

# THE EFFECT OF ALTERATION ON Sr-Nd ISOTOPES OF MAFIC ROCKS: EXAMPLES FROM RIO CEARÁ-MIRIM DYKE SWARM, NE BRAZIL

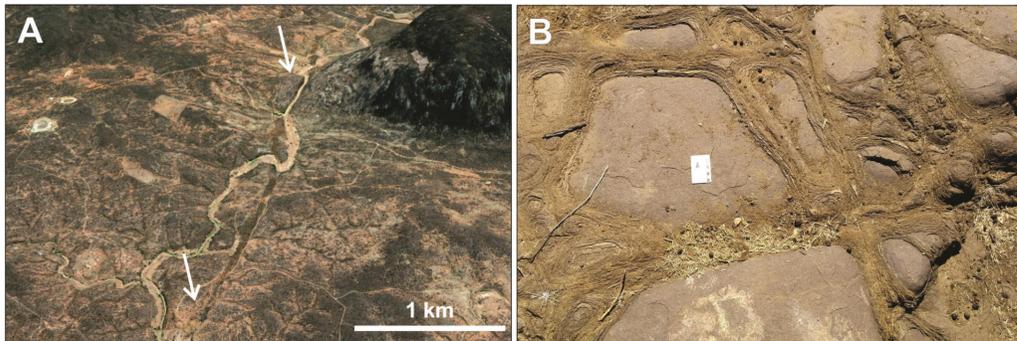
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## INTRODUCTION

The Rio Ceará-Mirim magmatism is represented by a giant dyke swarm ca. 1000 km-long (Fig. 1), comprising mafic dolerites with Early Cretaceous age (~130 Ma). The dykes intruded into the Precambrian Borborema Province (NE Brazil) across a region of ca.  $5 \times 10^5$  km<sup>2</sup> and are arranged along an arcuate trend (E-W to NE-SW) from the Atlantic coastline towards NW border of the São Francisco craton. They comprise one of the largest Mesozoic dyke swarms related to the Gondwana breakup. Individual magmatic bodies can reach a maximum of ca. 190 m in widths and 40 km in length. In the field the dykes are commonly recognized by onion-skin weathering (Fig. 2) aspect. This work assesses the role of post-magmatic alteration on the Sr-Nd isotope signature of these magmatic rocks.



**Figure 2.** Field aspects of Rio Ceará-Mirim magmatism. A) Huge dyke parallel to fault zone adjacent to the border of the São Francisco Craton. B) Onion-skin weathering aspect of dolerites.

## METHODOLOGY

Fresh hand samples were collected taking into consideration the geographic setting besides faciological and compositional variation of lithologies. The samples were analysed using XRF in order to determine major oxide content, ICP-MS to obtain trace element and REE content and ID-TIMS to measure Sr-Nd ratios.

Sr-Nd isotopic analyses were performed at the Laboratório de Geologia Isotópica (Cpgeo), Universidade de São Paulo, Brazil. The rock samples were sawed and diminished on an agate ring and puck mill to obtain a homogeneous whole-rock powder. Approximately 50 mg were then dissolved on Savillex® beakers with sub-boiling (on hot plate at 100°C) purified HF, HNO<sub>3</sub> and HCl acids. The product of digestion was refluxed into 6 M HCl and prepared to be poured into cation-exchange columns.

Sr and REE were collected from using an Eichrom Sr-Spec®, RE-Spec® and LN-Spec® resins to isolate Sr, REE and Nd, respectively. The separated elements (Sr and Nd) were loaded onto single Ta evaporation filaments (99.959% H. Cross®) and double Re filaments (99.995% H. Cross®) respectively for Sr and Nd measurements. Natural isotopic compositions were measured by thermal ionization mass spectrometry (TIMS) on a multicollector Thermo Scientific Triton Mass Spectrometer set on static mode operating at 1300 to 1500°C for Sr and reaching up to 1630°C for Nd degassing.

The Sr and Nd isotope ratios were mass fractionated and normalized to  $^{86}\text{Sr}/^{88}\text{Sr} = 0.1194$  and  $^{146}\text{Nd}/^{144}\text{Nd} = 0.7219$ , respectively. Moreover, NBS-987 and JNd-1 standards analysis yielded natural values of  $^{87}\text{Sr}/^{86}\text{Sr} = 0.710248 \pm 0.000039$  and  $^{143}\text{Nd}/^{144}\text{Nd} = 0.512101 \pm 0.000006$  (errors quoted at 2σ level).  $^{87}\text{Rb}/^{86}\text{Sr}$  and  $^{147}\text{Sm}/^{144}\text{Nd}$  ratios were determined from Rb, Sr, Sm and Nd values obtained by the elemental geochemical analyses. Ion beam intensities of  $^{88}\text{Sr}$  on NIST SRM 987 and  $^{148}\text{Nd}$  on JNd-1 standard were always higher than 1 V.

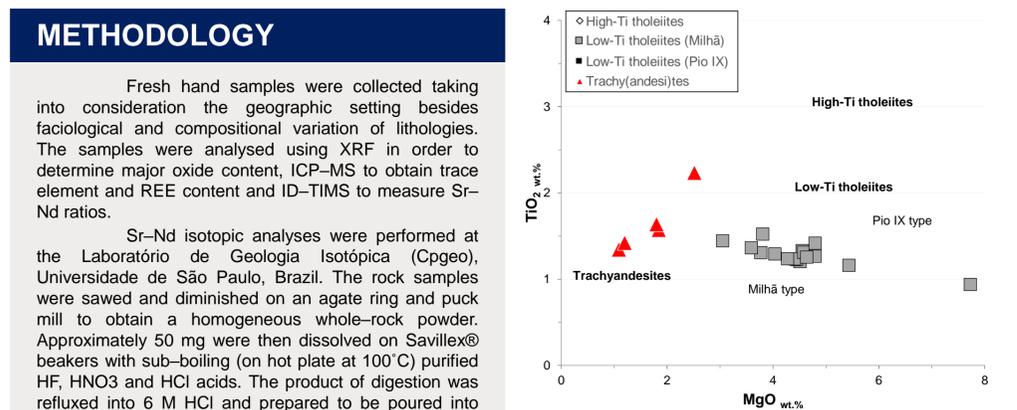
## RESULTS

The dolerites are equigranular to microporphyratic, fine-grained to medium-grained and hypocrystalline to holocrystalline. The mineral assemblages identified are plagioclase, augite, pigeonite, Fe-Ti oxides, sulphides, apatite and rare olivine (pseudomorphs). Secondary minerals (clays) present on few samples record some degree of weathering in primary rock forming minerals. The dykes are characterized as low-Ti tholeiites ( $\text{TiO}_2 < 2\%$ ), high-Ti tholeiites ( $\text{TiO}_2 > 2\%$ ) and trachytes to trachyandesites ( $\text{TiO}_2 < 2.2\%$  and  $\text{SiO}_2 > 57\%$  wt; Fig. 3).

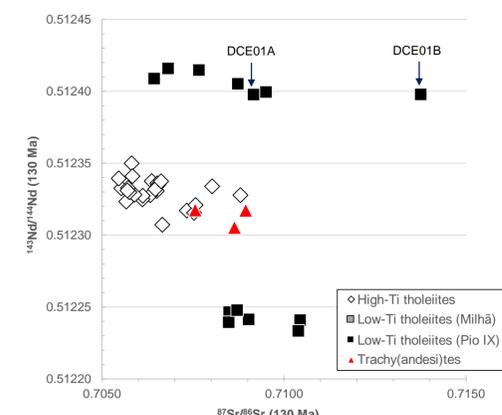
The high-Ti tholeiites have  $^{87}\text{Sr}/^{86}\text{Sr}_{(i)} = 0.70364\text{--}0.70880$  and  $^{143}\text{Nd}/^{144}\text{Nd}_{(i)} = 0.51204\text{--}0.51237$  (Fig. 4). The low-Ti tholeiites can be further subdivided into two groups: (i) Milhã Type ( $^{87}\text{Sr}/^{86}\text{Sr}_{(i)} = 0.70392\text{--}0.71107$ ;  $^{143}\text{Nd}/^{144}\text{Nd}_{(i)} = 0.51219\text{--}0.51244$ ) and (ii) Pio IX Type ( $^{87}\text{Sr}/^{86}\text{Sr}_{(i)} = 0.70644\text{--}0.71375$ ;  $^{143}\text{Nd}/^{144}\text{Nd}_{(i)} = 0.51240\text{--}0.51242$ ). The trachyandesites which have  $^{143}\text{Nd}/^{144}\text{Nd}_{(i)} = 0.51231\text{--}0.51232$ ;  $^{87}\text{Sr}/^{86}\text{Sr}_{(i)} = 0.70756\text{--}0.70895$  are fractionation products of high-Ti tholeiites.

All geochemical groups exhibit low values of loss on ignition (LOI) with apparent ambiguous covariance with Sr-Nd ratios (Fig. 5), but somewhat with Rb. However, it was observed that high-Ti rocks and trachyandesites with  $^{87}\text{Sr}/^{86}\text{Sr}_{(i)} > 0.706$  and low-Ti tholeiites with  $^{87}\text{Sr}/^{86}\text{Sr}_{(i)} > 0.707$  without apparent variance in  $^{143}\text{Nd}/^{144}\text{Nd}_{(i)}$ , are moderately altered (Fig. 6).

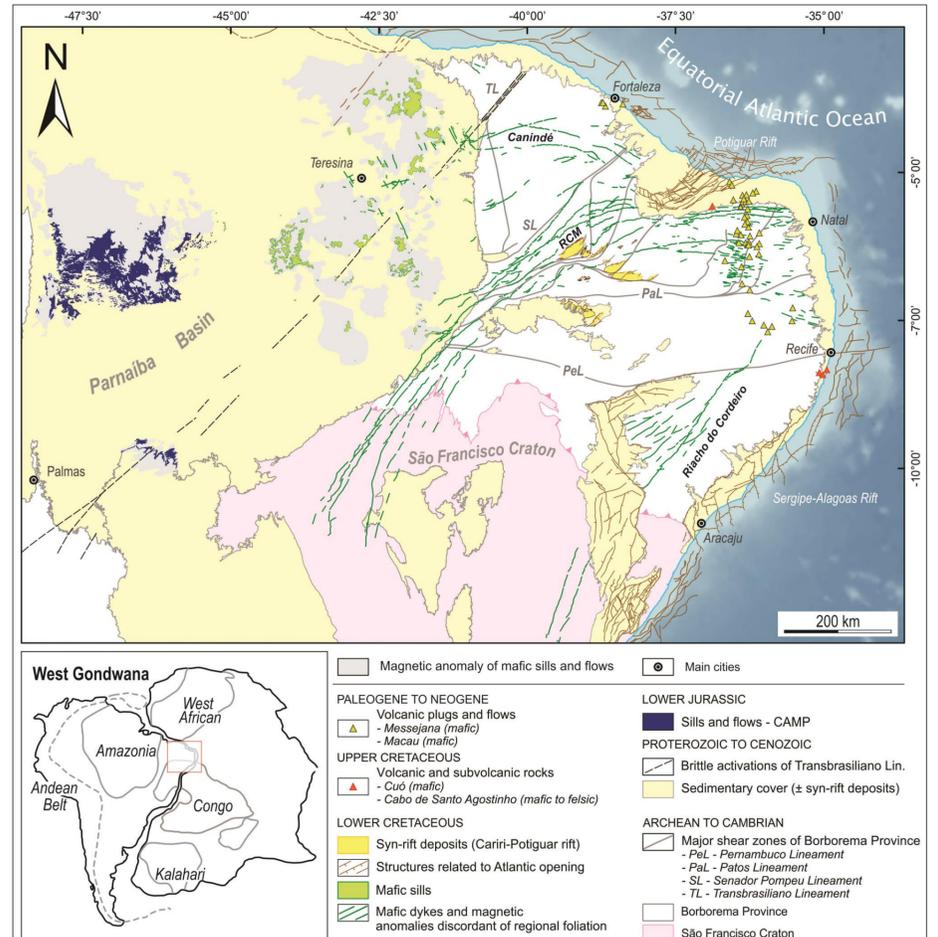
Two samples from the same outcrop were analysed to measure the isotope ratios variation. The centre of the dyke showed holocrystalline texture, medium-grained, slightly to moderately altered and  $^{87}\text{Sr}/^{86}\text{Sr} = 0.709778$ , while the fine-grained portion of the same dyke, strongly altered with  $^{87}\text{Sr}/^{86}\text{Sr} = 0.714742$ . The  $^{143}\text{Nd}/^{144}\text{Nd}$  ratios is practically the same in both samples (0.512527 vs. 0.512535, respectively; Fig. 7).



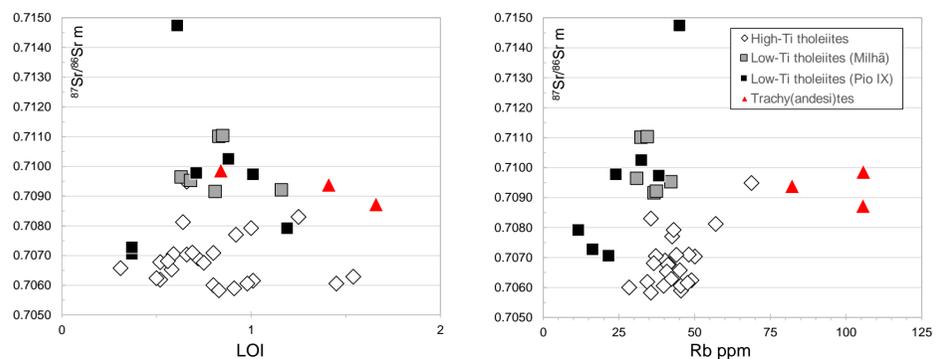
**Figure 3.** Compositional variability of RCM dykes in terms of  $\text{TiO}_2$  content.



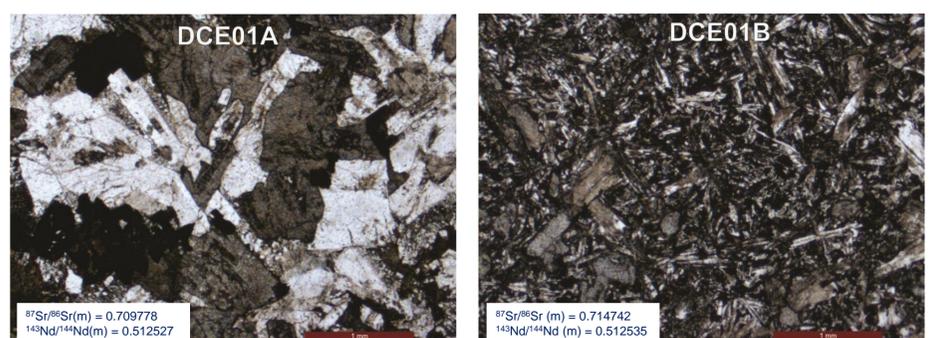
**Figure 4.** Sr-Nd initial isotope ratios for geochemical groups of Rio Ceará-Mirim magmatism.



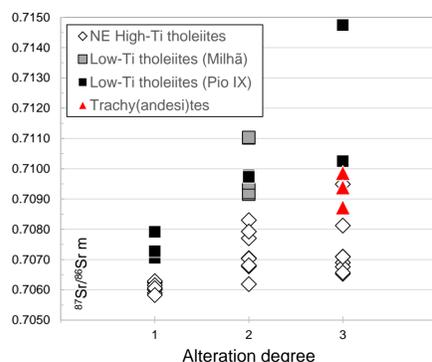
**Figure 1.** Geographical distribution of Phanerozoic magmatism in NE Brazil. The Rio Ceará-Mirim magmatism is represented by green lineaments.



**Figure 5.** Bivariate plots of  $^{87}\text{Sr}/^{86}\text{Sr}$  measured ratios versus  $\text{LOI}_{(\text{wt.}\%)}$  and  $\text{Rb}_{(\text{ppm})}$  for Rio Ceará-Mirim magmatism. This behaviour suggests that the dominant phase controlling  $^{87}\text{Sr}/^{86}\text{Sr}$  enriched in  $\text{H}_2\text{O}$  and Rb (most likely clays).



**Figure 7.** Low-Ti tholeiites collected in same outcrop (DCE01) from Pio IX type. A) Centre of dyke slightly to moderately altered showing  $^{87}\text{Sr}/^{86}\text{Sr} = 0.709778$ . B) Fine-grained portion of the same dyke strongly altered with  $^{87}\text{Sr}/^{86}\text{Sr} = 0.714742$ . The  $^{143}\text{Nd}/^{144}\text{Nd}$  ratios is practically the same in both samples (0.512527 vs. 0.512535, respectively).



**Figure 6.** Alteration degree checked by optical microscopy versus  $^{87}\text{Sr}/^{86}\text{Sr}$  measured ratios Rio Ceará-Mirim dykes. Alteration degree: 1 weak, 2 moderate, 3 strong.

## Conclusion

Variations on the  $^{87}\text{Sr}/^{86}\text{Sr}$  isotopic system, accompanied by variations in the  $^{143}\text{Nd}/^{144}\text{Nd}$  ratios is usually ascribed to AFC processes. However, strong discrepancies in the  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios accompanied by invariance in the  $^{143}\text{Nd}/^{144}\text{Nd}$  system may be linked to late to post magmatic alteration.

The use of different geochemical parameters to investigate a possible disturbance of the isotopic system by weathering may not always yield reliable results. In contrast, a simple approach that analyses the alteration degree of magmatic rocks by optical microscopy is still a powerful tool to side-step samples with high perturbation on the  $^{87}\text{Sr}/^{86}\text{Sr}$  isotopic system.

## Acknowledgements

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