Petrology and Geochemistry of granulites from the São Fidelis area, Ribeira Belt, SE Brazil

Petrologia e Geoquímica de granulitos na região de São Fidelis, Faixa Ribeira, SE do Brasil

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Abstract

The São Fidelis area is located in the central part of Ribeira Fold Belt, a Neoproterozoic belt that spans along the SE coast of Brazil. Lithologically, it comprises migmatitic gneisses (metatexites), diatexites and charnokites, as well as blastomilonites that resulted from late shearing and exhumation at the end of the Braziliano Orogeny.

New geochemical data obtained for these granulitic rocks indicate that they are LILE-enriched peraluminous granodiorites. Harker diagrams correlation trends for TiO_2, Al_2O_3, Fe_2O_3t, MgO, P_2O_5, Sr, Zr, Hf, Th, U, REE_t, LREE/HREE and La/Lu suggest that charnockites are a co-genetic sequence; variations on CaO, MnO, Y and HREE can be explained by garnet melting during charnockite formation. Diatexites seem to be genetically linked with charnockites, since they plot on the same correlation trends for the most incompatible elements. Moreover, a charnockite, diatexite, orthogneisse and migmatitic leucossome genetic link is suggested by REE patterns, revealing that partial melting of paragneisses formed migmatites and diatexites and high-grade metamorphism produced orthogneisses and charnockites.

Data suggest that charnockites formed by a two step process: generation of a hydrated igneous protolith by partial melting of paragneisses, followed by high-grade metamorphism that transformed "type-S granitoids" (leucossomes and diatexites) into orthogneisses and, as metamorphism and dehydration progressed, into charnockites.

Keywords: Ribeira Belt, Geochemistry, Petrology, Granulite, Charnockite

Resumo

A região de São Fidelis situa-se na zona central da Faixa Ribeira, uma faixa orogénica Neoproterozóica que se estende ao longo da costa SE do Brasil. Do ponto de vista litológico, a área em estudo é composta por gnaisses migmatíticos (metatexitos), diatexitos e charnoquitos, bem como blastomilonitos que resultaram de deformação cisalhante tardia no final da Orogenia Brasiliana.

Novos dados geoquímicos obtidos para estes granulitos indicam que estes são tipicamente granodioritos peraluminosos enriquecidos em LILE. A existência de correlações para TiO_2, Al_2O_3, Fe_2O_3t, MgO, P_2O_5, Sr, Zr, Hf, Th, U, REE_t, LREE/HREE e La/Lu nos diagramas de Harker sugere que os charnoquitos sejam uma sequência cogenética; variações para CaO, MnO, Y e HREE nos diagramas de Harker podem ser explicadas pela existência de fusão de granada aquando da formação dos charnoquitos. Os diatexitos aparentam estar geneticamente ligados aos charnoquitos, pois ambos apresentam correlações positivas para os elementos mais incompatíveis. Uma relação genética entre charnoquitos, diatexitos, ortognaisses e leucossomas de migmatitos é igualmente sugerida pelos padrões de elementos das Terras Raras, revelando que a fusão parcial de paragnaisses terá formado os migmatitos e os diatexitos, e o metamorfismo de alto grau os ortognaisses e os charnoquitos.

Estes dados sugerem que os charnoquitos se formaram em duas etapas: geração de um protólito ígneo hidratado por fusão parcial de paragnaisses, seguido de metamorfismo de alto grau que transformou os "granitóides do tipo S" (leucossomas e diatexitos) em ortognaisses e, à medida que o metamorfismo e a desidratação progredia, em charnoquitos.

Palavras-chave: Faixa Ribeira, Geoquímica, Petrologia, Granulito, Charnoquito

Introduction

Although several studies have been made with the purpose of constraining the geodynamic evolution of Ribeira Fold Belt (Cordani, 1971; Campos Neto & Figueiredo, 1995; Pedrosa Soares & Wiedmann-Leonardos, 2000; Heilbron & Machado, 2003; Tassinari et al., 2006), several doubts still remain about the lithological, petrological and geochemical transformations that these granulites experienced during Neoproterozoic high-grade metamorphism. This report addresses the evolution of these rocks, with particular focus on charnockite development during the Braziliano Orogeny.

Geologic Setting and Field Observations

The São Fidelis area is located in the central-north Ribeira Belt (Cordani, 1971), SE Brazil. Ribeira Belt is a NE-SW to NNE-SSW trending Neoproterozoic mobile belt formed in the Braziliano Orogeny, as outcome of the collision between the São Francisco and Congo cratons 575 Ma ago (Heilbron & Machado, 2003; Bento dos Santos et al., 2006).

Ribeira Belt is a complex orogenic belt composed of several geological units, separated by deep dextral shears. The São Fidelis area is located immediately SE to one of this mega-shears that vigorously deformed the area rocks imposing a NE-SW trending transpressive shear deformation associated with high-grade metamorphism. Intense granulite facies metamorphism simultaneous with D_1 collisional phase (250º, 55-70º NW) produced generalized migmatization by partial melting of paragneisses. Outcrops in the area comprise: **a)** migmatites (garnet-biotite metatexites), often interlayered with amphibolites; **b)** garnet-biotite-hornblende diatexitic migmatites; **c)** massive charnockites (granulites) associated with their orthogneissic precursors and garnet aplites. According to occurrence and petrology, charnockites can broadly be divided in three types: i) massive, undeformed, homogeneous garnet charnockites (s. s.) that correspond to the massifs' cores; ii) finely banded, highly deformed and retrogressed garnet charnockites (s. s.), corresponding to the massifs' margins; and iii) banded, coarse abundantly amphibolitized garnet enderbites; and **d)** blastomilonites that resulted from shearing deformation (D_2: 50-65º, 70-85º NW) and retrogression of the other rock types. Blastomilonites still preserve xenoliths of flaser gabbros that represent fragments of mantle derived magma chambers (underplating). Finally, a fragile/brittle event (D_3) occurred, coeval with the intrusion of late granites and pegmatites (290-320º, sub vertical).

Geochemistry

Whole rock geochemistry was performed in 24 representative samples of the study area diverse lithologies (including 7 charnockites, 6 diatexites, 2 orthogneisses, 1 late granite, 1 garnet aplite, 1 metatexitic leucossome, 3 amphibolites and 3 gabbros). Six major elements analyses of charnockites from Rego (1989) are also included in this study.

Charnockites are dominantly granodioritic in composition, with a SiO_2 range of 61 to 75%, and extending in the TAS diagram from quartz-monzonites to granites (Fig. 1a); they are weakly peraluminous (Fig. 1b) and have Sr/Rb = 1.7 to 4.25 and K/Rb = 96 to 170. Diatexites are mainly granodiorites, (but also include dioritic and granitic compositions), weakly peraluminous and show Sr/Rb = 1.0 to 2.5 and K/Rb = 64 to 163. Orthogneisses, aplites and migmatitic leucossomes, (together with charnockites (s. s.), enderbites, diatexites and late-granites) display an AFM trend in accordance with that of calc-alkaline sequences (Irvine & Baragar, 1971). Amphibolites and gabbros have clear tholeiitic affinities.

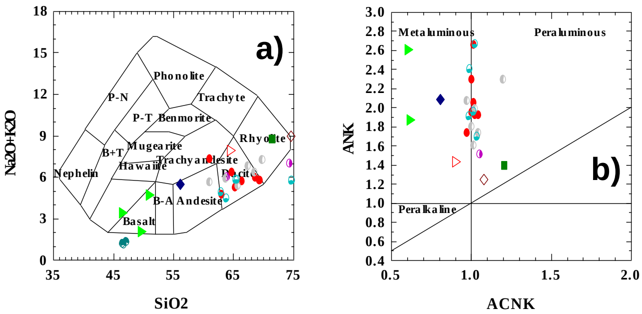

Fig. 1: a) TAS diagram; and b) alumina index by Maniar & Piccoli (1989). Symbols are: - charnockites; - charnockites from Rego (1989); - enderbite; - diatexites; - orthogneisses; - migmatitic leucossome; - aplite; - late granite; - amphibolites; - gabbros.

Harker diagrams (Fig. 2a to 2c) reveal that charnockites have negative correlations of SiO_2 with TiO_2, Al_2O_3, Fe_2O_3t (Fig. 2a), MgO, P_2O_5, Sr, Zr, Hf, Th, REE_t (Fig. 2b), LREE/HREE, LREE and La/Lu, a positive correlation for U and no correlation with Na_2O (Fig. 2c), K_2O, Ba, Rb, CaO, MnO, Nb, Y and HREE.

Diatexites show very similar Harker diagram patterns for the above elements. In fact, diatexites are almost always juxtaposed to charnockites, revealing a genetic proximity. Significant geochemical differences between charnockites and diatexites include: **a)** MnO, CaO, Y and HREE in which diatexites display negative correlations, indicating residual garnet; and **b)** Sr and Th, which are not correlated with SiO_2. Orthogneisses also show similar trends in Harker diagrams, suggesting a genetic proximity to charnockites and diatexites.

Plotting incompatible element pairs (Th-Hf, Th-La or La-Hf; Fig. 2d) for charnockites, diatexites and orthogneisses supports the idea that these lithotypes are co-genetic, since they display similar positive correlation trends.

Charnockites and diatexites also display similar REE patterns (Fig. 3a). Both rock types have well fractionated REE patterns with ranges of chondrite normalized (Palme & O'Neill, 2003) La/Lu = 10 to 143 in charnockites and La/Lu = 12 to 25 in diatexites. Higher La/Lu ratios in residual charnockites compared to those of diatexites is in accordance with petrological data implying extensive garnet melting (Stahle et al., 1987) during charnockite formation. Charnockites and diatexites have Eu/Eu* variations, ranging from 0.62 to 1.16, and 1.89 to 0.37, respectively.

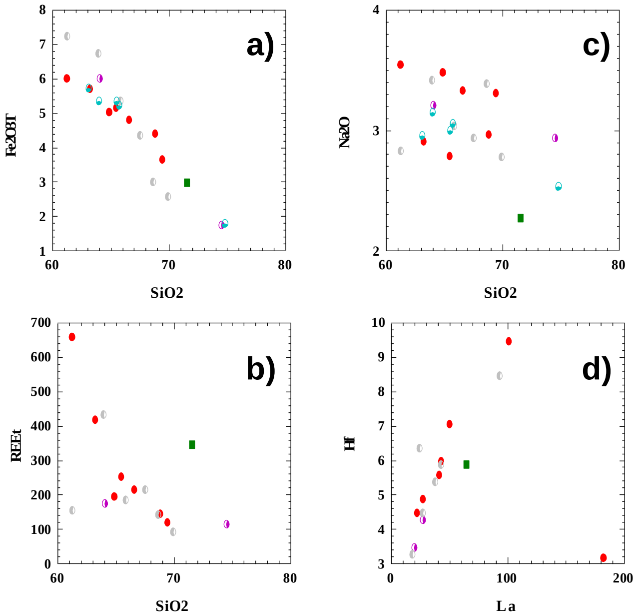

Fig. 2: Harker diagram examples and incompatible element plotting La-Hf for charnockites, diatexites and orthogneisses. Symbols are as in Fig. 1.

An important feature of REE patterns is the close compositional proximity among charnockites, orthogneisses, diatexites and metatexite leucossomes (Fig. 3b), suggesting that all of these rock types had a similar origin: they may have been derived from partial melting of granitoid/parageneissic rocks, a feature commonly observed in the field.

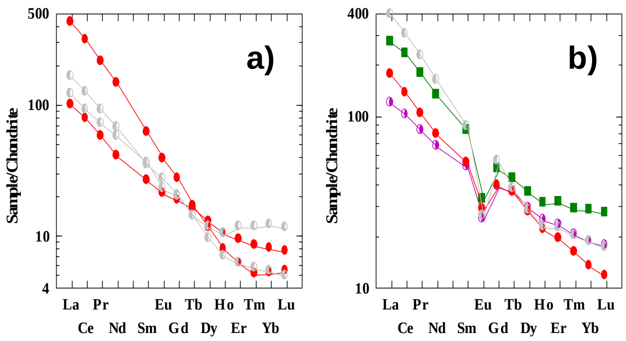

Fig. 3: a) REE patterns for charnockites and diatexites; b) REE patterns for charnockites, diatexites, orthogneisses and migmatitic leucossomes. Symbols are as in Fig. 1.

Garnet-bearing aplitic veins that cut charnockites show REE patterns with strong MREE depletion, suggesting that they were formed by amphibole dehydration-melting (Sisson, 1994). This feature provides important geochemical evidence supporting the hypothesis that charnockites are residual rocks developed via amphibole dehydration-melting of granodioritic rocks (Bento dos Santos et al., 2006).

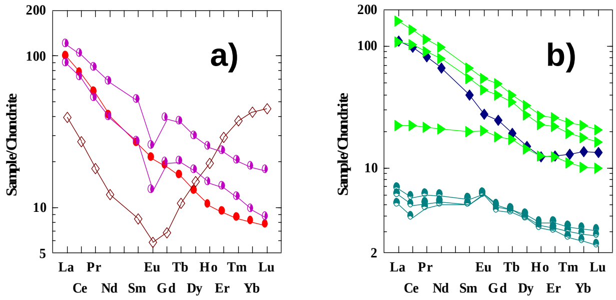

Fig. 4: a) REE patterns for garnet aplites and field related rocks; b) REE patterns for mafic rocks. Symbols are as in Fig. 1

REE patterns of mafic rocks (Fig. 4b) display variable REE contents and LREE/HREE fractionation. Meta-gabbroic rocks have relatively low REE contents and display positive Eu anomalies, indicative of plagioclase accumulation. All amphibolites show LREE enrichment with chondrite normalized La/Lu ranging from 2 to 8, similar to that of E-MORB and some ocean island or enriched continental basalts. REE patterns of enderbites are similar to those of LREE enriched amphibolites, but display lower normalized HREE values suggesting involvement of garnet ± amphibole in their genesis.

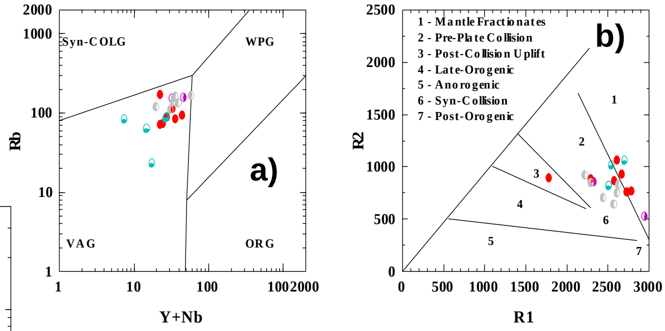

Fig. 5: Discriminant diagrams for charnockites, diatexites and orthogneisses: a) Pearce et al. (1984); b) De La Roche (1980). Symbols are as in Fig. 1.

Discriminant diagrams (Fig. 5a to 5b) show that charnockites, as well as, orthogneisses and diatexites may have been derived from volcanic arc (VAG) or sin- to pre-plate collision granitoids (Pearce et al., 1984; De La Roche, 1980). These discrepancies are probably due to the use of diagrams that employ elements that were not immobile during high-grade metamorphism.

Specific discriminant diagrams for basaltic rocks suggest that most amphibolites are metamorphosed within plate basalts.

Discussion

Harker diagrams of immobile elements and incompatible element patterns suggest that charnockites, diatexites and orthogneisses are related to a similar protolith. All these rocks reflect high-grade metamorphic processes. Orthogneisses were derived from pre-existing granitoid bodies, whereas charnockites correspond to residual rocks after biotite ± amphibole dehydration melting of a granitic/granodioritic continental source that gave rise to generalized migmatization and diatexite formation.

LILE remobilization during granulitic metamorphism has been stated as a major process for lower crust evolution (Fyfe, 1973). The transition from amphibolitic to granulitic facies is simultaneous with biotite and amphibole dehydration melting, releasing water to the ascending melts; thus, depleting the lower crust in LILE. Nevertheless, contradicting observations of several authors suggest that this is not the case for charnockite development. According to Subba Rao & Divakara Rao (1988), charnockites are enriched in K and Rb and depleted in Ba and Sr, while Newton (1992) refers Na gain and Rb loss, and Dobmeier & Raith (2000) even suggest a general LILE enrichment. Despite these contradicting arguments our data clearly indicate that LILE were not immobile during high-grade metamorphism - charnockites display no correlation for LILE in Harker diagrams, whereas more immobile elements retained the original signature of their protoliths.

Conclusions

In summary, the new data suggest that the São Fidelis area charnockites are indeed metamorphic rocks, formed at high-grade anhydrous conditions; they had an igneous protolith, which was previously developed by partial melting of metasediments.

Our observations indicate a complex long-term evolution for charnockitic rocks. Thus, initial hydrous melting of paragneisses generated diatexites and type-S granitoids; then, progressive dehydration during melt extraction gave rise to charnockites.

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References

Bento dos Santos, T., Munhá, J., Tassinari, C., Dias Neto, C., Fonseca, P., 2006. Petrologia, Geoquímica e Geocronologia de Granulitos no sector São Fidelis – Santo António de Pádua, RJ, SE Brasil. *Ext. Abst. VII Cong. Nac. Geol*., 1, 241-244.

Campos Neto, M. C., Figueiredo, M. C. H., 1995. The Rio Doce orogeny, Southeastern Brazil. *Jour. South Amer. Earth Sci*., 8, 2, 143-162.

Cordani, U. G., 1971. Síntese da geocronologia Pré-Cambriana da região costeira atlântica meridional da América do Sul. *Ext. Abst. 25th Cong. Bras. Geol*., 179-180.

De La Roche, H. J. 1980. A classification of volcanic and plutonic rocks using R_1-R_2 Diagram and major element analyses – Its relationships with current nomenclature. *Chem. Geol*., 29, 183-210.

Dobmeier, C., Raith, M., 2000. On the origin of "arrested" charnockitization in the Chilka Lake area, Eastern Ghats Belt, India: a reappraisal. *Geol. Mag*., 137, 1, 27-37.

Fyfe, W. S., 1973. The granulite facies , partial melting, and the Archean crust. *Phil. Trans. Royal Soc. London*, A273, 457-461.

Heilbron M., Machado, N., 2003. Timing of Terrane Accretion in the Neoproterozoic-Eopaleozoic Ribeira Orogen SE Brazil. *Precamb. Res*., 125, 87-112.

Irvine, T. N., Baragar, W. R., 1971. A guide to the chemical classification of common volcanic rocks. Can. Jour. Earth Sci., 8, 523-548.

Maniar, P. D., Piccoli, P. M., 1989. Tectonic discrimination of granitoids. *Geol. Soc. Am. Bull*., 101, 635-643.

Newton, R. C., 1992. Charnockitic alteration: evidence of CO_2 infiltration in granulite facies metamorphism. *Journ. Met. Geol.*, 10, 383-400.

Palme, H., O'Neill, H., 2003. Cosmochemical estimates of mantle composition. *In:* Carlson, R. (Ed) *Treatise on Geochemistry, 2 – The Mantle and Core*, 1-38.

Pearce, J. A., Harris, N. B. W., Tindle, A. G., 1984. Trace element discrimination diagrams for the tectonic interpretation of granitic rocks. *Jour. Pet*., 25, 956-983.

Pedrosa-Soares, A. C., Wiedemann-Leonardos, C. M., 2000. Evolution of the Araçuai Belt and its connection to the Ribeira Belt, Eastern Brazil. In: Cordani, U. G., Milani, E. J., Thomaz-Filho, A., Campos, D. A (Eds) *Tectonic Evolution of South America*, 265-285.

Rego, I. T. S. F., 1989. *Petrologia e geoquímica da unidade charnockítica Bela Joana, Região de São Fidelis – RJ*. Unpublished PhD Thesis, 333.

Sisson, T. W., 1994. Hornblende-melt trace-element partioning measured by ion-microprobe. *Chem. Geol*., 117, 331-344.

Stahle, H. J., Raith, M., Hoernes, S., Delfs, A., 1987. Element mobility during incipient granulite formation at Kabbaldurga, southern India. *Jour. Pet.*, 28, 803-834.

Subba Rao, M. V., Divakara Rao, V., 1988. Chemical constraints on the origin of the charnockites in the Eastern Ghat Mobile Belt, India. *Chem. Geol*., 69, 37-48.

Tassinari, C., Munhá, J., Dias Neto, C., Bento dos Santos, T., Cordani, U., Nutman, A., Fonseca, P., 2006. Constrains on thermochronological evolution of Ribeira Fold Belt, SE Brazil: evidence for long-term elevated geothermal gradient of Neoproterozoic orogenies. *Ext. Abst. V Simp. Sud-Amer. Geol. Isot*., 200-203.