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Problemas e soluções das taxas de arrefecimento petrológicas baseadas em difusão mineral em granulitos da Faixa Ribeira, Brasil: poderá a difusão granada - biotite ser usada para algo?

Pitfalls and breakthroughs of petrological cooling rates based on mineral diffusion from granulites in Ribeira Belt, Brazil: can garnet – biotite diffusion mechanisms be used for anything?

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RESUMO: O uso de *software* capaz de remover a dispersão nas taxas de arrefecimento petrológicas em migmatitos e granulitos da Faixa Ribeira (Brasil) revela padrões de arrefecimento congruentes com resultados termocronológicos baseados na integração de múltiplos sistemas isotópicos: a) os migmatitos arrefeceram rapidamente a partir de altas temperaturas, diminuindo as taxas de arrefecimento com o tempo; b) os granulitos experimentaram taxas de arrefecimento baixas a altas temperaturas, seguindo-se um período curto de arrefecimento muito rápido, aumentando as taxas de arrefecimento durante a retrogradação.

PALAVRAS-CHAVE: Taxas de arrefecimento petrológicas; Difusão Fe-Mg; Faixa Ribeira; charnockitos.

ABSTRACT: The use of software that removes dispersion from petrological cooling rates in migmatites and granulites from Ribeira Belt (Brazil) shows that these results are in broad agreement with thermochronological results based on integration of multiple isotopic systems: a) migmatites cooled rapidly from high temperatures, decreasing cooling rates through time; b) granulites endured low cooling rates at high temperatures, being followed by fast cooling, increasing cooling rates during retrogression.

KEYWORDS: Petrological cooling rates; Fe-Mg diffusion; Ribeira Belt; charnockites.

1. INTRODUCTION

Several authors have tried to use mineral diffusion mechanisms in order to determine cooling rates (e.g.: Spear & Parrish, 1996 and references therein). These authors assumed that diffusion induced by compositional variation in the garnet-biotite interface is a function of $Kd_{(Mg/Fe)}^{Garnet-Biotite}$ in response to thermal changes, such as cooling during retrogression. During cooling garnet is enriched in Fe/(Fe+Mg), whereas biotite inclusions become poorer. When temperature drops below closure temperature, diffusion becomes negligible. The diffusive process is limited by the rate of diffusion in garnet, because $D_{Fe/Mg}^{Biotite} >> D_{Fe/Mg}^{Garnet}$ and mass balance determines that the rate of cation transfer between garnet and biotite must be the same. Therefore, Fe/(Fe+Mg) variations will be a function of biotite inclusion size and Fe/(Fe+Mg) results in garnet and biotite inclusions can be transformed in their respective apparent closure temperatures, providing cooling rate patterns. This work explores the assumptions that allow petrological cooling rates to be applied to natural systems, as well as the potential pitfalls regarding this methodology, namely the difficulty in assuring that open-system behaviour did not take place in complex orogenic belts, such as the Ribeira Belt. It also provides a new interpretation for complex cooling patterns and a possible solution to this problem.

2. GEOLOGICAL SETTING AND FIELD OBSERVATIONS

The studied São Fidelis – Santo António de Pádua (SFSAP) sector is located in the central-north Ribeira Belt (RB), SE Brazil. The RB is a 1500 km long NE-SW to NNE-SSW trending Neoproterozoic belt formed during the Braziliano Orogeny as outcome of the collision between the São Francisco and West Congo cratons, from which resulted Western Gondwana (Cordani et al., 1973). RB is a complex orogenic belt composed of several geological units, separated by deep dextral shears. The SFSAP sector is located SE to one of these mega-shears, the Além Paraíba – Santo António de Pádua shear (APPS) that vigorously deformed the area rocks imposing a NE-SW trending transpressive shear deformation associated with HT/LP metamorphism (Bento dos Santos et al., 2007; 2008). Intense granulite facies metamorphism produced generalized migmatization by partial melting of paragneisses. Outcrops in the area comprise: a) migmatites; b) massive charnockites (granulites); and c) blastomylonites that resulted from shearing and retrogression of the other rock types.

3. PETROLOGICAL COOLING RATES RESULTS

The Spear & Parrish (1996) method is based on Fe-Mg exchange modelling between a garnet megablast and corresponding biotite inclusions. Fe/(Fe+Mg) variations will be a function of biotite inclusions size if diffusion is exclusive between garnet and the several biotites included. This will produce larger compositional variations in smaller biotite inclusions. Therefore, Fe/(Fe+Mg) in each inclusion can be transformed in its respective apparent closure temperature using the garnet's core composition, the diffusion coefficients of Chakraborty & Gangully (1992) and the Ferry & Spear (1978) thermometer.

Fig. 1 shows two contrasting correlations between biotite inclusions size and Fe/Mg (i.e. apparent closure temperature): some samples show high Fe/Mg variation and significant temperature dispersion (Fig. 1a-b) with cooling rates spanning from 0.1 to 200ºC/Ma, whereas others show very narrow Fe/Mg variation that provide flat closure temperature patterns (Fig. 1c-d) with cooling rates spanning from 1 to 200ºC/Ma. The latter, although providing correlation trends between Fe/Mg results and biotite inclusions size, have a maximum Fe/Mg range < 0.2. This is problematic, since small amplitudes in Fe/Mg of biotite inclusions provide a very narrow closure temperature range (< 50ºC). This implies that Fe-Mg diffusion between garnet and respective biotite inclusions was insufficient to display cooling rate patterns.

However, using the garnets and biotites that show sufficient Fe/Mg variation (e.g.: Fig. 1a-b), and, consequently, high dispersion of closure temperatures, it is possible to observe that there is a significant difference between migmatites and granulites regarding cooling rate patterns (Fig. 2). This is emphasized after using software that removes result dispersion (Fig. 2b).

Definitive cooling rates results for charnockites and migmatites are presented in Fig. 2b. Migmatites show high cooling rates at high T (6ºC/Ma) and low cooling rates at low T (0.1ºC/Ma), displaying a decrease in cooling rates with time, whereas charnockites underwent low cooling rates at high T (2ºC/Ma) and high cooling rates at low T (120ºC/Ma).

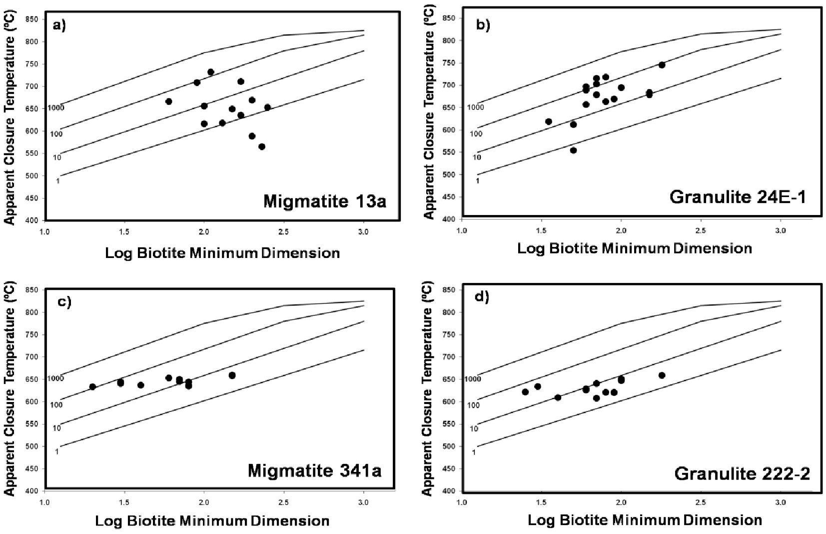

Figure 1 – Petrological cooling rates using the Spear & Parrish (1996) method. Samples 13a and 24E-1 (Fig. 1a-b) show high closure temperature dispersion, whereas samples 341a and 222-2 (Fig. 1c-d) show flat apparent closure temperature patterns due to very narrow Fe/Mg variation.

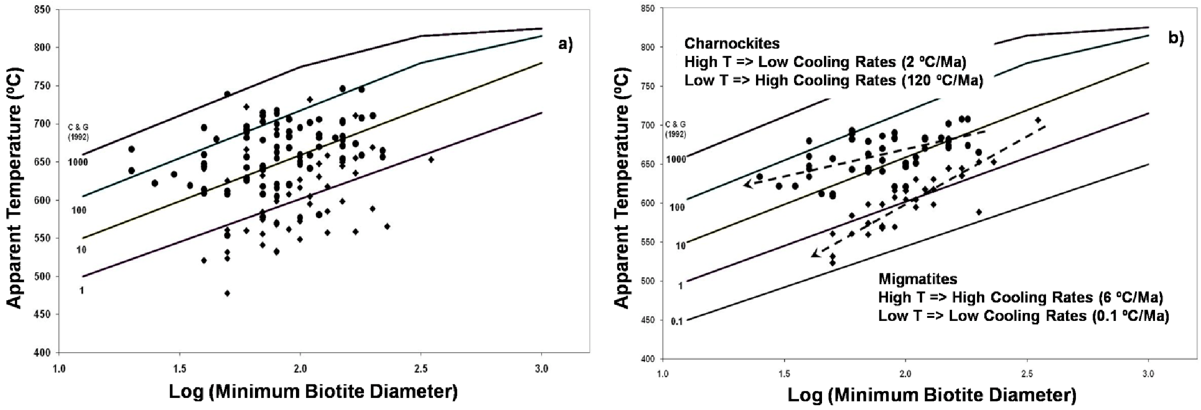

Figure 2 – Petrological cooling rates using the Spear & Parrish (1996) method, considering solely the garnets and biotites that show large closure T variation (a). Fig. 2b shows the effect of applying software that removes dispersion from the results, revealing the cooling trends for charnockites and migmatites.

4. DISCUSSION

The results obtained with the Spear & Parrish (1996) method are difficult to interpret both for granulites and migmatites, because biotite dimension (logarithmic) vs. garnet – biotite apparent closure temperatures show a very low range of apparent closure temperatures for biotites that are very different in terms of size. This suggests that garnet and respective biotite inclusions must have been reequilibrated (re-homogenized) at high temperatures and then cooled very fast, inhibiting significant change in the Fe/Mg of biotite inclusions, and consequently, in the apparent closure temperatures. In other cases, a high dispersion of closure temperatures is observable. This implies that cationic exchange with mass balance preservation between garnet and biotite inclusions (i.e. close system behaviour) was not exclusive. Intense deformation caused by long-term sub-horizontal transpressive shearing in central RB (Fonseca et al., 2008; Bento dos Santos et al., 2009) can be seen in sheared migmatites and granulites (as previously described). This is the probable cause for the open-system behaviour found in some samples. It may have altered biotite diffusion mechanisms and reequilibrated garnet with minerals or fluids outside the garnet

– biotite inclusion system, adding complexities and increasing the uncertainties regarding the use of this methodology.

The use of garnets and biotites that present large Fe/Mg variation (high dispersion of closure temperatures) and software that removes the dispersion of the results (Fig. 2), show that migmatites cooled faster than charnockites at high temperatures, being removed from high T sooner. Later, charnockites were cooled much faster (120ºC/Ma) during the last stages of retrogression.

Bento dos Santos et al. (2008) provided thermochronological constraints for the SFSAP sector based on integration of multiple isotopic systems. They concluded that migmatites were cooled at relatively stable 3 – 5ºC/Ma, whereas granulites were maintained at lower crustal levels with a very slow cooling rate (< 2ºC/Ma) during long-term sub-horizontal transpressive shearing (Fonseca et al., 2008). This period of slow-cooling endured until orogenic collapse occurred, leading to abrupt fast cooling of charnockites (8 to 30ºC/Ma) in the last stages of Brasiliano Orogeny. The obtained petrological cooling rates are difficult to interpret, but provide qualitative and quantitative results in agreement with Bento dos Santos et al. (2008) conclusions, such as the idea of high temperature maintenance that reequilibrated the garnets, followed by very fast cooling that did not allow significant Fe/Mg diffusion between garnet and biotite inclusions.

Therefore, although with some important difficulties, garnet – biotite diffusion mechanisms can be used to obtain reliable petrological cooling rates.

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