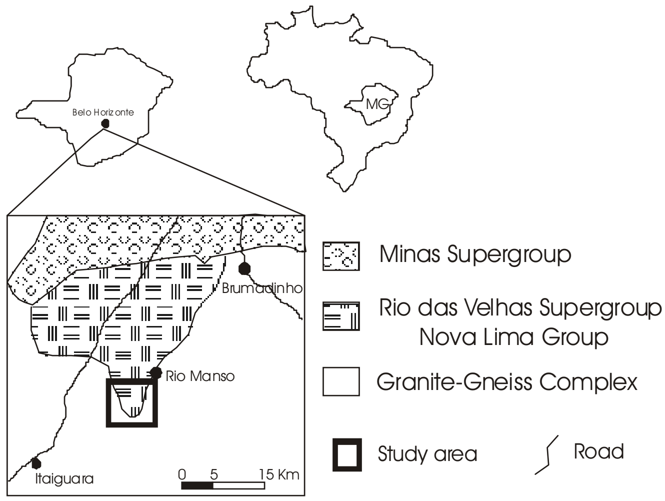

Figure 1 – Location map showing the Rio Manso study area in Minas Gerais (MG), Brazil

KOMATIITES AND ULTRAMAFIC ROCKS The northern and central portions of the dominantly meta-ultramafic belt consist mainly of rocks where no spinifex texture is observed. However, in the Morro da Onça, located west of Barro Preto in the southern portion of the area (Fig. 2), well-defined spinifex texture and probable lava tubes are exposed.

Spinifex textured units display textural zoning which is defined by the change in grain size of tremolite, serpentine and subordinate chlorite crystal aggregates; the latter are pseudomorphs after laminar/ plate-like crystals of primary olivine. Layering trends close to N80E and dips vertically; flow tops point south. Individual komatiitic flows are about 0.5 to 3 m thick. As there often occurs a false spinifex-like texture, sometimes true spinifex texture may only be confirmed through microscopic observation. One single outcrop shows fourteen thin units where spinifex textured layers alternate with fine-grained isotropic homogeneous rock. Spinifex textured layers are about 20 cm thick, while the isotropic rock layers are approximately 10 cm thick. Chemically, spinifex-textured layers and isotropic layers correspond to pyroxenite and peridotite respectively. This layered volcanic sequence may exhibit very open folds, which are interpreted as the result of movement of partially consolidated lava. A similar structure has also been described in komatiitic basalts from the Nondweni greenstone

1 - Instituto de Geociências, Universidade Federal de Minas Gerais, Av. Antonio Carlos, 6627 CEP 31270-010 Belo Horizonte, M.G., Brasil
2 - Instituto de Geociências, Universidade de Brasilia, CEP 70910-900, Brasilia, D.F., Brasil

belt in the southern part of the Kaapval craton, South Africa (Wilson and Versfeld 1994).

It is emphasized that even in Morro da Onça outcrops exhibiting unequivocal spinifex texture are few; they are adjacent to ultramafic rock outcrops without spinifex texture. Therefore, the prevailing lithotypes in the area are massive meta-ultramafic rocks devoid of spinifex texture.

Meta-ultramafic rocks without spinifex texture are easily characterized on textural grounds. They are coarse grained, exhibiting pyroxene crystals with well-defined shapes, identifiable even when partially or totally replaced by talc. Some outcrops display distinct layering, characterized by the alternation of rocks of “pyroxenitic” composition with others of a more “peridotitic” composition. In the southern part of the area there is a set of meta-ultramafic rock outcrops, where metric width layers of ultramafic rocks containing very coarse pyroxene grains (1-2cm) are intercalated with ultramafic rocks carrying serpentinized olivine and amphibole. A peculiar ultramafic rock with coarse olivine “nodules” occurs in Morro da Onça. These “nodules” are embedded in a fine to medium grained groundmass consisting of tremolite and serpentine.

Komatiitic basalt exhibiting pillow-lava structures and epidote-rich inter-pillow material is exposed west of Bernardes (Fig. 2).

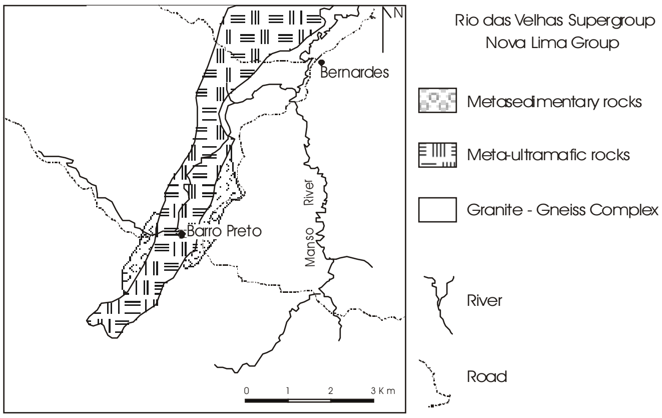

Figure 2 – Simplified geological map of the Rio Manso ultramafic rocks

OTHER ROCK TYPES Layers of finely banded quartz amphibolite (“ferruginous quartzite” when weathered) of limited lateral extent are part of the dominantly meta-ultramafic belt. Rare metasedimentary rocks, such as sericite-quartz-chlorite schists, sericite-quartz schists and quartzites as well as rare metaconglomerate associated with garnet-sillimanite quartzite, all belonging to the Nova Lima Group, are exposed mainly along the eastern border of the belt.

Small intrusive bodies Rare metabasite bodies and a small metadiorite intrusion occur close to the contact of the dominantly ultramafic sequence with the Granite-Gneiss Complex.

PETROGRAPHY AND TEXTURAL EVOLUTION **Primary textures** Meta-ultramafic rocks were subdivided into metakomatiites and ultramafic rocks devoid of spinifex texture. Metakomatiitic rocks originally consisted of igneous olivine, clinopyroxene and chrome-spinel plus a glass-like groundmass. They exhibit textures of random spinifex and plate spinifex types. The latter displays pseudomorphs of tabular olivine crystals in sub-parallel arrangement. However, it is no longer possible to observe the internal morphology of these grains because of metamorphic changes. Metakomatiitic rocks may either show well-preserved or poorly-preserved spinifex texture.

Metamorphism and Textural Evolution Meta-ultramafic rocks without spinifex texture do not show any relict igneous textures. In contrast, metakomatiitic rocks are composed of metamorphic ferromagnesian minerals preserving igneous textures. Previous olivine plates now consist of chlorite associated with minute opaque grains. Zones formed by pre-existing clinopyroxene grains have been changed to tremolite/actinolite and hornblende. Talcification obliterates these features but opaque grain trails still mark previous spinifex plate outlines. Amphibole blastesis overprinting pre-existing spinifex texture occurs in various ways: (a) pseudomorphic amphiboles after clinopyroxene interstitial to olivine plates with random texture; (b) short granoblastic/prismatic amphibole grains intercalated with aggregate of fine chlorite that are pseudomorphic after spinifex olivine and (c) late prismatic amphibole.

Metakomatiites with poorly preserved spinifex texture are characterized by parageneses resulting from intense metamorphic replacements. Spinel grains occur in two distinct ways in these rocks: (a) forming trails in portions that correspond to previous spinifex textured zones and (b) disseminated grains. Spinel grains are usually xenoblastic displaying chlorite and opaque mineral fringes. Highly talcified orthopyroxene porphyroblasts were identified in some rocks displaying spinifex texture.

Metakomatiites usually consist of Ca-amphibole, serpentine, talc, and subordinate chlorite, besides opaque grains and spinels. The spinifex texture is marked by brownish spinel grain trails having opaque mineral rims. In some intensely talcified rocks without orthopyroxene remnants, traces of opaque grain trails are evidence of spinifex texture relicts. Thus the main criterion for the identification of previous olivine plates is the presence of minute opaque grain trails associated with amphibole bands representing pre-existing clinopyroxene zones.

Bands of fine serpentine probably result from progressive metamorphism up to amphibolite facies yielding olivine grains that were later retrometamorphosed forming the serpentine minerals. The presence of orthopyroxene porphyroblasts in rocks with spinifex texture also points to high-grade metamorphism. In most metakomatiites orthopyroxene has been replaced by talc and olivine formed during high-grade metamorphism has been totally serpentinized. Thus it is concluded that these rocks were composed of parageneses of high metamorphic grade, having undergone selective reequilibration during the lower grade retrometamorphic stages.

Ultramafic rocks without spinifex texture are the most abundant type in the area. They were subdivided into four petrographic types: (a) orthopyroxene and olivine-bearing rocks; (b) serpentine and talc-bearing rocks; (c) talc and/or serpentine-rich rocks and (d) Ca-amphibole-bearing rocks. Orthopyroxene (mostly porphyroblastic) and olivine-rich ultramafic rocks are less common than the other rock types. Partially serpentinized olivine occurs as inclusions in orthopyroxene and as interstitial grains. Brown to green spinel is abundant, occurring as disseminated translucent grains and as inclusions in orthopyroxene. Zoned spinel displaying a dark brown core and light brown rim is also observed. Some spinel grains show opaque borders and others present the opaque part in a green spinel core. Chlorite is rather uncommon.

Talcified and subsequently serpentinized orthopyroxene is common in these rocks. In advanced stages of metamorphic alteration, serpentinization may become the most important process and rare talc (ex-orthopyroxene) is left. Thus rocks consisting of serpentine and talc are the result of strong talcification and serpentinization. Meta-ultramafic rocks that consist mainly of amphibole also contain talc, serpentine and chlorite along with spinels and opaque grains. Anthophyllite- bearing rocks are rare.

A meta-ultramafic rock containing large “nodular” olivine crystals (0.2 to 4 cm in diameter) is exposed in Morro da Onça. The “nodules” correspond to irregular poikilo-porphyroblastic olivine grains of $Fo_{82.7-83.4}$ composition. This olivine is sometimes partially serpentinized; it contains inclusions of amphibole associated with opaque grains, brown spinel, chlorite and carbonate.

The main parageneses of amphibolite facies and superimposed low-grade metamorphism both for the metakomatiitic and meta-ultramafic rocks devoid of spinifex texture are respectively:

a. Orthopyroxene (⟹ talc) + olivine (⟹serpentine) + Ca-amphibole + green/brown spinel ± chlorite ± opaque minerals.

b. Serpentine + talc + Ca-amphibole ± chlorite ± spinel + opaque minerals.

Mineral Chemistry Amphiboles of the metakomatiitic and meta-ultramafic rocks without spinifex texture correspond to tremolite, tremolitic hornblende, actinolitic hornblende and magnesio-hornblende. They show a positive trend in the Al^{IV} X Al^{VI} diagram characterizing tschermak and edenite type replacements. The majority of the chlorites in the ultramafic rocks present Al^{IV} content between 2.0 and 2.5 and Al^{IV}/Al^{VI} ratio close to 1 (tschermak replacement). The limiting Al content in chlorites is near 4.8 atoms p.f.u. which is equivalent to one (x)Al of 2.4 for the ideal chlorite structural formula (28 O basis). Spinels of metakomatiitic and meta-ultramafic rocks without spinifex texture display a metamorphic trend in the Cr/(Cr+Al) X $Fe^{2+}/(Fe^{2+}+Mg)$ diagram. The most important replacements in the spinels are between Cr-Al. The composition of orthopyroxene is $En_{87.5-80.5}$ while that of olivine is within the $Fo_{78.9-93.5}$ range.

DISCUSSION AND CONCLUSIONS

Spinifex-textured metakomatiític rocks from Rio Manso show parageneses resulting from intensive metamorphic replacements. However, even when talcification is strong spinifex texture is still clearly discernible. Metakomatiites typically display triangular features associated with random type spinifex texture.

The presence of spinifex texture, pillow-lava structures and probable lava tubes indicate that the komatiític lavas were discharged in sub-aquatic, probably submarine environment. The highly magnesian composition of these lavas is attributed to a high degree of partial melting of the mantle and a high geothermal gradient in the Archean.

The Rio Manso metakomatiites are associated with rocks of peridotitic and pyroxenitic composition devoid of spinifex texture. The latter rocks are locally layered possibly including metamorphosed cumulate terms. In addition, the Rio Manso ultramafic and mafic lavas with minor associated metasedimentary rocks demonstrate the continuity of the Rio das Velhas greenstone belt WSW of the Quadrilátero Ferrífero.

The parageneses of the Rio Manso meta-ultramafic rocks evolved from rocks containing chlorite and calcic amphibole of the tremolite-actinolite type in greenschist facies conditions. This paragenesis evolved through gradual aluminum enrichment of Mg-chlorite and Ca-amphibole. Olivine porphyroblasts were formed from magnesium released by chlorite and amphibole along with the generation of spinel and orthopyroxene. Medium and higher grade, amphibolite facies parageneses are observed in the both types of meta-ultramafic rocks; they consist of orthopyroxene (remains) + amphibole (Mg-hornblende) + spinel and opaque grains in metakomatiites and orthopyroxene ± olivine + amphibole (Mg-hornblende) + green spinel in meta-ultramafic rocks without spinifex texture.

Metamorphic evolution of the ultramafic rocks began with the Mg-chlorite + Ca-amphibole paragenesis. In ultramafic rocks without chlorite, where there was total Mg-chlorite consumption, the lower temperatures for this phase are 730 to 780° C for pressures between 3 and 6 kbar, and total pressure = p H_2O (Evans 1977). In ultramafic rocks Mg-chlorite usually has Al content near the upper thermal stability limit or (x)Al ≈ 1.2. Final Mg-chlorite breakdown results from the reaction: Mg-chlorite ⇔ forsterite + enstatite + spinel + H_2O. Al-tschermakitic replacements alone are not enough to explain the aluminous character and thermal stability of the amphiboles; in this case, an additional control would be provided by sodium incorporation (Szabó 1996). Progressive aluminum enrichment of amphiboles in relatively sodium-rich rocks (when chlorite is metastable) is explained by the combination of tchermak and edenite replacements. When tchermak (Si_{-1} Mg_{-1} ⇔ $Al^{IV}Al^{VI}$) and edenite (Si_{-1} ⇔ $NaAl^{IV}$) substitutions are combined, tschermak replacements produce Si:Mg in enstatite proportion, while edenite replacements release silica, which reacts with olivine, formed by chlorite breakdown reactions, leading again to enstatite formation.

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