LEAD ISOTOPES OF EARLY CRETACEOUS COASTAL DYKES OF PARANÁ MAGMATIC PROVINCE (FLORIANÓPOLIS SWARM): PRELIMINARY RESULTS

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INTRODUCTION

The origin of large continental flood basalts is a intensively studied object in recent years, and there is not at all a consensus about the associated geodynamic process which caused the production of such large volumes of extrusive basic rocks. Specifically for the Paraná Magmatic Province (PMP), which preceded the opening of South Atlantic Ocean, there is presently an important debate about the causes of the magmatism, and consequently, about the involvement of asthenospheric and/or lithospheric mantle sources in the genesis of its rocks.

According to some interpretations (e.g. Gibson et al., 1995, 1999; Milner & Le Roex, 1996) the PMP basalt compositions reflect the participation of deep asthenosphere, since these models claim the igneous activity was triggered by the impact of Tristan da Cunha mantle plume beneath Western Gondwanaland. Conversely, an origin in heterogeneous lithospheric mantle is proposed (e.g. Peate and Hawkesworth, 1996; Piccirillo & Melfi, 1988; Comin-Chiaramonti et al., 1997; Marques et al., 1999), in order to explain the geochemical and isotope characteristics of low- and high-TiO_2 tholeiites, which also have different spatial distribution in the province. In this case, if the PMP magmatism was generated by the Tristan da Cunha plume, its participation was restricted to a heat source.

Very recently, Ernesto et al. (2002) ruled out the involvement of Tristan da Cunha mantle plume in the PMP tholeiitic genesis, proposing an alternative model compatible with geochemical, isotopic, paleomagnetic, and geoid anomaly data. According to those authors, the basaltic magmas were generated in the lithospheric mantle, due to small extension across an anomalously heated region, which remained over a thermal anomaly for about 50 Ma (from c.a. 180 to 130 Ma). This thermal anomaly is still present in the western African Plate, north of Walvis Ridge, and does not coincide with the Tristan da Cunha Island location.

Taking into account that the PMP dyke swarms (Ponta Grossa, Florianópolis and Santos-Rio de Janeiro) were emplaced after the main volcanic activity, they are crucial for obtaining information about the mantle sources involved in the late stages of the magmatism. Considering that Pb isotopes are essential for this kind of investigation, the aim of this study is to present preliminary lead isotopic data obtained on coastal dykes of Florianópolis Swarm to better constrain the mantle sources that participated in the magma generation. Additionally, an analytical procedure to measure Pb isotopic ratios of low concentration silicate rocks is presented, since they are very sensitive to contamination during sample preparation and/or lead chemical separation.

GEOLOGICAL OUTLINES

The Paraná Magmatic Province is mainly composed of continental flood tholeiites, and subordinate intrusive magmatism represented by sills and three dyke swarms (Ponta Grossa, Florianópolis, and Santos-Rio de Janeiro).

The volcanic and intrusive rocks are characterized by predominant tholeiitic basalts, which are divided in two groups: (1) LTi basalts, low in TiO_2 (< 2 wt %) and incompatible elements (e.g. P, Sr, Ba, Zr, Ta, Y and LREE) and (2) HTi basalts, high in TiO_2 (> 2 wt %) and incompatible elements. The HTi tholeiites dominate the northern PMP (north of latitude ~26°S), whereas the LTi ones prevail in the southern PMP (south of latitude ~26°S). Minor HTi and LTi rocks are also found in the southern and northern PMP, respectively.

Geochemical and isotopic data indicated significant differences between LTi tholeiites from southern and northern PMP, as well as between HTi basalts from those regions of PMP (Bellieni et al., 1984; Piccirillo & Melfi, 1988, Marques et al., 1989). The incompatible trace element distribution patterns normalized to primordial mantle, for tholeiites with initial $^{87}Sr/^{86}Sr$ lower than 0.7060, show that all southern and northern tholeiites have significant Ta negative anomalies, which are considered mantle source features.

The Florianópolis Dyke Swarm is located in Santa Catarina Island, comprising also the adjacent continental area. The dykes have thicknesses from 0.1 to 70 m, and are mainly cost-parallel (NE-SW trending), although a NW-SE trend is also found. Their $^{40}Ar/^{39}Ar$ radiometric ages vary from 129 to 119 Ma, and are concentrated in relatively narrow ranges of 129 - 126 Ma and 122 - 119 Ma (Raposo et al. 1998; Deckart et al. 1998). The paleomagnetic results also indicate that most Florianópolis dykes belong to the youngest magmatic episode.

Similarly to the Ponta Grossa and Santos - Rio de Janeiro Swarms, most of the Florianópolis dykes are of HTi-type (Comin-Chiaramonti et al. 1983; Piccirillo et al. 1990; Hawkesworth et al. 1992; Marques et al., 1993, Marques, 2001), corresponding to about 90% of the exposed basic rocks.

ANALYTICAL PROCEDURES

Eleven samples of Florianópolis dykes previously analyzed for major, minor and some trace elements (Cr, Ni, Rb, Ba, Sr, Y, Zr and Nb) by X-ray florescence, at University of Trieste (Italy), were selected (Marques et al., 1993; Marques, 2001 and unpublished data). Concentrations of rare earth and other incompatible trace elements (Ta, Th, U, and Hf) determined by instrumental neutron activation analysis are also available for those samples. The latter analyses were carried out at the Instituto de Pesquisas Energéticas e Nucleares (CNEN/SP, Brazil). Precision and accuracy are better than 3% for major and minor elements, and better than 10% for trace elements (Bellieni et al., 1983; Figueiredo & Marques, 1989; Marques, 2001).

Lead isotopic compositions were determined in the selected samples at the Centro de Pesquisas Geocronológicas of São Paulo University (Brazil). The sample preparation procedure employed was similar to that reported by Marques et al. (1999). The external surface of each sample was entirely removed, with especial care to eliminate sawed sections, which may provoke lead contamination in high levels. All the samples were hand broken in small fragments (diameters less than 0,5 cm), using a stainless steel mortar and pestle, then washed in distilled water, for several times until the washing solution is clean. Finally the sample is ultrasonically washed in ultrapure 0.25N HNO_3, for at least 3 times, and dried under ultraclean conditions. After that, rock fragments were powdered in a mechanical tungsten carbide crusher. In order to verify if the adopted sample preparation procedure introduces lead contamination, two basaltic rocks from the PMP, previously analyzed for Pb isotopes (418 and 980; Marques et al., 1999) were also chemically processed.

Complete sample dissolution was done using ultrapure HF, HNO_3, and HCl. The Pb separation was performed by ion-exchange chromatography method, using anionic resin and 0.6M HBr-HCl media. Lead was purified by repeating the elution in the ion-exchange chromatography column (Babinski et al., 1999). Several tests indicated that the lead purification process is necessary for obtaining reproducible results. After separation, lead was loaded on zone-refined rhenium filaments with phosphoric acid and silica gel.

The Pb isotopic ratios were measured on a VG354 mass spectrometer. The whole procedure analytical blanks were lower than 100 pg, which are negligible in comparison to the reported lead concentrations of PMP tholeiites. Replicate analyses of the SRM981 NBS standard was used for mass discrimination correction.

LEAD ISOTOPIC DETERMINATIONS IN REFERENCE GEOLOGICAL MATERIALS AND SOME PMP BASALTS

The described chemical procedure for lead isotopic analysis was applied to two USGS reference materials. The results for Pb isotopic ratios and the respective errors (2σ absolute standard deviations) of replicate analysis of the BCR-1 (4 aliquots) and AGV-1 (3 aliquots) geological standards were $^{206}Pb/^{204}Pb = 18.766 \pm 0.014$; $^{207}Pb/^{204}Pb = 15.636 \pm 0.011$; $^{208}Pb/^{204}Pb = 38.687 \pm 0.027$, and $^{206}Pb/^{204}Pb = 18.938 \pm 0.011$; $^{207}Pb/^{204}Pb = 15.651 \pm 0.011$; $^{208}Pb/^{204}Pb = 38.548 \pm 0.048$, respectively. Taking into account associated errors, the obtained results are in agreement to those reported in the literature (e.g. Woodhead and Hergt, 2000), showing the high accuracy and precision of the adopted methodology.

The sample preparation procedure, which is a very delicate step of lead analysis due to the possibility of contamination, is also appropriate. The determined lead isotopic compositions (Table 1) for the two analyzed basalts of PMP agree with those published (the absolute errors correspond to 2σ), since the relative deviations are lower than 0.2%.

Table 1. Lead isotopic compositions determined for PMP basalts in the present study (a) and published data (b).

Sample	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$
418[(a)]	18.430±0.008	15.624±0.007	38.585±0.016
418[(b)]	18.387±0.006	15.609±0.007	38.520±0.024
980[(a)]	17.922±0.004	15.534±0.004	38.432±0.013
980[(b)]	17.918±0.006	15.547±0.007	38.437±0.024

LEAD ISOTOPES OF FLORIANÓPOLIS DYKES

The Florianópolis dykes which were selected for Pb isotopic determinations are of HTi-type ($TiO_2 > 3\%$) and according to De La Roche et al. (1980) they correspond to tholeiitic andesi-basalts (7 samples), lati-basalts (2 sample), and lati-andesites (1 sample). In addition, one LTi-type dyke was analyzed, which is a tholeiitic andesite ($SiO_2 = 55\%$). All investigated dykes have NE orientation, which is the dominant trend, corresponding to about 80% of the outcrops.

The tholeiitic andesite dyke has Pb isotopic compositions very similar to the LTi volcanics from southern PMP affected by low pressure crustal contamination ($^{87}Sr/^{86}Sr_i > 0.7060$).

On the other hand, the Pb isotopic ratios of HTi dykes show large variations ($^{206}Pb/^{204}Pb$: 17.747 - 19.441; $^{207}Pb/^{204}Pb$: 15.501 - 15.720; $^{208}Pb/^{204}Pb$: 38.222 - 39.482) and there is no systematic difference between the rocks that belong to the tholeiitic series (andesi-basalts and lati-andesite) and those of transitional nature (lati-

basalts). The least radiogenic compositions ($^{206}Pb/^{204}Pb$ < 17.9) are very similar to those of the HTi basalts from PMP, whereas the higher lead isotopic ratios, in general, coincides with those of the LTi from southern PMP. In addition, two andesi-basalts and a lati-basalt present very radiogenic lead ratios, mainly of $^{206}Pb/^{204}Pb$ (> 19.0), which are even higher than those of the LTi tholeiites from southern PMP, with $(^{87}Sr/^{86}Sr)_i > 0.7060$.

DISCUSSION

The data discussed here show that the LTi dyke of Florianópolis Swarm was affected by low pressure crustal contamination, since it has lead isotopic compositions and highly incompatible trace element ratios (e.g. La/Th, Th/Ta, Th/U) very similar to those of the LTi basalts from southern PMP, with $(^{87}Sr/^{86}Sr)_i > 0.7060$.

The Pb non-radiogenic compositions of the Florianópolis HTi dykes reinforce the interpretation that they are genetically related to the HTi basalts from southern PMP, as pointed out in previous geochemical studies (Marques, 2001).

The lead isotopic ratios of six HTi dykes of Florianópolis Swarm are comparable to or higher than those of the LTi basalts of southern PMP, with $(^{87}Sr/^{86}Sr)_i > 0.7060$. Although the lead isotopes may suggest a low pressure crustal contamination process, this interpretation is not compatible with the behavior of major (SiO_2), minor (K_2O) and trace elements (e.g. La, Th, Ta), as well as the incompatible trace element ratios (e.g. La/Th, La/Yb, Th/Ta) of those dykes. Alternatively, the very radiogenic lead isotopic compositions might be due to the involvement of a HIMU component in their genesis. However, additional isotopic data and further investigation is necessary to confirm this hypothesis.

The Pb isotopes and the geochemical data also rule out a significant participation of MORB and/or OIB (Tristan da Cunha) mantle components in the genesis of the dykes of Florianópolis Swarm. Therefore, the results contradict the classic plume model for the origin of PMP, which asserts that the basaltic compositions reflect the Tristan da Cunha plume component (e.g. Gibson et al., 1995, 1999). Moreover, considering that the Florianópolis Swarm represents the youngest magmatic episode of PMP, the data do not support some models of continental flood basalt generation (e.g. White & Mckenzie; 1989; Peate & Hawkesworth, 1996), which predicts a significant contribution of depleted mantle components (MORB-type) in the late stages of the magmatic activity.

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