Granulite Geochemistry of the São Fidelis region, Central Ribeira Fold Belt, Rio de Janeiro State, SE Brazil

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Abstract

New geochemical data obtained for the São Fidelis region (Central Ribeira Fold Belt) 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 form a co-genetic sequence, whereas variations on CaO, MnO, Y and HREE can be explained by garnet melting during charnockite formation. REE patterns suggest a genetic link between charnockites, diatexites, orthogneisses and migmatitic leucossomes, revealing that partial melting of paragneisses formed migmatites and diatexites and high-grade metamorphism produced orthogneisses and charnockites. These new data indicate a two step process for charnockite development: 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 Fold Belt, Geochemistry, Charnockite

Introduction

Although several studies have constrained the geodynamic evolution of Ribeira Fold Belt (RFB) (Cordani, 1971; Heilbron & Machado, 2003; Tassinari et al., 2006), several doubts still remain about the lithological, petrological and geochemical transformations that these granulites experienced during Braziliano high-grade metamorphism. This work will try to unravel the geochemical evolution of these rocks, with particular focus on charnockite development.

Geologic Setting and Field Observations

The São Fidelis region is located in the central-north RFB (Cordani, 1971), SE Brazil. RFB is a NE-SW to NNE-SSW trending Neoproterozoic mobile belt formed during the Braziliano Orogeny, as outcome of the collision between the São Francisco and Congo cratons 575 Ma ago (Heilbron & Machado, 2003). RFB is a complex orogenic belt composed of several geological units, separated by deep dextral shears. The São Fidelis region is located immediately SE to one of these 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 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 are divided in three types: i) massive, undeformed garnet charnockites (s. s.) that correspond to the massifs' cores; ii) banded, highly retrogressed garnet charnockites (s. s.), corresponding to the massifs' margins; and iii) banded, coarse, amphibolitized garnet enderbites; and **d)** blastomilonites that resulted from shearing and retrogression of the other rock types. Blastomilonites still preserve xenoliths of flaser gabbros that represent fragments of mantle derived magma chambers (underplating). Late granite and pegmatite intrusions cut all the other rock types.

Whole-rock Geochemistry

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 of Irvine & Baragar (1971). Amphibolites and gabbros have clear tholeiitic affinities (AFM diagrams are not shown).

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. 2c), LREE/HREE, LREE and La/Lu, a positive correlation for U and no correlation with Na_2O (Fig. 2b), 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.

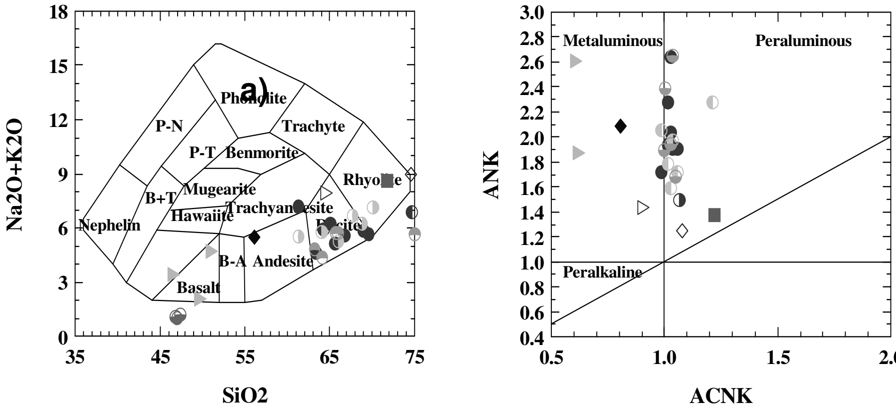

Figure 1: a) TAS diagram; and b) Alumina index by Maniar & Piccoli (1989). Symbols are: ● - charnockites; ◒ - charnockites from Rego (1989); ◆ - enderbite; ◑ - diatexites; ◐ - orthogneisses; ■ - migmatitic leucossome; ◇ - aplite; ▷ - late granite; ▶ - amphibolites; ◒ - gabbros.

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 indeed 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.

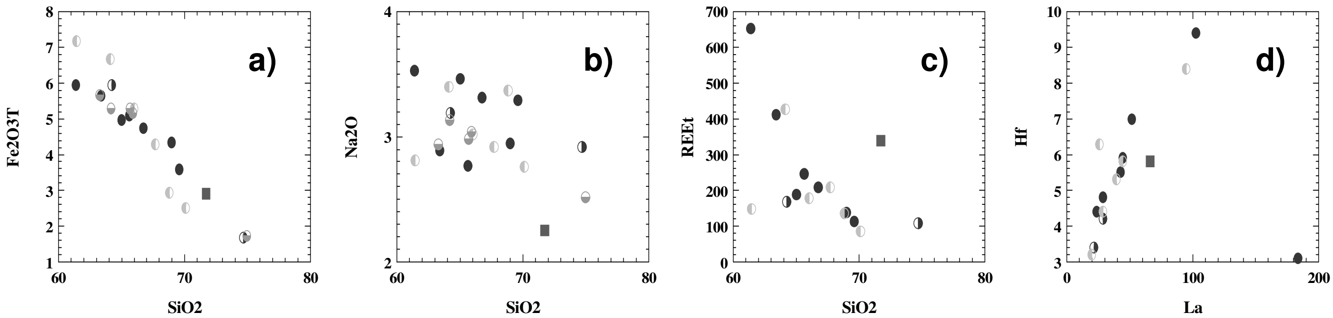

Figure 2: Harker diagram examples and incompatible element plotting La-Hf for charnockites, diatexites and orthogneisses. Symbols are as in figure 1.

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/paragneissic rocks, a feature commonly observed in the field.

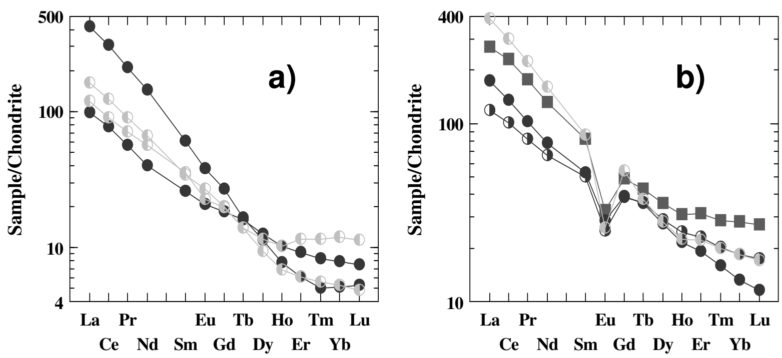

Figure 3: a) REE patterns for charnockites and diatexites; b) REE patterns for charnockites, diatexites, orthogneisses and migmatitic leucossomes. Symbols are as in figure 1.

Garnet-bearing aplitic veins that cut charnockites show REE patterns (Fig. 4a) 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).

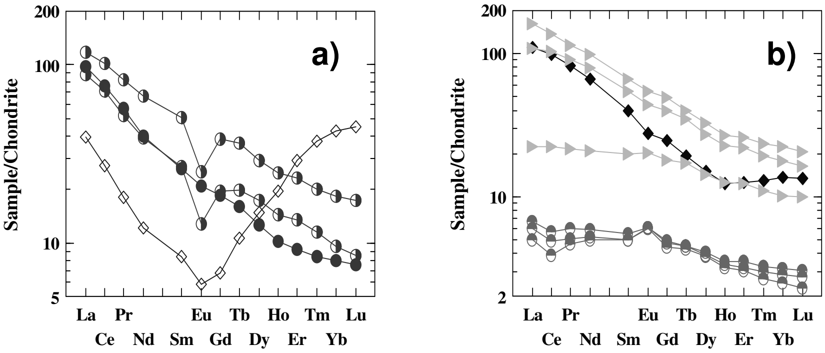

Figure 4: a) REE patterns for garnet aplites and field related rocks; b) REE patterns for mafic rocks. Symbols are as in figure 1.

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 HREE values suggesting involvement of garnet ± amphibole in their genesis.

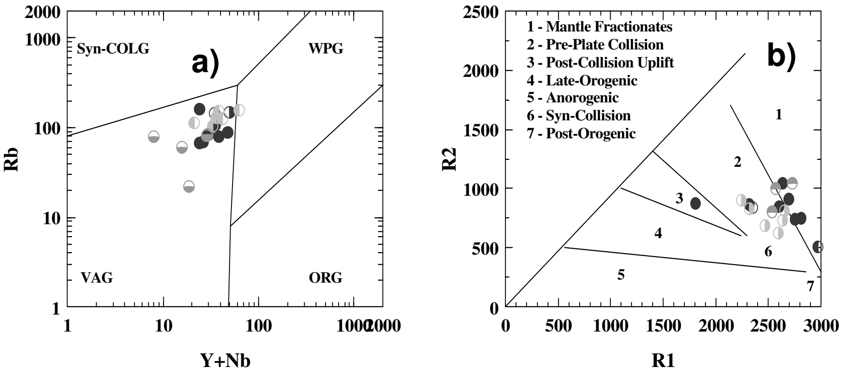

Figure 5: Discriminant diagrams for charnockites, diatexites and orthogneisses: a) Pearce et al. (1984); b) De La Roche (1980). Symbols are as in figure 1.

Discriminant diagrams (Fig. 5a and 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, whereas 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 region 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: 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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