Lithospheric contribution to Santiago Island magmatism (Cape Verde): Isotopic (Sr-Nd-Hf) and elemental evidence

Contribuição litosférica para o magmatismo na ilha de Santiago (Cabo Verde): evidência isotópica (Sr-Nd-Hf) e elementar

Martins, S. 1, 2; Mata, J. 1, 2; Munhá, J. 1, 2; Mattielli, N. 3

1 Departamento de Geologia, Faculdade de Ciências, Universidade de Lisboa
2 Centro de Geologia da Universidade de Lisboa
3 Département des Sciences de la Terre et de l’Environnement, Université Libre de Bruxelles, Belgium

Abstract
New Sr, Nd and (the first) Hf isotopic data obtained for Santiago lavas are presented and discussed in conjunction with elemental geochemistry. The data reinforce the role of lithospheric domains to the erupted lavas and demonstrate the important influence that it can exert on the variability of magmatic chemistry.

Keywords: Isotopes, mantle, heterogeneity, carbonatitic metasomatism

Resumo
Novos dados de Sr, Nd e (os primeiros resultados isotópicos) de Hf obtidos para Santiago, são apresentados e discutidos simultaneamente com geoquímica elementar. Os dados reforçam o papel desempenhado pelos domínios litosféricos nas lavas extruídas e demonstra a importante influência que pode exercer na variabilidade química dos magmas.

Palavras-chave: Isótopos, manto, heterogeneidade, metassomatismo carbonatítico
**Introduction**

This report presents new Sr and Nd isotopic values, as well as the first Hf data for the Cape Verde archipelago. The main aims are: 1) to discuss the existence of mantle heterogeneities and metasomatism stemming from elemental data (Martins et al., 2003); and 2) to identify mantle components present in the Santiago Island source(s).

**Geochemical context**

Santiago is the largest (991 km$^2$) of the ten islands that make up the Cape Verde archipelago (located in the Central Atlantic Ocean; 15-17ºN, 23-26ºW). The islands are arranged into alignments with distinct orientation which include Northern (Santo Antão, São Vicente, Santa Luzia, São Nicolau, Sal and Boavista) and Southern (Brava, Fogo, Santiago and Maio) groups.

Cape Verde islands developed on 120-140 Ma old oceanic crust (Courtney et al., 1989) within a topographic swell that rises 2 km above normal oceanic floor. This elevation is associated with gravity, geoid and heat flow anomalies, which in conjunction with recent seismic tomography data, provide evidence for a plume extending down to the core-mantle boundary (Montelli et al., 2006).

Stratigraphic relations of Santiago were established by Serralheiro (1976) and Alves et al. (1979): the island comprises 7 volcano-stratigraphic units. The Old Eruptive Complex represents the plutonic basement of the island and comprises silicate plutonic rocks, a basaltic dike complex and carbonatitic rocks. The Flamengos Formation is characterized by submarine lavas, breccias and pyroclasts (5.5 Ma, Holm et al., 2005). The Orgãos Formation is sedimentary in origin and represents an erosional period. The most important eruptive phase occurred at 3-2 Ma and is represented by the Pico da Antónia Formation, which was formed by voluminous sub-aerial (upper Pico da Antónia) and submarine volcanic activity (lower Pico da Antónia). The Assomada and Monte das Vacas Formation are characterized by lava flows and pyroclastic cones and correspond to the last volcanic manifestations of the island (0.7-1.1 Ma, Holm et al., 2005).

**Geochemistry of Santiago lavas**

**Major and trace element data**

Santiago samples are ultrabasic alkaline lavas, comprising basanites, melanephelinites, nephelinites and melilitites. Mg# values range from 42 to 76, with Monte das Vacas Formation being the most evolved (Mg# down to 52) and exclusively represented by basanites.

Due to the high SiO$_2$-undersaturated compositions, Santiago lavas exhibit significant enrichment in incompatible elements and strong REE fractionation $[(\text{La/Yb})_n=14-42]$. Primitive lavas are characterized by HFSE enrichment (Nb, Ta) relative to the LILE and LREE. Significant geochemical features also include significantly high Ba/Rb ratios and a pronounced K negative anomaly for the Assomada and Upper Pico da Antónia Formations.

The Santiago mantle source is characterized by a complex and variable residual paragenesis, composed of garnet (REE fractionation, variable Tb/Yb and La/Yb ratios), Ti-amphibole (negative K anomalies, concomitant compatible behaviour of K and Ti) and to a lesser extent phlogopite (compatibility of Ba) (Martins, 2003; Martins et al., 2003).

**Isotopic data**

Eighteen representative lavas were selected for Sr, Nd and Hf isotopic analysis, in order to describe the geochemical diversity of the Santiago Island.

New isotopic results cover the following ranges: $^{86}\text{Sr}/^{87}\text{Sr} = 0.703177$ to 0.703907, $^{143}\text{Nd}/^{144}\text{Nd} = 0.512613$ to 0.512868, $^{176}\text{Hf}/^{177}\text{Hf} = 0.282841$ to 0.282975. Sr and Nd data are in agreement with previous results for the Southern islands, plotting along more radiogenic Sr and less radiogenic Nd, relative to the Northern group (Gerlach et al., 1988; Davies et al., 1989; Doucelance et al., 2003) (Fig. 1). Consistent with previous observations (Gerlach et al., 1988) there is a general decrease in $^{143}\text{Nd}/^{144}\text{Nd}$ and increase in $^{87}\text{Sr}/^{86}\text{Sr}$ ratios over time in Santiago lavas.

![Fig. 1](https://example.com/fig1.png)

**Fig. 1** New Sr and Nd isotopic data projected on the fields previously defined for the Cape Verde archipelago. See main text for references.

The Santiago lavas plot in the depleted quadrant of the Sr-Nd and Nd-Hf diagrams, implying their derivation from sources with time-integrated depletion in the more incompatible trace elements (Fig 1 and 2).
Discussion

The variable isotopic signature of the Santiago lavas, as well as variations on specific trace element ratios (high Ba/Nb, low Rb/Nb, K/Nb, La/Nb) suggest mixing between a HIMU and EM1 component, as previously described by others authors for the southern islands (Gerlach et al., 1988; Kokfelt et al., 1998; Doucelance et al., 2003; Escrig et al., 2005). The significant contribution of HIMU and an enriched mantle component is endorsed by our Hf isotopic data (Fig. 2).

The highly enriched incompatible element character of Santiago lavas has been explained, to some extent, as resulting from mantle metasomatism (Martins et al., 2006). Subchondritic Ti/Eu values (as low as 3630), high Ca/Sc, Sr/Sm and Ce/Pb ratios, interaction with residual amphibole + phlogopite, and the presence of carbonate bearing peridotitic xenoliths in Santiago lavas (Mendes, 1995) suggest the influence of a carbonatitic metasomatic agent constraining the mineralogy and geochemistry of Santiago mantle source(s). This situation is also endorsed by the broadly occurrence of outcropping carbonatites at Santiago and by Fig. 3.

In detail, the trend developed by Santiago lavas does not exactly match a simple mixing line between HIMU -and EM1 type enriched mantle end-member, deviating towards significantly higher Ce/Pb ratios (Fig. 3) compatible with the influence of a carbonatite metasomatic agent.

Considering the limits imposed by the stability field of amphibole (stable below 1150°C), the evidence for hydrous residual minerals implies the interaction between ascending magmas and metasomatized domains located in the lithosphere. Also, the enriched mantle component in Cape Verde has been assigned to the presence in the region of delaminated sub-continental lithospheric mantle (e.g. Doucelance et al., 2003). Our data reinforce the role of lithospheric domains to the erupted lavas and demonstrate the significant, and variable, influence it that can exerts on magmatic chemistry.

The enriched mantle component sampled by Southern Cape Verde islands has been ascribed to the presence of EM1 (Gerlach et al., 1988; Kokfelt et al., 1998; Doucelance et al., 2003; Escrig et al., 2005). However from our data (see Fig. 2) it can be concluded that Santiago lavas define a trend deviating towards lower 143Nd/144Nd, 87Sr/86Sr and higher 176Hf/177Hf, as compared with the proxies of EM1.

Acknowledgements

This is a contribution from FCT project PLINT (POCTI/CTA/45802/2002) and a PhD scholarship from FCT (SFRH/BD/17453/2004) co-financed by FEDER.

References

ilha de Santiago (Cabo Verde). Garcia da Orta, Série de Geologia, 3, 47-74.


