Evolução geodinâmica da Faixa Ribeira (SE do Brasil) baseada no estudo de inclusões fluidas e na modelação da fO_2

Geodynamic evolution of Ribeira Fold Belt (SE Brazil) based on fluid inclusion studies and fO_2 modelling

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SUMÁRIO

A aplicação de diversas metodologias ao estudo das inclusões fluidas e da fugacidade do oxigénio permitiu a caracterização do percurso tardio dos granulitos da Faixa Ribeira. Após o pico metamórfico, uma rápida exumação das rochas a T ~ 450 ºC levou à formação de inclusões fluidas de CO_2 pouco densas, seguidas do influxo de água no sistema a P < 1 kbar, passando o sistema de oxidado para reduzido, o que provocou a precipitação de grafite em migmatitos.

Palavras-chave: Faixa Ribeira; inclusões fluidas; fugacidade do oxigénio; evolução P-T-fluido

SUMMARY

Several procedures applied to fluid inclusion and oxygen fugacity studies allowed to characterize the late retrograde path of Ribeira Fold Belt. After metamorphic peak cooling, at about 450 ºC, a significant pressure drop occurred, leading to low-density CO_2 inclusion formation, followed by the influx of water at P < 1 kbar, which turned the system from highly oxidized to reduced and caused the precipitation of graphite in migmatites.

Key-words: Ribeira Belt; fluid inclusions; oxygen fugacity; P-T-Fluid evolution

Introduction

Although fluid inclusion studies have long been a concern among metamorphic geologists to unravel the mysteries of the lower crust (Touret, 1971), work has yet to be done in order to understand the dynamics of fluid evolution in the Braziliano Cycle. Thus, this work addresses T, P, fO_2, age, origin and evolution of fluids in the Ribeira Belt in order to constrain the retrograding P-T-Fluid path of this granulitic belt.

Geologic setting and field observations

The studied São Fidelis – Santo António de Pádua (SFSAP) sector is located in the central-north Ribeira Belt, SE Brazil. The Ribeira Belt is a NE-SW to NNE-SSW trending Neoproterozoic belt formed in the Braziliano Orogeny by the collision of the São Francisco and West Congo cratons, from which resulted Western Gondwana (Cordani, 1971). Ribeira Belt 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 high-grade granulite facies metamorphism, producing generalized migmatization. Outcrops in the area comprise: (1) migmatitic paragneisses (metatexites), commonly interlayered with amphibolites and marbles; (2) diatexites; (3) massive and incipient-type charnockites; and (4) blastomilonites that resulted from late retrogression of the major rock types. Also present in the area are khondalites (graphitic gneisses) that resulted from incipient charnockitization of metatexites in areas of contact with charnockites.

Oxygen Fugacity calculations

Oxygen fugacity was determined for 6 charnockites, 1 migmatite, 3 blastomilonites and 1 amphibolite, using the QUILF algorithm (Andersen & Lindsley, 1988). MH (Magnetite-Hematite) temperature determinations ranged from 370 to 771 ºC, indicating post-metamorphic Ti-magnetite oxidation in accordance with observation of exsolution of ilmenite from magnetite. Thus, Ti-magnetite compositions were reconstructed at the appropriate P-T range (Bento dos Santos et al., 2006) in order to estimate the metamorphic fO_2 conditions. MH, OHQ (Orthopyroxene-Hematite-Quartz) and AHQ (Augite-Hematite-Quartz) (Harlov, 1992) fO_2 estimates range from $10^{-11.538}$ to $10^{-17.799}$ bar for the calculated temperature range of 896 to 656 ºC. Figure 1 shows that high-T charnockites (and amphibolites) have fO_2 values above the QFM buffer (QFM +1), whereas migmatites and blastomilonites provide fO_2 at QFM -1. Thus, the inferred fO_2 evolution suggests that metamorphic fluids experienced relative reduction during cooling. This is consistent with field and petrographic observations indicative of late graphite deposition in khondalites.

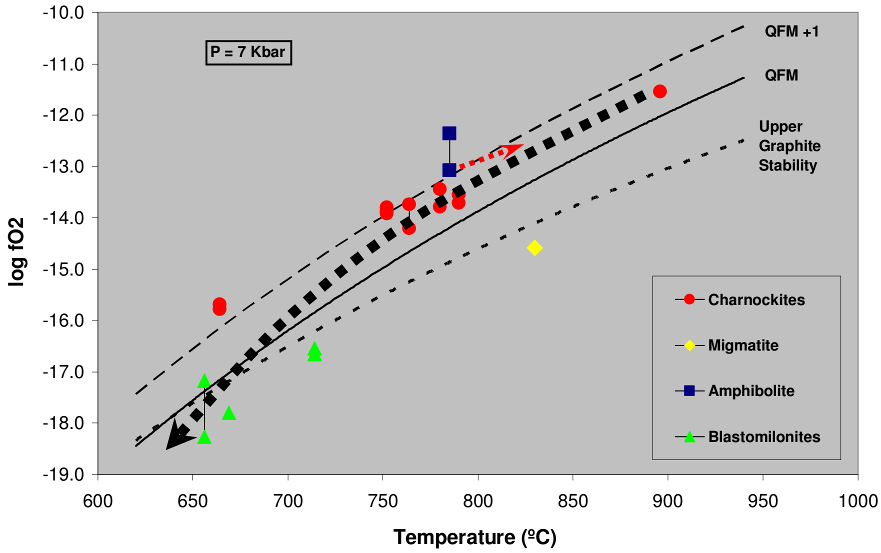

Fig.1 – fO_2 of studied samples at respective metamorphic peak temperatures (Bento dos Santos et al., 2006).

Fluid Modelling

Fluid modelling in the C-O-H system was performed in order to determine fluid compositional variations (H_2O, CO_2, CO, CH_4 and H_2) at a given T, P and fO_2. Results show that CO_2-rich fluid inclusions should be stable during charnockite formation (at the estimated P, T, fO_2 conditions), whereas aqueous fluids (with minor CH_4 and CO_2) were dominant in migmatites (and blastomilonites).

Fluid Inclusion (FI) and Raman Studies

Fluid inclusions were analysed in 4 charnockites, 1 diatexite, 2 migmatites, 2 khondalites and 2 blastomilonites (amounting to several hundred measurements in quartz and garnet crystals). Inclusions are typically < 10 µm in size and are referred as primary, secondary or late, according to their relative textural relations following Roeder (1984) classification. On this basis 6 fluid inclusion groups were defined, and their evolving characteristics are summarized in Table 1. G3a is the most common FI type; G4 FI group is characteristic of khondalites (that lack G2 and G3 FI).

Graphite analysis

Graphite is a common occurrence in granulite facies meta-sediments as the result of conversion of organic matter into crystalline graphite. Because mineral structure of graphite cannot be retrogressed and is, therefore, mainly dependent on temperature, it can be used to estimate crystallization temperatures (Pasteris & Wopenka, 1991). The use of analytical procedures that evaluate its mineral structure, such as Raman Spectroscopy and X-ray diffraction, and the use of appropriate formulation (Beyssac et al, 2002) supplied T estimates in the 333 to 449 ºC range for graphites in the studied khondalite samples.

Table 1: Summary of fluid inclusion microthermometry and Raman Spectroscopy results.

Group	Composition	Phases	Occurrence	Flw	Tm CO_2	Tm Ice	Th CO_2	TH	CO_2	N_2	CH_4	d (g/cm^3)	Salinity (Wt% Eq. NaCl)
1	N_2-CH_4	Mono	P	-	-	-	-	-	-	94 - 95	5 - 6	-	-
2a	CO_2; CO_2-N_2	Mono	P	-	-58.1 : -59.6	-	-16.3 : 6.2 (L)	-	92 - 100	0 - 8	-	0.86 - 1.01	-
2b	CO_2; CO_2-N_2	Mono	P or S	-	-58.5 : -63.2	-	6.4 : 10.9 (L)	-	89 - 100	0 - 11	-	0.79 - 0.86	-
2c	CO_2; CO_2-N_2	Mono e Bi	P or S	-	-58.4 : -62.2	-	13.4 : 30.1 (L)	-	94 - 100	0 - 6	-	0.59 - 0.81	-
3a	CO_2; CO_2-N_2	Bi	P or S	-	-57.2 : -59.5	-	17.3 : 31.0 (C)	-	64 - 100	0 - 36	-	0.19 - 0.29	-
3b	N_2-CO_2; N_2	Mono	P or S	-	-	-	-	-	0 - 30	70 - 100	-	-	-
4	CO_2-N_2-CH_4-H_2O	Bi	P or S	0 - 0.1	-60.0 : -62.8	-	8.7 : 19.0 (L)	-	94 - 95	3	2 - 3	0.73 - 0.82	-
5	CO_2-H_2O	Bi	S - Late	0.3 - 0.7	-58.8 : -59.7	-3.7 : -5.4	9.5 : 13.1 (L)	232 : 404 (L)	100	-	-	0.56 - 0.99	6.1 - 10.5
6a	H_2O	Bi	Late	0.6 - 0.95	-	-0.1 : -4.5	-	86 : 367 (L)	-	-	-	0.57 - 0.93	0 - 7.2
6b	H_2O	Bi	Late	0.9 - 0.95	-	-4.0 : -9.3	-	98 : 174 (L)	-	-	-	0.97 - 0.99	6.5 - 13.2

P-T-Fluid evolution

FI microthermometry indicates that the SFSAP sector rocks evolved in equilibrium with N_2 ± CH_4 and CO_2-N_2 rich fluids at high metamorphic temperatures. During the retrograding path fluids became progressively enriched in water, generating CO_2-H_2O fluids and late low-salinity H_2O fluids. Representative FI were used for isochore calculations presented in Fig. 2. Observation of the P-T-Fluid evolution shows that all FI are late, (relative to the peak of metamorphism), being trapped during cooling and decompression (exhumation) of their host metamorphic rocks.

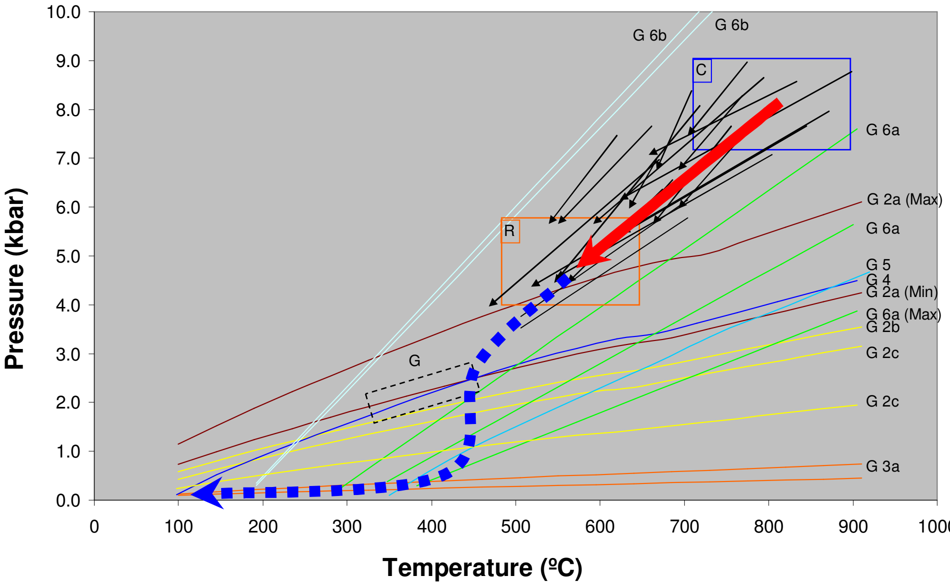

Fig.2: P-T-Fluid evolution (C and R: core and rim temperature estimates (Bento dos Santos et al., 2006); G: Graphite temperature estimates for this study).

Discussion

CO_2 is the most oxidized fluid in the C-O-H system and its influx into lower crust from deep-seated sources has been advocated to explain charnockite development (Newton et al., 1980), which is consistent with the oxidized conditions estimated for SFSAP charnockites. However, Touret (1971) and Cesare et al. (2005) argued that Fe^{3+} reduction during biotite dehydration-melting could cause graphite oxidation, producing CO_2 and globally rising fO_2 (if water is leaving the system). Thus, early CO_2 predominance in SFSAP fluids is interpreted as a result of relative concentration of the least mobile fluids, whereas water is preferentially removed by ascending melts. This process would also induce relative oxidation, as estimated for the studied charnockites.

The late P-T-Fluid path involved cooling and decompression until about 450 ºC, followed by a significant pressure drop (probably associated with orogenic collapse). Indeed, graphite deposition in khondalites is a relatively late process that took place after significant cooling down to 450 - 330 ºC. Accordingly, graphite deposition should be coeval with late tectonic imbrication (orogenic collapse) and the consequent cooling and decompression, enhancing permeability and admixture of reducing H_2O-rich fluids into the system. This stage is related to the formation of (early) low-density CO_2 fluid inclusions (G3a in Fig. 2) and (late) low-salinity H_2O fluids, as the rock pile progressively approached the surface, interacting with shallow aquitards/aquifers.

Conclusions

Fluid evolution reflects compositional readjustments related to rapid decompression and cooling during the late stages of the Ribeira Belt exhumation path. Results indicate that high-T (> 550 ºC) fluids were dominated by CO_2 – N_2 components. At 450 ºC rocks were already exhumed to 3–10 km depths, producing generalized low-density CO_2 (+ H_2O) inclusions, followed by interaction with shallower aquifer waters. fO_2 decreased substantially during cooling and mixture of CO_2 and H_2O, causing late graphite deposition.

Incipient charnockitic development by "CO_2 influx" is possible for some khondalites, but this process does not explain the massive charnockite formation in Ribeira Belt. We suggest that CO_2-rich, high-T metamorphic fluids should have resulted mainly from CO_2 concentration after water removal to ascending granitic melts, as originally proposed by Fyfe (1973).

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