AFC MODELING (Sr-Nd-O AND TRACE ELEMENTS) FOR THE HIGH-TIO_2 SUITE OF THE SERRA DO MAR DYKE SWARM, RIO DE JANEIRO

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INTRODUCTION

The main events related with the reactivation of the South American Platform include widespread tholeiitic basalt magmatism and the formation of rift basins along the Brazilian continental margin. These events are related with the rifting of the West Gondwanaland which may have started as early as ca. 193 Ma (K-Ar, whole-rock, Guedes et al., 2005) but peaked in Early Cretaceous times (ca. 137 Ma; Ar-Ar, whole-rock and plagioclase, Turner et al., 1994). Such magmatism is mostly represented by the extrusion of basaltic flows in both Paleozoic (Paraná) and Mesozoic basins (Pelotas, Santos, Campos and Espírito Santo). Coeval dyke swarms, namely the Serra do Mar Dyke Swarm, the Ponta Grossa (and East Paraguay) Dyke Swarm and the Florianópolis Dyke Swarm occur associated with those basaltic flows.

The Serra do Mar dykes intrude gneisses and granitoids of the Upper Proterozoic/Cambro-ordovician, Ribeira Orogen (Schmitt et al., 2004). The dolerites are included in a transitional tholeiitic series that can be divided in low- and high-TiO_2 suites. This paper presents AFC (*Assimilation and Fractional Crystalization*) models based on elemental and isotope (Sr-Nd-O) data obtained for the high-TiO_2 basalts.

SR-ND AFC MODELING: CONSTRAINING LIKELY CONTAMINANTS

The high-TiO_2 tholeiitic flows, sills and dykes associated with the Paraná CFB in SE Brazil are usually supposed to be largely unaffected by contamination as opposed to the more contaminated low-TiO_2 basalts which display a wider range in Sr isotope composition (*e.g.* Cordani *et al.*, 1988). Nevertheless, it is worth noting that coeval high-TiO_2 dolerites in the Ponta Grossa and Serra do Mar dyke swarms systematically diverge from the field of the high-TiO_2 Paraná basalts towards more radiogenic Sr isotope compositions (Valente, 1997). So far, the most radiogenic initial Sr compositions have not exceeded ~0.708 which is still low when compared to the contaminated low-TiO_2 Paraná basalts (~0.716, *e.g.* Peate *et al.*, 1990). Nevertheless, an AFC process has been invoked to explain the Sr-Nd isotope variations in the high-TiO_2 Paraíba dolerites (Regelous, 1993). The AFC numerical modeling was developed by DePaolo (1981).

The major assumptions necessary to be made for AFC modeling are the respective compositions of the uncontaminated parental magma and the contaminant. In many cases, the global bulk-average compositions of upper or average crust (*e.g.* Taylor & McLennan, 1985) are used as the contaminants end-members. However, these averages include analyses of sedimentary rocks which cannot be considered potential contaminants for the dolerites in Rio de Janeiro. The country rocks in Rio de Janeiro are predominantly metamorphic, being mainly granitic in composition but including granulites of intermediate compositions. The granitic gneisses were metamorphosed in upper amphibolite facies and together with abundant intrusive granitoids are likely to represent the upper crustal rocks in Rio. On the other hand, the granulites, often more strongly deformed, are at a higher metamorphic grade and possibly represent lower crust materials. The gneisses, granitoids and granulites in Rio can all be considered potential contaminants for the dolerites.

Three samples were selected from the country rocks for major/trace element and Sr-Nd isotope analysis. They are thought to be representative of the aforementioned three main country rock groups in the area. Sample MB-CM-43C is a granulite from the Juiz de Fora Complex, RJ/C-200 is a plagioclase gneiss from the Upper Series and sample RJ/C-199 is a granitoid from the Pedra Branca massif in Rio. The rocks vary in SiO_2 content from intermediate in the granulite to acid compositions in the gneiss and granitoid. The Rb/Sr ratio is also variable being low in the granulite, intermediate in the granitoid and high in the gneiss. The $^{143}Nd/^{144}Nd_{(132)}$ values are more or less the same for the upper crust samples but the lower crust granulite is less radiogenic than the other two acid country rocks. The gneiss has much more radiogenic Sr than the granulite and the granitoid. Overall, these three representative country rocks show remarkable differences in their compositions which would be expected to be reflected in the compositions dolerites contaminated by such lithologies.

Figure 1 shows possible AFC solutions superimposed on the Sr and Nd isotope data for the main compositional trend in the high-TiO_2 basalts. The least evolved sample RJ-19 has been taken as the "uncontaminated" parental magma. The results for the three contaminants are shown for r=0.5. Albeit a rough approximation, this is assumed to represent an intermediate value between those r values which are likely to prevail in the upper (r=0.3) and lower (r=0.7) crustal levels due to respectively higher and lower temperature gradients between magma and wall rocks.

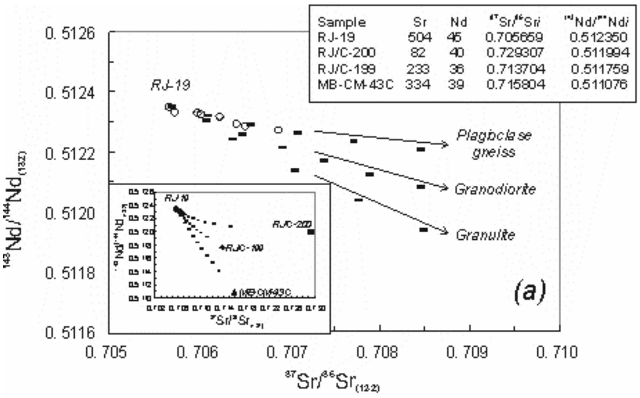

Figure 1: Possible AFC solutions superimposed on the Sr and Nd isotope data for the high-TiO_2 basalts of the Serra do Mar Dyke Swarm (open circles). r=0.5, D_{sr}=0.7207 and D_{Nd}=0.6382 (calculated for an assemblage with clinopyroxene, plagioclase, Fe-Ti oxide and olivine = 40/38/16/6 and $\mathbf{K}_{di}$ values in Rollinson, 1993). Other parameters are indicated in the diagrams. The contaminants (insets) as in text. The AFC trends (tick marks) are shown at 0.1 intervals.

Under such conditions, the main compositional trend in the high-TiO_2 basalts best fits an AFC model incorporating a contaminant such as the plagioclase gneiss RJ/C-200 which may be taken as representative of upper crust levels in Rio. The range of Sr-Nd isotope compositions in the basalts can be explained by up to 27% AFC of a composition such as RJ-19 involving an acid contaminant with the highest Rb/Sr and $^{143}Nd/^{144}Nd_{(132)}$ among the potential contaminants in the area. One of the main drawbacks of the AFC modeling is to constrain the parameters for the uncontaminated parental composition. Although sample RJ-19 does have the highest initial ε_{Nd} and least radiogenic Sr of the dolerites in the high-TiO_2 suite, its δO^{18} (6.30‰) indicates a possible minimum involvement of a crust component. The basalts trend diverges from an AFC trend for a contaminant such as the MB-CM-43C granulite taken as representative of the lower crust in the area. This contaminant has the lowest Rb/Sr and $^{143}Nd/^{144}Nd_{(132)}$ among the representative country rocks in the area. A solution for a contaminant such as the Pedra Branca granitoid RJ/C-199 cannot be totally precluded. Nevertheless, the basalts trend seems to diverge from the extension of the mantle array towards more radiogenic Sr compositions at nearly constant $^{143}Nd/^{144}Nd_{(132)}$ values which would be more consistent with a Nd isotope composition in a contaminant such as RJ/C-200.

TRACE ELEMENT AFC MODELING

AFC models were also elaborated for immobile (Zr, Y, Nb) and mobile (Ba) trace elements compositions of high-TiO_2 suite of the swarm. Tests were done based on the composition of a local superior crust represented by the plagioclase gneiss (RJ/C-200) constrained in the previous section. The fractionating assemblage and $\mathbf{K}_{di}$ values are those stated in Figure 1. The variation of Zr and Y concentrations in the high-TiO_2 basalts can be explained by a maximum of 30% of AFC (Fig. 2).

Alternative models were tested including 1% of apatite in the fractionating assemblage since this phase is seen as inclusions in plagioclase phenocrysts. It is important to note that there are not values of Zr and Y to apatite in equilibrium with basaltic liquids available in the literature. However, tests which were realized with values of Kd of Zr and Y to apatite in equilibrium with riolitic liquids ($0<K_{dY}<10$; $0,1<K_{dZr}<0,64$), configurating an extreme case, did not produce appreciable changing in the model. AFC models constrained for Nb and Ba corroborated the results obtained in the Zr-Y model.

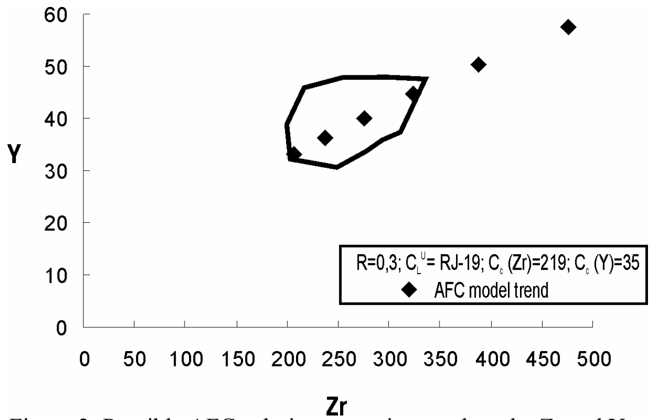

Figure 2: Possible AFC solutions superimposed on the Zr and Y data for the high-TiO_2 basalts of the Serra do Mar Dyke Swarm (closed field). r=0.3, D values calculated for an assemblage with clinopyroxene, plagioclase, Fe-Ti oxide and olivine = 40/38/16/6 and $\mathbf{K}_{di}$ values in Rollinson (1993). Parental compositions (RJ-19) are Zr=219ppm and Y=35ppm. Other parameters are indicated in the diagrams. The contaminant is represented by sample RJ/C-200. The AFC trends (tick marks) are shown at 0.1 intervals.

CONCLUSIONS

The results of the modeling showed that an upper crustal material is the more likely contaminant for the high-TiO_2 basalts in an AFC process. The Sr-Nd isotope trend in the dolerites seems to diverge from an AFC model with a lower crust contaminant such as the Juiz de Fora granulite considered here. The Rb content and $^{143}Nd/^{144}Nd$ ratio in the Juiz de Fora granulite (Valente, 1997) seem to be just too low to be able to control the Sr-Nd isotope trend in the high-TiO_2 suite by means of an AFC process. The results obtained by the Sr-Nd isotope modeling have been confirmed by elemental modeling on the basis of immobile and mobile trace element compositions of the basalts. As such, isotope and elemental data point to a maximun of 30% of AFC, involving a fractionating assemblage dominated by plagioclase and augite and subordinate amounts of olivine and Fe-Ti oxides.

The AFC solutions appear to favour an upper crustal contaminant for the studied high-TiO_2 basalts. As shown, there are two main representatives of such composition readily available in the country rocks in Rio. Interestingly, both produced similar results for the modeling although displaying substantial differences in Sr and $^{87}Sr/^{86}Sr_{(132)}$. One possible explanation for this is that the "uncontaminated" parental magma (or magmas) was already enriched in Sr (and possibly other incompatible elements) as well as radiogenic Sr so that it was largely insensitive to the enriched compositions of the upper crust contaminants. This could also explain the restricted Sr isotope range resulting from the contamination process in the high-TiO_2 suite.

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RESUMO

Os principais eventos relacionados com a reativação da Plataforma Sul Americana incluem amplo magmatismo basáltico e a formação das bacias de rifte ao longo da margem continental brasileira. Estes eventos encontram-se associados com rifteamento do Supercontinente Gondwana Oeste durante o Cretáceo Inferior (ca. 137 Ma) ou mais cedo (ca. 193 Ma). Este magmatismo é representado principalmente pela extrusão de lavas basálticas em bacias Paleozóicas (Paraná) e Mesozóicas. O Enxame de Diques da Serra do Mar ocorre associado com estes derrames basálticos. Os diques da Serra do Mar intrudem gnaisses e granitóides do Orógeno Ribeira de idade Neoproterozóica/Cambro-ordoviciana. Os diabásios constituem uma série transicional toleítica que pode ser dividida em suítes de baixo-TiO_2 e alto-TiO_2. Este trabalho apresenta modelos de AFC com base em dados elementais e isotópicos (Sr-Nd-O) obtidos para os basaltos de alto-TiO_2. A modelagem isotópica (Sr-Nd) e elemental apontam para um valor máximo de 30 % de AFC, envolvendo uma assembléia fracionante dominada por plagioclásio e augita e, subordinadamente, olivina e óxidos de Fe-Ti. Vale ressaltar que ambas as modelagens produziram resultados similares embora apresentem diferenças substanciais no Sr e na razão $^{87}Sr/^{86}Sr_{(132)}$. Uma possível explicação para isto reside no fato de que o magma (ou magmas) parental não contaminado já estaria enriquecido em Sr (e possivelmente em outros elementos incompatíveis) bem como em Sr radiogênico. Deste modo, o enriquecimento em Sr não foi perceptível para as composições enriquecidas dos contaminantes da costa superior.