THERMOCHRONOLOGICAL HISTORY OF THE IMATACA COMPLEX, NW AMAZONIAN CRATON

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INTRODUCTION AND GEOLOGICAL SETTING

Archean and Proterozoic events have played an important role on the geodynamic evolution of the Amazonian craton, whose tectonic stability took place at the end of the Late Mesoproterozoic (Cordani & Brito Neves, 1982).

The Archean Imataca Complex (IC) occurs in the Venezuelan NW corner of the Amazonian Craton and forms a ENE-trending, fault-bounded block adjacent to the Palaeoproterozoic Maroni-Itacaiúnas Belt. IC rocks are intensely deformed, by folding, thrusting and shearing. Transcurrent faults (like the Guri Fault) are important. along the southeastern edge of the IC. Imataca Complex (IC) comprises mostly medium- to high-grade facies quartz-feldspathic paragneisses (e.g. Sidder & Mendoza, 1995); granitoids and calc-alkaline gray gneisses of igneous derivation are also present, as well as dolomitic marbles, mafic/intermediate granulites and BIFs that constitute huge iron ore deposits of Algoma type. Several quartz-monzonite sills and granitoid plutons (e.g., Encrucijada granite) were emplaced into the IC during the Transamazonian orogeny, between 2.2 and 2.0 Ga, (e.g. Gibbs & Barron, 1983; Onstott et al., 1989).

Geophysical and isotopic evidence, coupled with the recognized polyphase tectonic framework of the Archean crust, indicate that the IC is an allochthonous block which was juxtaposed to the Maroni-Itacaiunas belt during Late Paleoproterozoic times (Onstott & Hargraves, 1981; Tassinari & Macambira, 1999). Therefore, Transamazonian events play an essential role on the development of major petrologic and tectonic features of IC. Accordingly, this study starts by characterizing Transamazonian granulitic metamorphism in the San Felix - Upata area. New petrological and isotopic data will be used to discuss the age/nature of protoliths and, particularly, their thermochronologic evolution during the Transamazonian event. In this respect our new data complements and updates previoius studies by Onstott et. al. (1989) and Swapp & Onstott (1989) on Imataca Complex.

METAMORPHISM

Rocks from the Imataca Complex of Venezuela record high temperature regional re-crystallization at granulite facies peak metamorphism during the Trans-Amazonian Orogeny (Dougan, 1974; Swapp & Onstott, 1989).

Within the collecting area, the general strike of metamorphic foliation is close to E-W (steeply the dipping to S) and predates the development of NE-SW left-lateral shearing, representing local expressions of the main Guri and El Pao regional fault zones. Four samples were selected for detailed petrological and isotopic analysis, because they contain convenient assemblages for geothermobarometric and thermochronological determinations, and/or reflect structural relations that constraint relative timing of metamorphism and deformation. Of the four selected samples, two (63A, 63B) are garnet + orthopyroxene + plagioclase + Kfeldspar + biotite bearing granulites, 65A is a two-pyroxene + plagioclase + Kfeldspar + hornblende + biotite + quartz granulite, and 65-1 is a felsic "blastomylonite" collected from a (metric) shear zone that cuts across previous metamorphic structures.

Sample 65-1 is composed of quartz + plagioclase + Kfeldspar + biotite ± muscovite. It has a distinctive planar fabric defined by aligned biotite and ribbons of quartz; feldspars have experienced grain size reduction and some grains have been deformed into sigmoid-shaped crystals. Shearing was associated with retrograde development of (secondary) muscovite, contrasting with the observations of Swapp & Onstott (1989) at El Pao mine.

Two pyroxene granulite 65A has typical granuloblastic texture and relatively homogeneous mineral compositions.

Garnet granulites have granoblastic texture, particularly well equilibrated in sample 63A. Sample 63B has higher modal amounts of garnet and displays gneissic structure due to alternating garnet + biotite- and feldspar-richer layers. Orthopyroxene and (particularly) garnet contain abundant biotite inclusions (especially, in sample 63B) and larger orthopyroxene crystals surround (earlier) garnet, separating it from plagioclase; these features, coupled with complex plagioclase + K-feldspar intergrowths, suggest that the decompression P-T path followed by these rocks may have reached conditions that were close to those of biotite dehydration melting (biotite + quartz $\rightarrow$ orthpyroxene + K-feldspar + liquid).

THERMOBAROMETRY: PEAK METAMORPHIC CONDITIONS AND P-T PATH

Previous estimates of Trans-Amazonian peak metamorphic conditions in the Imataca Complex have been reviewed by Swapp & Onstott (1989), who suggested T and P in the range of 750 - 800 °C and 8 - 8.5 kbar for granulites at El Pao mine.

Overall geothermobarometric data indicates that San Felix granulites reached similar peak metamorphic conditions at 750 - 800 °C, 6 - 8 kbar, followed by decompression and cooling.

Petrographic evidence to constraint the prograde P-T evolution of San Felix granulites has been mostly erased by subsequent reactions. However, our data is consistent with that of Swapp & Onstott (1989) and both suggest a clockwise P-T path involving decompression and heating to peak conditions; the general absence of early kyanite in Imataca rocks (Dougan, 1974; Swapp & Onstott, 1989) limits the amount of decompression to < 2 kbar. A constraint on the retrograde P-T path comes from noting that 3qz + gr + 2alm = 6fs + 3an equilibrium has an almost constant slope for the investigated compositions. Thus, the retrograde path was defined as to follow that line down to about 600 °C, at ~ 15 bars/degree °C. Regardless of the actual meaning of the estimated retrograde P-T path, it is worth noting that the San Felix granulites must have remained at relatively high temperatures for long enough to allow the observed retrograde re-equilibration.

ISOTOPE GEOLOGY

GEOCHRONOLOGY

Several radiometric studies were performed in the Imataca Complex (IC) (Hurley et. al., 1976, Montgomery, 1979, Montgomery et al., 1977, Onstott et al., 1989; Tassinari et. al.. 2001). The geochronological pattern indicates that the IC comprises na Late Archean (~ 2.8 Ga) reactivated during the Transamazonian orogeny (2.2 - 2.0 Ga)

$^{40}Ar/^{39}Ar$ data (Onstott et al., 1989) on El Pao mine (IC) high-grade gneisses range from 1.97 to 1.76 Ga, recording the warning stages of the Transamazonian orogeny (uplift and cooling.), whereas 1.4 - 1.1 Ga dates indicate further reactivation during the Mesoproterozoic.

During this study new SHRIMP zircon U-Pb age determinations were undertaken on banded granulitic rocks from San Felix-Upata area. Dominant oscillatory zoned, prismatic, zircons from a quartzo-feldspathic segregation vein yielded a core $^{207}Pb/^{206}Pb$ date of 3229 ± 39 Ma (MSWD = 5. 2), pointing towards an Archean age for the granulite igneous protolith.

Sm-Nd whole rock analysis indicates extensive isotope homogenization during Transamazonian granulite metamorphism; an average model age for this crustal segment is about 3 Ga, suggesting that the mantle-differentiation episode occurred shortly before the rock-forming event.

THERMOCHRONOLOGY

- Petrological cooling rates:

The theory and methods that use chemical zoning in minerals to infer cooling rates (referred to here as "petrological cooling rates" according to Spear & Parrish, 1996) have been discussed at length by a large number of workers and they will not be repeated here.

The method adopted in this study follows the technique developed by Spear & Parrish (1996) that uses diffusion modeling of Fe-Mg exchange between host garnet and biotite inclusions to assess cooling rates of their respective host rocks. As it should be expected, the results indicate that there is a broad correlation between inclusion biotite size and garnet-botite closure temperatures (550 - 720 C°). Using a slight modification of the technique proposed by Spear & Parrish (1996), regression of the data and comparison with controlled diffusion modeling experiments suggest that San Felix granulites cooled at a rate approaching 50 - 100 °C/Ma over the first 150 °C (800 - 650 °C), followed by much slower cooling.

- Geochronological Cooling Rates:

Previous thermochronological studies in the IC (Onstott et al., 1989) used Ar/Ar dating on metamorphic hornblende, biotite and Kfeldspar and adressed the lower temperature range of the retrograde Transamazonian metamorphic path. In this study we used a multi-isotope system (U/Pb, Sm/Nd and Rb/Sr) aproach in order to assess higher-T conditions, complementing the existing data.

The age of peak metamorphism is still not precisely defined. New SHRIMP spot analysis in zoned zircons yielded a $^{207}Pb/^{206}Pb$ age range from 2.63 - 2.82 Ga on core areas to 2.21 - 2.05 Ga on metamorphic overgrowths. The younger age is consistent with both whole rock Rb-Sr at 2.02 Ga (Montgomery and Hurley, 1978) and new WR-CPX Sm-Nd at 1.98 Ga, all indicating that peak metamorphic conditions may have lasted until 2 Ga (however, the available data does not put any constraints on its duration). Gt-WR Sm-Nd also cluster at 1.90 - 2.00 Ga , whereas biotite Rb-Sr ages from the same samples range from 1.77 to 1.72 Ga. Coupled with Onstott et al. (1989) Ar-Ar hornblende ages at 1.95 - 1.97 Ga, and considering typical closure temperatures for the respective isotope-mineral systems, the data requires that the San Felix granulites cooled very rapidly during the initial 200 °C (800 - 600 °C), followed by a drastic decrease in cooling rates to about 1 °C/Ma down to 350 °C. Geochronological and petrological cooling rate results are therefore consistent; in this respect, it is worth noting that congruence between the two thermochronological techniques, which are based on independent and quite distinct experimental data, strongly support the general reliability of both methods.

On this study we have also attempted to assess the age of the main shearing (mylonitic) event in the area.

Towards this aim, Rb-Sr isotope analysis have been performed on biotite - feldspar - WR from mylonitic sample 65-1, which was collected on discrete shear zone from the same outcrop as the granulites discussed above. Results indicate that shearing has promoted complete Sr isotope resetting at 1.39 Ga. This result suggests that the Ar-Ar biotite ages (1.45 - 1.25 Ga; as well as the 1.3 - 1.1 Ga Kfeldspar ages) attributed by Onstott et al. (1989) to the so-called Nickerie Orogeny, could instead represent local repeated reactivation related to the main Guri transcurrent fault system. Indeed, (except for specific igneous bodies) all the available radiometric data on the Guyana Shield within this time span has been attributed to dynamic overprinting (Berrangé, 1977; Gibbs & Barron, 1983), which we interpret as a consequence of late (Greenvillian; Sadowski & Bettencourt, 1996) collision between Laurentia and Amazonian Craton.

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