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ANALES XXXIV

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GEOCHEMISTRY AND Sr-Nd ISOTOPES OF THE TRINDADE MAGMATISM: CONSTRAINTS ON THE MANTLE SOURCE COMPOSITIONS

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INTRODUCTION

The Trindade and the Martin Vaz islands are located in the southern Atlantic Ocean. They rise ca. 5000 m above the ocean floor and constitute emerged parts of the Vitória-Trindade Ridge, whose W-E trend is believed to represent the volcanic track left by the Trindade mantle plume on the overriding South American plate (*e.g.* O'Connor and Duncan, 1990) since the Tertiary. A very complete geological map, together with a stratigraphic division and rock descriptions, was presented by Almeida (1961). Recent studies of Trindade volcanics deal mainly with trace elements and isotopes (Sr, Nd, Pb) and refer to a very few and different samples (Weaver, 1990; Halliday *et al.*,1995 and references therein). These data allowed a preliminary knowledge of the petrology and some genetic hypotheses for these igneous rocks were proposed.

This study aims to provide a further insight on the mantle source(s) and the processes responsible for the Trindade and Martin Vaz magma genesis, based on a larger set of new geochemical and Sr-Nd isotopic data.

GEOLOGICAL BACKGROUND

The available geological map of Trindade was produced by Almeida (1961), who distinguished five magmatic events, dated (K-Ar) 3.6 Ma to Present by Cordani (1970). Under the name *Trindade Complex* (3.6 to 1.1 Ma), exposed along the coast, Almeida (1961) gathered a heterogeneous group of subvolcanic bodies and pyroclastic deposits of variable composition and age (nephelinites to phonolites). The phonolitic domes, plugs, necks and dykes (2.9 to 2.3 Ma) are abundant and widespread. The larger intrusions may reach heights of over 400 m above sea level and diameters up to ca. 600 m. According to Almeida (1961), the Trindade Complex was subjected to extensive erosion which removed flows, leaving exposed only the feeder dykes (less than 5 m thick), with ages varying from 3.6 Ma to 1.1 Ma.

The volcanic event responsible for the *Desejado Sequence* (2.6 to 1.5 Ma) is represented by a thick succession (ca. 400 m) of phonolitic lavas and subordinate ultramafic flows intercalated with pyroclastic levels. The phonolitic flows cover the central parts of the island where the domes constitute the highest peaks (500 to 600 m).

The rocks of the last three volcanic events are all of ultrabasic nature. The *Morro Vermelho Formation* (< 0.27 Ma) is represented by numerous extensive flows (mainly nephelinites and ankaratrites) and scarce tuffs, which may have a total thickness of 230 m. The *Valado Formation*, the fourth volcanic event, is represented by the nephelinitic flows and pyroclastic deposits (20 m thick), which occur in restricted areas. The *Vulcão do Paredão Formation* represents the youngest volcanic event in Trindade. This event built up a large central volcano (200 m high), now partly eroded, located at the eastern border of the island, as well as smaller centers in the Morro Vermelho area. These occurrences are made up of pyroclastic materials and highly vesiculated ultramafic flows.

The magmatic rocks of the Martin Vaz archipelago

are virtually unknown. The only studied sample corresponds to a phonolite petrographically similar to that dated (less than 0.7 Ma) by Cordani (1970).

ANALYTICAL TECHNIQUES

Bulk-rock analyses for major, minor and trace elements (Cr, Ni, Rb, Ba, Sr, Y, Zr and Nb) were performed by X-ray fluorescence at University of Trieste (Italy). Analytical precision is 3% for major and minor elements, and better than 10% for trace elements. Neutron activation was used to determine REE and other trace elements (Ta, Th, U, Hf, Cs, Sc and Co) at the Instituto de Pesquisas Energéticas e Nucleares-CNEN/SP, Brazil. The accuracy and precision of the adopted methodology are better than 10%. Sr and Nd isotopic compositions were determined at the Centro de Pesquisas Geocronológicas of São Paulo University, Brazil. The Sr isotopic ratios were normalized to $^{86}Sr/^{88}Sr = 0.1194$; replicate analyses of $^{87}Sr/^{86}Sr$ for NBS987 standard gave a mean value of 0.71028 ± 0.00006 (2 σ); the blanks recorded during the analyses were less than 6.4 ng. The Nd isotopic compositions were normalized to $^{146}Nd/^{144}Nd = 0.72190$. The averages $^{143}Nd/^{144}Nd$ for the La Jolla and BCR-1 standards were 0.511847 ± 0.00005 (2 σ) and 0.512662 ± 0.00005 (2 σ), respectively; during this work the blanks were less than 0.03 ng.

WHOLE-ROCK COMPOSITIONS

Major and minor element variations show a bimodal distribution of the samples (Ulbrich *et al.*, 1997; Fig. 1). Important compositional gaps exist for MgO (8 - 2 wt%), SiO_2, TiO_2, Al_2O_3, FeO_t, CaO and K_2O. As expected, the phonolites have the highest content of SiO_2, Al_2O_3, Na_2O and K_2O, and the lowest concentration of MgO, TiO_2, FeO_t, CaO and P_2O_5. The nosean-bearing peralkaline (A.I. = 1.10) phonolite of Martin Vaz is compositionally similar to the Trindade analogues. The nephelinites are characterized by the lowest contents of SiO_2, TiO_2 and Al_2O_3, and the highest CaO concentrations. A striking feature is that the nephelinitic rocks (MgO = 10 - 12 wt%) have K_2O concentration ca. 4 - 5 times higher than the more evolved (MgO = 8 - 9 wt%) basanites-tephrites.

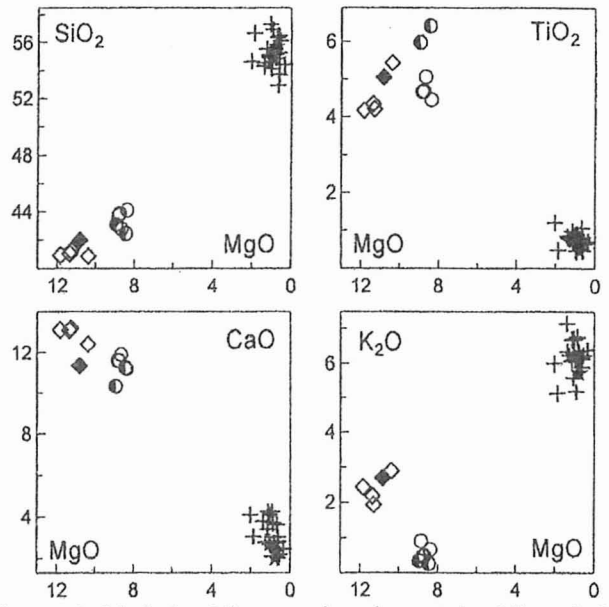

Figure 1: MgO (wt.%) vs. major element (wt.%) variation diagrams for the Trindade and Martin Vaz rocks. Symbols: open diamonds = nephelinites; solid diamond = Vulcão do Paredão nephelinite; open circles = basanites-tephrites; half-solid circles = basanites-tephrites of the Vulcão do Paredão; crosses = phonolites; solid star = Martin Vaz peralkaline phonolite.

Positive correlations between Th and other trace elements, such as LREE, Y, Nb, Ta and Sr, exist for the ultramafic rocks (Fig. 2), but not for the phonolites which, on the contrary, may show negative correlations (*e.g.* La, Ba, Sr). Therefore, the concentrations of incompatible trace elements of the phonolites are not significantly high when compared to the ultramafic rocks (*e. g.* La, Y, Nb, Ta, Ba). In particular, the concentrations of middle and heavy REE are even lower in the phonolites than those of the ultramafic rocks.

Sr - Nd ISOTOPIC DATA

The measured $^{87}Sr/^{86}Sr$ (Sr_m) ratios range from 0.7036 to 0.7039 (av. = 0.7037 ± 0.0001; N = 9) and are consistent with earlier reports (0.7036-0.7038; Halliday *et al.*, 1995 and references therein). The lowest Sr_m isotopic ratios belong to the phonolites. The measured $^{143}Nd/^{144}Nd$ (Nd_m) isotopic compositions vary between 0.51279 and 0.51288 (av. = 0.51284 ± 0.00004; N = 5), a range larger than the that (0.51276-0.51280) reported by Halliday *et al.* (1995).The Martin Vaz peralkaline phonolite presents

the highest Nd_m ratio, while one analysed tephrite has Nd_m (0.51287) significantly higher than data obtained from two analysed nephelinites (0.51279 - 0.51282).

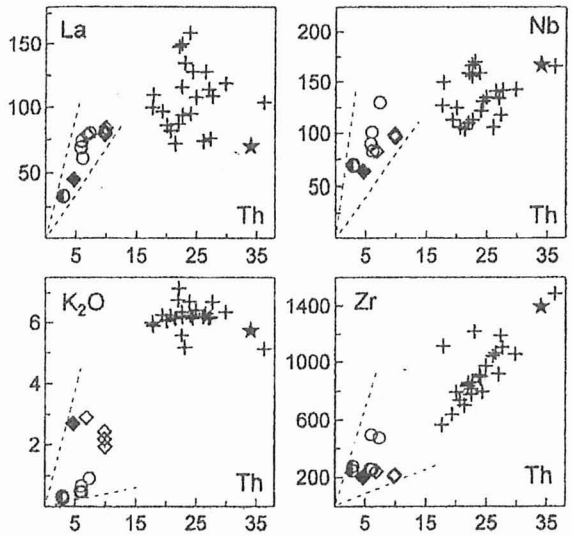

Figure 2: Th (ppm) vs. major (wt.%) and trace element (ppm) variation diagrams for the Trindade and Martin Vaz rocks. Symbols as in Fig. 1.

Both Sr and Nd isotopic compositions are time-integrated depleted relative to the Bulk Earth (Fig. 3), and are similar to the rocks from Fernando de Noronha and the Abrolhos Islands. The latter islands were interpreted by Thompson *et al.* (1998) as being part of the volcanic trace left by Trindade mantle plume on the Brazilian continental margin at about 52 Ma ago.

The Martin Vaz phonolite and most of the investigated Trindade samples have higher Rb/Sr and lower Sm/Nd ratios than the Bulk Earth (Fig 3). This is contrary to what would be expected from Sr and Nd isotopic ratios, suggesting that the present Rb/Sr and Sm/Nd ratios of the source(s) were modified (Rb vs. Sr and Nd vs. Sm enrichments) prior to melting processes.

MANTLE SOURCES

The geochemical and isotopic differences between the nephelinites and basanites-tephrites cannot be uniquely related to different degrees of partial melting of homogeneous mantle requiring, instead, the participation of different mantle sources. The basanites-tephrites are characterized by strong depletion in K relative to other incompatible trace elements indicating its retention in potassium-bearing residual minerals during partial melting (Fig. 4). The K behaviour may also reflect the metasomatic processes that occurred in the mantle sources.

According to Sr-Nd isotope mixing systematics the isotopic data can be explained by mixing between a dominant (ca. 70%) depleted mantle component, such as DMM or N-MORB, and a EMI component. Although Pb isotopes may suggest the involvement of a highly enriched radiogenic lead (HIMU) component, this is not supported by Sr and Nd isotopes, which are quite distinct from those of Santa Helena, precluding an important contribution of a HIMU source-type.

As earlier outlined the Trindade and Martin Vaz rocks exhibit decoupling between Sr-Nd isotopes and Rb/Sr and Sm/Nd ratios, respectively (Fig. 3). These isotopic and trace element features may be explained by the involvement of fluids and/or small volume melts related to mantle metasomatism (Menzies *et al.*, 1987).

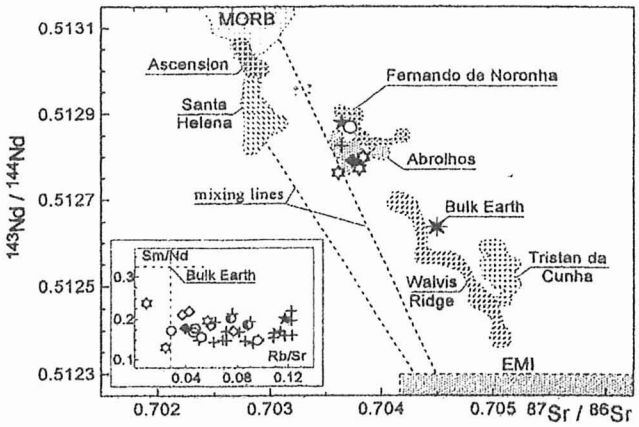

Figure 3: Measured Sr and Nd isotopic compositions for Trindade and Martin Vaz rocks (symbols as in Fig. 1). The mixing lines between N-MORB - EMI and Santa Helena - EMI are displayed. Open stars: data from Trindade ultramafic rocks from Halliday et al. (1995 and references therein). Sm/Nd vs. Rb/Sr data are shown in the inset.

Assuming that Sm/Nd ratio of the mantle source was not significantly modified during the melting process, the $T_{DM}(Nd)$ model age may provide an indication of the time at which the metasomatic event(s) occurred. The available Nd isotope data of the ultramafic rocks yielded a mean value of 456 ± 116 Ma (range: 292 - 616; N = 6). Note that this model age agrees with those related to the Brasiliano Cycle (750 - 450 Ma) between the São Francisco craton and the coast. This may suggest the

involvement of detached continental lithospheric mantle, left at shallow levels, which was melted by the Trindade plume.

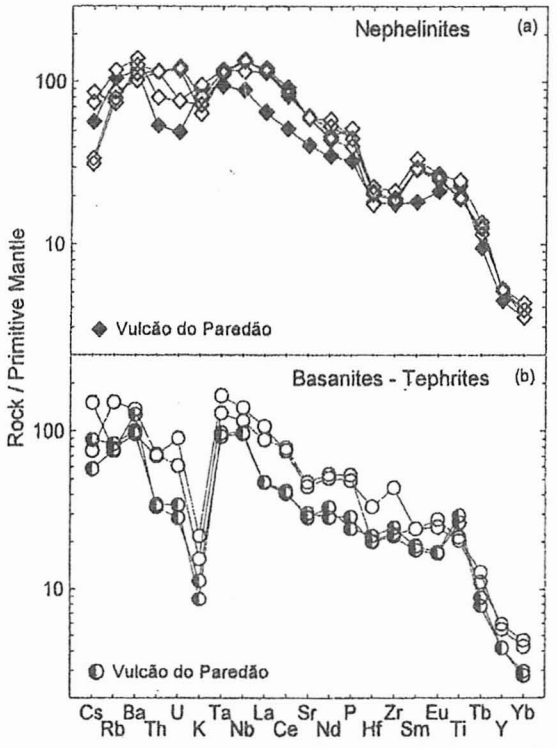

Figure 4: Mantle-normalized trace element distribution patterns of the ultramafic rocks of Trindade.

If we consider that Nd model age represents the time of the metasomatic event(s) that promoted enrichment in incompatible trace elements, then the mantle sources were isotopically depleted relative to the Bulk Earth, before this episode. Another possible explanation is that the metasomatic processes occurred recently (tens of millions years as suggested by Pb isotopes; Halliday *et al.*, 1995 and references therein) and then did not affect the isotopic signatures. It is important to mention that according to Halliday *et al.* (1995) young strong enrichments in U and Th relative to Pb occurred in the Trindade mantle source.

The close similarity among Sr and Nd isotopes of the basalts of Abrolhos Archipelago, located on the Brazilian coast north to Vitória-Trindade ridge, and those of Trindade and Martin Vaz rocks indicates the participation of similar mantle components in their magma genesis.

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REFERENCES

Almeida, F.F.M., 1961. Geologia e petrologia da Ilha de Trindade. Depto. Nac. Produção Mineral (DNPM). Rio de Janeiro, 197 p.

Cordani, U. G., 1970. Idade do vulcanismo no Oceano Atlântico Sul. Boletim IGA, 1, 9-75.

Halliday, A.N., Lee, D.C., Tommasini, S., Davies, G. R., Paslick, C.R., Fitton, G.J. and James, D.E., 1995. Incompatible trace elements in OIB and MORB and source enrichment in the sub-oceanic mantle. Earth and Planetary Science Letters, 133, 379-395.

Menzies M.A., Rogers N.W., Tindle A. and Hawkesworth C.J., 1987. Metasomatic enrichment processes in lithospheric peridotites, an effect of asthenosphere-lithosphere interaction. In: M.A. Menzies and C.J. Hawkesworth (Eds.) *Mantle Metasomatism* , pp. 313-361.

O'Connor, J.M. and Duncan, R.A., 1990. Evolution of the Walvis Ridge - Rio Grande Rise hot spot system: implications for African and South American plate motions over plumes. Journal of Geophysical Research, 95, 17475-17502.

Thompson, R.N., Gibson, S.A., Mitchell, J.G., Dickin, A.P., Leonardos, O.H., Brod, J.A. and Greenwood, J.C., 1998. Migrating Cretaceous-Eocene Magmatism in the Serra do Mar Alkaline Province, SE Brazil: Melts from the deflected Trindade mantle plume? Journal of Petrology, 39, 1493-1526.

Ulbrich, M.N.C., Marques, L.S., Ruberti, E. and Alves, F.R., 1997. Petrografia e geoquímica de rochas da Ilha de Trindade e do fonólito de Martin Vaz. IV Congr. Geoquim. Países de Língua Portuguesa, Braga, Portugal, Actas, 157-160.

Weaver, B.L., 1990. Geochemistry of highly-undersaturated ocean island basalt suites from the South Atlantic Ocean: Fernando de Noronha and Trindade Islands. Contributions to Mineralogy and Petrology, 105, 502-515.