ISSN 1028-334X, Doklady Earth Sciences, 2007, Vol. 412, No. 1, pp. 85–88. © Pleiades Publishing, Ltd., 2007.
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GEOCHEMISTRY

Heterogeneity of Isotope Sources of Alkaline Magmatism in the Hot Spot of the Southwestern Atlantic: Fernando de Noronha Islands

Academician of the RAS L. N. Kogarko, V. A. Lebedev, and L. K. Levskii

Received August 30, 2006

DOI: 10.1134/S1028334X07010199

New data on age and isotopic characteristics of alkaline magmatism in the hot spot of the Fernando de Noronha Islands have been obtained. For the first time, a new aspect of isotope heterogeneity expressed in enrichment in radiogenic Sr was revealed.

The Fernando de Noronha Archipelago is situated 345 km away from the Atlantic coast of Brazil and is confined to a transform fracture zone. The Fernando de Noronha lineament is traced far to the west by the Rocas atoll, a chain of seamounts, and occurrences of alkaline magmatism on the continent. According to the tectonic interpretation, this lineament is regarded as a track of a hot spot.

The commonly accepted subdivision of volcanic rocks in the Fernando de Noronha Archipelago was proposed by Almeida [1] who recognized the following three formations (from older to younger): Remédios, Quixaba, and São José. The oldest Remédios Formation, which occupies the central part of the island, extends as a tract from the northeastern coast (Boldro and Conceição bays) to the southeastern coast (sector between Sueste and Atalaia bays) and crops out at steep cliffs on the eastern coast. The Remédios Formation also includes the highest areas of the archipelago that represent phonolitic and trachytic stocks. The maximum evolved rocks of this formation combine two fractionation trends directed toward the quartz-normative trachyte and undersaturated phonolite. Phonolites prevail in outcrops. Pyroclastic rocks of the Remédios Formation comprise agglomerates, breccia, lapilli tuffs, and volcanic ash. Angular and subrounded fragments, up to 1 m in size, are common. The petrographic composition of rock fragments shows that the pyroclastic units are products of explosion eruptions of phonolitic and trachytic magmas. The dike suite of the Remédios Formation numbers approximately 120 bodies [1], which are commonly up to a few meters thick and extend largely in the northeastern direction. In petrography, the dikes often resemble primitive lavas of the overlying Quixaba Formation.

According to K–Ar datings reported by Kordani [2], the Remédios Formation varies from 11.79 to 8.91 Ma in age.

The Quixaba Formation covers a plain approximately 70 masl. As a rule, this plain is bounded by ~50-m-high steep escarpments, where one can observe alternation of ankaratrite flows a few meters thick and pyroclastic layers of the same composition.

Table 1. Chemical compositions of volcanic rocks from the Fernando de Noronha Archipelago, wt %

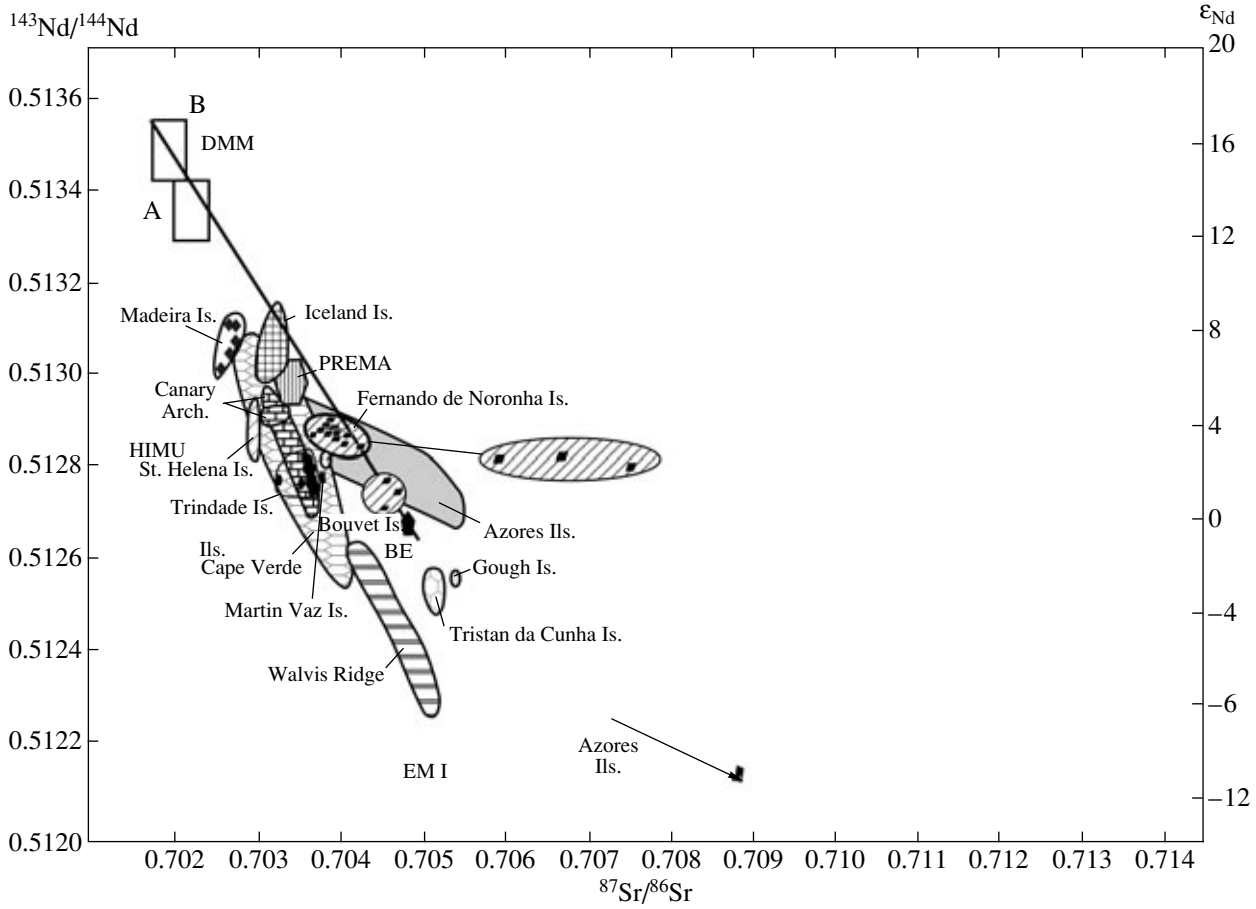
Sample	Rock	Formation	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	L.O.I.	Total
91-FN50	Phonolite	Remuédios	55.64	0.19	22.15		1.95	0.20	0.58	0.10	10.34	5.34	0.03	3.60	100.12
91-FN51a	The same	The same	56.76	0.19	22.48		1.98	0.18	0.35	0.22	6.74	5.09	0.04	6.06	100.09
91-FN-33	Trachyte	"	62.22	0.49	19.84	0.41	2.07	0.16	0.77	2.19	5.61	6.16	0.08	0.80	100.80
91-FN-70	The same	"	60.81	0.49	19.86	0.44	2.26	0.19	0.57	2.67	7.28	5.34	0.09	0.65	100.65
91-AT-121	Ankaramite	Quixaba	37.47	4.27	10.10	2.23	11.39	0.22	12.86	13.60	4.25	2.41	1.21	0.30	100.31
91-FN59	Ankaratrite	The same	39.28	3.23	11.02		11.88	0.19	13.90	13.03	2.15	0.74	1.15	3.06	99.63
91-FN-10a	Nephelinite	Sáo José	45.72	2.68	12.33	1.90	9.68	0.17	10.98	11.53	3.13	1.20	0.71	0.20	100.23

Vernadsky Institute of Geochemistry and Analytical Chemistry, Russian Academy of Sciences, ul. Kosygina 19, Moscow, 117975 Russia; e-mail: kogarko@geokhi.ru

Table 2. Isotopic characteristics of volcanic rocks from the Fernando de Noronha Archipelago

Whole-rock sample	Rock	Formation	$^{147}Sm/^{144}Nd$	$^{143}Nd/^{144}Nd$ measured	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$ measured	K–Ar age, Ma	$^{87}Sr/^{86}Sr$ primary	$^{143}Nd/^{144}Nd$ primary
10a	Alkali basalt	Sáo José	0.1205	0.512834 ± 7	0.1294	0.703895 ± 18	11.7 ± 0.6*	0.703892	0.512825
109	Analcime ankaratrite	Quixaba	0.1123	0.512823 ± 9	0.1415	0.703648 ± 15	3**	0.703642 3–2	0.512821
59	Ankaratrite	The same	0.065	0.512827 ± 8	9.0548	0.707269 ± 27	2.8 ± 0.2*	0.706909	0.512826
101	Olivine melanephelinite	″	0.113	0.512837 ± 9	0.1092	0.703851 ± 18	3**	0.703846	0.512835
79	Ankaratrite	″	0.11	0.512828 ± 7	0.1354	0.703935 ± 21	3**	0.703929	0.512826
121	Ankaramite	″	0.1121	0.512828 ± 9	0.1807	0.703744 ± 14	2.75 ± 0.25*	0.703737	0.512826
50	Phonolite	Remuédios	0.0636	0.512816 ± 8	54.65	0.714094 ± 35	8.6 ± 0.3*	0.70742	0.512812
51a	The same	The same	0.0658	0.512821 ± 6	9.8932	0.707290 ± 16	9.5 ± 0.25*	0.705955	0.512817
11	Sannaite	″	0.1051	0.512809 ± 8	0.1956	0.704021 ± 18	3**	0.704013	0.512807
70	Trachyte	″	0.072	0.512770 ± 9	0.5391	0.704681 ± 27	11.7 ± 0.3*	0.704591	0.512764
73	Phonolite	″	0.1054	0.512825 ± 8	0.2202	0.703944 ± 17	11**	0.70391	0.512817
77	Monchiquite	″	0.1056	0.512828 ± 9	0.2097	0.703822 ± 16	11**	0.703789	0.51282
85	Melanephelinite	″	0.1187	0.512850 ± 5	0.115	0.703851 ± 18	11**	0.703833	0.512841
91	Alkali syenite	″	0.0962	0.512818 ± 8	0.0394	0.703972 ± 19	11**	0.703966	0.512811
7	Phonolite	″	0.0701	0.512820 ± 8	1.626	0.704062 ± 21	11**	0.703808	0.512815
33	Trachyte	″	0.0716	0.512757 ± 9	0.8867	0.704815 ± 20	11.8 ± 0.3*	0.704666	0.512751
4	Ankaramite	″	0.1298	0.512766 ± 9	0.1535	0.704702 ± 24	11**	0.704678	0.512757
124	Dike rock	″	0.103	0.512804 ± 9	0.1551	0.704246 ± 22	11**	0.704222	0.512797

Note: (*) Our data; (**) Kordani [2] and our data.



Distribution of alkaline rocks of the Fernando de Noronha Archipelago on the mantle correlation diagram.

The rocks of the Quixaba Formation overlie the hiatus-related erosion surface of the Remédios Formation. No sedimentary rocks were found at the Remédios/Quixaba stratigraphic boundary, but fossil remains in the rocks testify to subaerial erosion. Pyroclastic rocks of the Quixaba Formation consist of tuff, lapilli tuff, tuffaceous breccia, and ankaratritic agglomerate. The tuffs are mainly composed of lapilli-sized lava fragments and ashes with olivine and less frequent clinopyroxene crystals. Volcanic blocks and bombs are fragments of variously textured (often corded pahoehoe in appearance) lavas always characterized by porphyritic and vesicular structures.

Lava flows are composed of olivine melanephelinites with or without melilite. In contrast to the Remédios Formation, the Quixaba Formation is distinguished by a scarcity of dikes. They are also composed of nephelinites with clinopyroxene and nepheline as the common phenocrysts. The K–Ar age of the Quixaba Formation is 3.19–1.73 Ma [2].

Nepheline basanites exposed on the São José, Cuscus, and Fora inlets near the northeastern promontory of the main island differ appreciably from olivine melanephelinites of the Remédios Formation. Based on the absence of basanites on the main island, Almeida regarded these lava flows as the independent São José Formation [1]. He suggested that basanites are younger than Quixaba ankaratrites, although contact between these rocks is hidden below sea level. Almeida's suggestion comes into conflict with the K–Ar date (9.49 Ma) [2], which falls within the chronological range of the Remédios Formation. Solution of this contradiction is one of the objectives of the present work. The representative chemical compositions of rocks from the Fernando de Noronha Islands are shown in Table 1.

The isotopic composition of rocks was studied with the method described in [3]. The K–Ar age was determined following the technique in [4] (Table 2). According to these data, alkaline basanites of the São Josée Formation (11.7 ± 0.6 Ma) and trachytes of the Remédios Formation (11.8–11.7 Ma) are the oldest rocks in the Fernando de Noronha Islands. Some phonolites of this formation are younger (9.5–8.6 Ma). Olivine melanephelinites of the Quixaba Formation are the youngest rocks. Thus, our data do not confirm the model of alkaline magmatism in the Fernando de Noronha Islands outlined by Almeida [1] and they refine the results obtained by Kordani [2]. Basanites of the São José Formation and alkaline differentiates (tra-

chytes and phonolites) were formed at the early stages of the evolution of the Fernando de Noronha hot spot, whereas the primitive alkaline magnesian melts erupted at the final stages. The same sequence was established in the hot spot of Trindade Island in the southern Atlantic [5].

The samples of alkaline rocks were taken from the Fernando de Noronha Islands in Cruise 17 of R/V *Akademik Boris Petrov*. The representative chemical compositions of the studied rocks and the results of isotopic study are given in Tables 1 and 2, respectively. The data adjusted to rock ages demonstrate the heterogeneous character of magma sources, especially with respect to radiogenic Sr, whereas the $^{143}Nd/^{144}Nd$ ratio changes insignificantly. The $^{87}Sr/^{86}Sr$ ratio varies within a range of 0.703648–0.707420. The distribution of data points of rocks from the Fernando de Noronha Islands in the mantle correlation ($^{143}Nd/^{144}Nd$ versus $^{87}Sr/^{86}Sr$) diagram allows recognition of three types of reservoirs of alkaline magmatism in the hot spot beneath the study region.

(1) Source with typical parameters of the FOZO mantle reservoir. This source is considered the deepest material supplied from the Earth's lower mantle/core boundary. Volcanic rocks of the Quixaba and São José formations pertain to this reservoir (figure).

(2) Reservoir relatively enriched in radiogenic Sr and Nd isotopes. The oldest rocks of the Remédios Formation fall into this field.

(3) Reservoir markedly enriched in radiogenic Sr ($^{87}Sr/^{86}Sr$ up to 0.7140). In terms of the $^{143}Nd/^{144}Nd$ ratio, this source occupies a transitional position between the first and second sources.

The alkaline rocks of the third group are enriched in radiogenic Sr to the highest degree in comparison to rocks from all other OIB rocks in the Atlantic Ocean. Therefore, we suggest the following alternative interpretations: (i) we have found a unique reservoir with anomalously high Rb/Sr ratio retained for millions of years; (ii) oceanic water with the present-day Sr isotopic composition ($^{87}Sr/^{86}Sr = 0.7095$) participated in the genesis of alkaline rocks of the third group. In [6], we proposed the idea of possible penetration of seawater into shallow-seated transitional magma chambers in the Ascension Island region on the basis of oxygen isotopic composition.

Thus, appreciably heterogeneous mantle sources are characteristic of the oldest volcanics on Fernando de Noronha Island. A similar mantle heterogeneity is typical of initial stages of evolution of some continental superplumes.

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