

Geochemical and geochronological evidences for long-term elevated geothermal gradient in the São Fidelis – Santo António de Pádua sector, central zone of the Ribeira Fold Belt, SE Brazil

Evidências geoquímicas e geocronológicas para a existência de elevado fluxo geotérmico no sector São Fidelis – Santo António de Pádua, zona central da Faixa Ribeira, SE do Brasil

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Abstract

The São Fidelis-Santo António de Pádua sector, located in the central part of Ribeira Fold Belt, a Neoproterozoic belt that spans along the SE coast of Brazil, comprises migmatitic gneisses (metatexites and diatexites) and charnockites, as well as blastomylonites that resulted from shearing and exhumation at the end of the Brazilian Orogeny.

Integration of several new geochronological data (U-Pb, Sm-Nd, Rb-Sr and K-Ar) as thermochronological cooling paths, aided by garnet – biotite Fe-Mg diffusion petrological cooling rates, suggest that metamorphic peak M_1 and main deformation phase D_1 occurred at about 572 ± 13 Ma and that the rocks underwent low cooling rates (mean $\sim 3^\circ \text{C} / \text{Ma}$) from 800°C (metamorphic peak average temperature) to 350°C (Rb-Sr closure temperature in biotite). Charnockites and metatexites display distinct thermal evolutions: whereas metatexites show an overall (stable) $3^\circ \text{C} / \text{Ma}$ cooling rate from 800°C to 350°C , charnockites evolved under slow cooling rates down to $T \sim 650^\circ \text{C}$ (at 480 – 510 Ma), being then rapidly exhumed ($\sim 30^\circ \text{C} / \text{Ma}$) onto the migmatites during post-orogenic fault tectonics (D_3 deformation phase), which coincides with late-granite and pegmatite emplacement in the area.

The thermochronological evolution of these charnockites implies the existence of a long-term elevated geothermal gradient. These abnormal thermal conditions promoted lower crustal melting and widespread charnockite development for a wide period of time (~ 60 to 100 Ma).

Keywords: Ribeira Belt, Geochronology, Thermochronology, Cooling rate, Charnockite

Resumo

O sector São Fidelis – Santo António de Pádua, situado na zona central da Faixa Ribeira, uma faixa orogénica Neoproterozóica que se estende ao longo da costa SE do Brasil, é composto por gnaisses migmatíticos (metatexitos e diatexitos) e charnoquitos, bem como blastomilonitos, resultantes de deformação cisalhante no final da Orogenia Brasileira.

A integração de novos dados geocronológicos (U-Pb, Sm-Nd, Rb-Sr e K-Ar) como caminhos termocronológicos de arrefecimento, auxiliados por taxas de arrefecimento baseadas na difusão Fe-Mg entre granada e biotite, sugerem que o pico metamórfico (M_1) e a fase de deformação principal D_1 ocorreram à 572 ± 13 Ma e que as rochas estudadas apresentam taxas de arrefecimento muito baixas ($3^\circ \text{C} / \text{Ma}$) para arrefecimento dos 800°C (temperatura média do pico metamórfico) até aos 350°C (temperatura de fecho do sistema Rb-Sr na biotite). Os charnoquitos e metatexitos apresentam evoluções tectonotermiais distintas: enquanto os metatexitos tiveram um arrefecimento estável de $3^\circ \text{C} / \text{Ma}$ entre os 800 e os 350°C , os charnoquitos evoluíram em condições de baixo arrefecimento até $T \sim 650^\circ \text{C}$ (480 - 510 Ma), sendo depois rapidamente exumados ($30^\circ \text{C} / \text{Ma}$) sobre os migmatitos, provavelmente como resultado de acidentes pós-orogénicos (fase de deformação D_3) coincidentes com a instalação de granitos e pegmatitos tardios na região em estudo.

A evolução termocronológica destes charnoquitos implica a manutenção de condições de elevado fluxo geotérmico. Estas condições térmicas pouco usuais promoveram abundante fusão da crosta inferior e desenvolvimento generalizado de charnoquitos durante um período de 60 a 100 Ma.

Palavras-chave: Faixa Ribeira, Geocronologia, Termocronologia, Taxa de arrefecimento, Charnoquito

Introduction

Distinct geodynamic evolution models for Ribeira Fold Belt in SE Brazil have long been proposed by several authors (Cordani, 1971; Campos Neto & Figueiredo, 1995; Pedrosa Soares & Wiedmann-Leonardos, 2000), making it one of the best studied orogenic belts of Western Gondwana. However, some of the tectonometamorphic P-T conditions, as well as the sequence of burial, heating, cooling and uplift stages of this Neoproterozoic orogeny are yet unknown.

Geologic Setting and Field Observations

The studied São Fidelis – Santo Antônio de Pádua (SFSAP) sector is located in the central-north Ribeira Belt (Cordani, 1971), SE Brazil (Fig. 1). The Ribeira Belt is a NE-SW to NNE-SSW trending Neoproterozoic mobile belt formed in the Brazilian Orogeny, as outcome of the collision between the São Francisco and West Congo cratons, from which resulted Western Gondwana at around 575 Ma ago (Heilbron & Machado, 2003). Various tectonic models for the geodynamic evolution of the Ribeira Belt, supported by U-Pb dating and structural analysis (Campos Neto & Figueiredo, 1995; Schmitt et al., 2004; Heilbron & Machado 2003), consider that Ribeira Belt included several terranes during Neoproterozoic to Eopaleozoic times. This led to the concept of a poly-orogenic Brazilian cycle, in which the older orogeny of the Ribeira Belt corresponds to the 630 – 610 Ma Rio Negro Orogeny (Tupinambá, 1999), followed by the 580 – 540 Ma Araçuaí Orogeny (Pedrosa Soares & Wiedmann-Leonardos, 2000) and the late ~ 520 Ma Búzios Orogeny (Schmitt et al., 2004) in the Cabo Frio terrane.

Ribeira Fold Belt is a complex orogenic belt composed of several geological units, separated by deep dextral shears. The SFSAP sector is located immediately SE to one of this mega-shears, the Além Paraíba – Santo Antônio de Pádua shear (APPS) that vigorously deformed the area rocks imposing a NE-SW trending transpressive shear deformation associated with high-grade metamorphism. From a structural point of view, the studied area underwent polyphase deformation: three main tectonometamorphic phases that globally correspond to three main geochronologic periods (see Fig. 2). The earliest deformation (D_1) corresponds to high-grade thrusts (250° , $55-70^\circ$ NW) with a stretching lineation of $55-65^\circ$, $5-20^\circ$, that were mostly erased by the main D_2 event. This corresponds to a dextral mega-shear zone (APPS: $50-65^\circ$, $70-85^\circ$ NW) with a sub horizontal stretching lineation ($5-15^\circ$, $172-178^\circ$); finally, a event (D_3) is coeval with the reactivation of D_2 conjugate fault systems ($290-320^\circ$, sub vertical) and with the intrusion of late granites. Granulite facies metamorphism was associated with D_1 (collisional phase) and produced generalized migmatization and partial melting. Different

lithotypes outcropping in the studied area comprise migmatitic paragneisses (metatexites; sometimes, interlayered with marbles) diatexitic migmatites, massive charnockites (associated with orthogneisses and syn-metamorphic garnet-aplite intrusions), and blastomylonites that resulted from intense deformation (D_2) and retrogression in areas closer to the APPS. Xenoliths of flaser gabbros and pyroxenitic cumulates are locally observed representing dismembered fragments of early mantle derived from magma chambers.

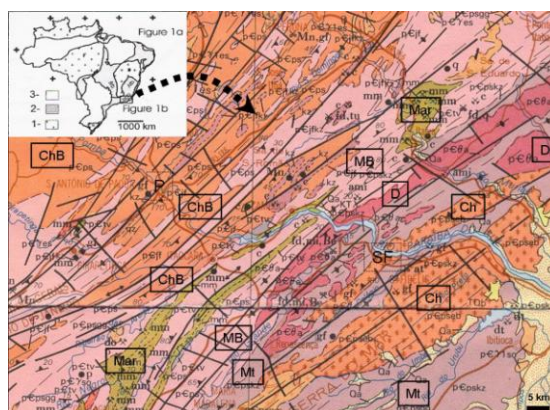


Fig. 1: Location of the SFSAP sector in Ribeira Belt, Brazil. Ch: Charnockites; Mt: Metatexites; D: Diatexites; Mar: Marbles; ChB: Charnockitic Blastomylonites; MB: Migmatitic Blastomylonites; SF: São Fidelis; P: Santo Antônio de Pádua.

Geochronology and Thermochemistry

SHRIMP U-Pb zircon age data range from 610 ± 13.0 Ma for an amphibolite to 555 ± 7.8 Ma for a diatexite. Charnockite and associated orthogneiss samples range from 560 ± 15.0 Ma to 575 ± 12.0 Ma, yielding identical ages (within error). Thus, peak regional metamorphic conditions (coeval with D_1) occurred at 572 ± 13 Ma, being simultaneous with the emplacement of garnet-aplites (561 ± 17 Ma) into charnockites. A D_3 granite was also dated yielding a SHRIMP U-Pb zircon age of 491 ± 7.1 Ma, which confirms its younger emplacement age.

Post-metamorphic peak cooling ages were also obtained. Garnet-whole rock Sm-Nd dating yielded the following ages: charnockites (541 ± 11 Ma to 472 Ma ± 17 Ma); retrogressed-biotite rich charnockite (biotitite) (491 ± 27 Ma), associated orthogneiss (502 ± 11 Ma), garnet-aplite (513.4 ± 4.5 Ma), metatexites (533.2 ± 7.7 Ma to 522.2 ± 3.8 Ma), diatexite (518.1 ± 7.8 Ma) and a blastomylonite (553 ± 4.0 Ma). Plagioclase-whole rock Rb-Sr dating results for charnockites, metatexites, diatexite and blastomylonite range from 526.2 ± 9.7 Ma to 474.3 ± 5.2 Ma, whereas most biotite-whole rock Rb-Sr ages range from 473 ± 4.0 Ma to 454.5 ± 4.4 . Biotite K-Ar data were also obtained, but the results indicate that the ages are affected by excess ^{40}Ar , producing scattered results from 576 ± 10 Ma to 462 ± 9 Ma.

Geochronological Cooling Rates

Integration of the geochronological results and using characteristic closure temperatures for the different isotopic systems (Fig. 2) results in an overall 3° C / Ma cooling rate. This very low general cooling rate means that rocks sustained long-term high-temperature conditions and low initial exhumation rates. However, observation of Fig. 2 indicates that the studied rocks underwent distinct (complex) thermochronological paths: metatexites and two charnockite samples were cooled to ~ 650 °C during 10 to 40 Ma after metamorphic peak, whereas most charnockites, orthogneisses and diatexites remained for at least 60 to 100 Ma above 650° C (until 510-480 Ma ago). Afterwards, T dropped abruptly ($\Delta T = 400^\circ$ C) in a short period of time (15 to 60 Ma), implying increased cooling rates (~ 30° C / Ma), probably related to tectonically (D_3) induced exhumation. This period of fast cooling is coeval with late granite emplacement at 490 Ma.

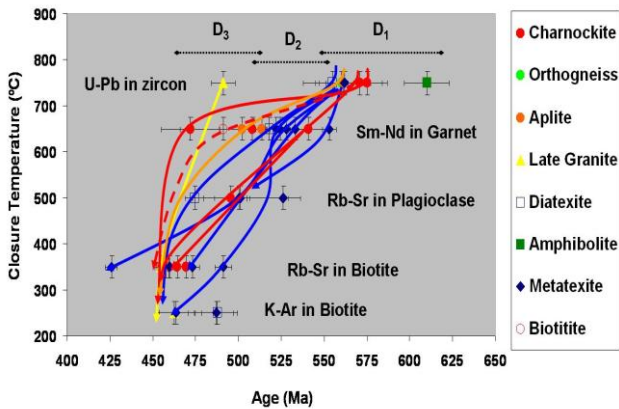


Fig. 2: Geochronological cooling rates by integrating different closure temperatures (inferred deformation phases are displayed). Metamorphic peak conditions are from Bento dos Santos et al. (2006).

Petrological Cooling Rates

Here we employ the method proposed by Spear & Parrish (1996) that uses Fe-Mg exchange diffusion modelling between garnet and its biotite inclusions in order to infer metamorphic cooling rates.

Results for charnockites and metatexites are presented in Fig. 3. Metatexites show high cooling rates at high T and low cooling rates at low T, displaying a decrease in cooling rates with time, whereas charnockites underwent low cooling rates at high T (near peak conditions) and high cooling rates at low T. These qualitative results are generally compatible with those obtained from thermochronology.

Discussion

The obtained thermochronological results are compatible with those reported for the S and N sectors of Ribeira Belt (Dias Neto, 2001; Munhá et al., 2005; Tassinari et al., 2006). Available structural, petrological and thermochronological

data suggest that D_1 may be related to the early exhumation of metatexites, ≥ 10 Ma after peak metamorphism (572 ± 13 Ma), whereas most charnockites, orthogneisses and some diatexites remained for ≥ 60 Ma at lower crustal conditions. At ~ 520 - 490 Ma rocks were rapidly exhumed, probably related to D_3 tensional fault tectonics (D_3), coeval with the initial development of Paraná-type basins and sedimentary infilling.

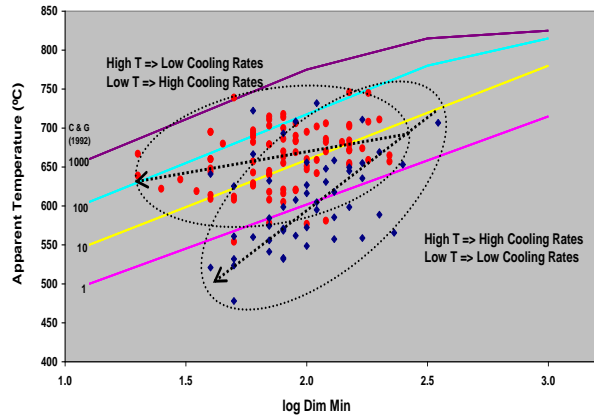


Fig. 3: Petrological Cooling Rates using Fe-Mg diffusion between garnet and inclusions of biotite. Symbols are as in Figure 2.

The general tectonothermal evolution implies long-term elevated geotherms, followed by orogen collapse caused by thermal erosion and progressive thinning of the lithosphere. These features may have been partially driven by heating from the mantle (asthenospheric upwelling and magma underplating), as well as thermal insulation, sustaining the long-term thermal anomaly. These conditions promoted lower crustal melting and widespread charnockite development at different stages of the Ribeira Belt evolution. Crystallization of newly-formed zircon at different times could become possible in different areas, reflecting this lasting thermal anomaly. Thus, Ribeira Belt tectonics may be congruently envisaged from the perspective of a single long-term orogeny, removing unnecessary complexities inherent to previously proposed poly-orogenic scenarios.

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