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MORB-like mantle beneath Lanzerote Island, Canary Islands

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Abstract. Our newly obtained data on the He-Ar and Sr-Nd isotopic systematics of mantle xenoliths and their host basalts suggest the absence of a mantle plume beneath Lanzerote Island. The R/R_a ratio of the xenoliths lies within the range typical of MORB. The He isotopic composition of basalts from Lanzerote Island provides evidence of the mixing of two sources: MORB and atmospheric. The He isotopic ratios of both the xenoliths and the basalts do not show any correlations with the Sr and Nd isotopic characteristics.

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Introduction

Lanzerote Island is one of the seven islands of the Canary Archipelago close to the African continent, and the geological evolution of this island was related to the opening of the Atlantic Ocean. The island sits within a zone of quiet mantle field of Jurassic age on transitional-type crust from continental to oceanic one [*Arana and Ortiz*, 1991].

The island is noted for active volcanism, which started earlier than 15 Ma, continues with just brief interludes until nowadays [*Carracedo et al.*, 1998, 2002], and has formed more than 300 volcanoes. Modern volcanism is responsible for the 1730 fissure eruptions of basalts and has produced 30 cinder cones in the Timanafaya area and three volcanoes during the 1824 eruption [*Arana and Ortiz*, 1991]. Volcanoes on Lanzerote Island typically contain numerous ultramafic nodules in their lavas and cinders.

The composition of the ultramafic xenoliths, their mineralogy, and particularly, microtextures were examined in the dissertation by *Sagredo* [1969], who has established than the great majority of nodules in the lavas are harzburgites and dunites, whereas lherzolites, wehrlites, and pyroxenite are very rare. This conclusion was later confirmed in [*Grachev et al.*, 1992, 1994; *Neumann et al.*, 1995].

Studies of the He, Sr, Nd, and Pb isotopic composition of xenoliths in basalts from Lanzerote Island were launched under the international project "Teide Laboratory Volcano" in 1994 [*Grachev et al.*, 1994; *Ovchinnikova et al.*, 1995].

The very first data on the He isotopic composition of basalts and xenoliths from Lanzerote Island were obtained by *Grachev et al.* [1992] and *Vance et al.* [1992] and were later examined in basalts from other Canary Islands (La Gomera, Tenerife, El Hierro, and La Palma) [*Day and Hilton*, 2011; *Grachev*, 2001a, 2001b].

Our present research was focused on xenoliths and their host basalts from the Timanafaya volcanic field, from Tamia, Pico Partido, and Ermita de la Magdalena volcanoes, and from the area of the historical 1824 eruption (Figure 1). It is pertinent to mention that *Vance et al.* [1992] have also studied the He isotopic composition of a dunite xenolith from Pico Partido volcano.

Figure 1. A Google-Earth map showing the location of the studied xenoliths samples. Insert: area of historical eruptions after [*Romero et al.*, 1986].

Methods

Monomineralic separates were obtained from our samples of ultramafic xenoliths with the use of heavy liquids and the subsequent magnetic separation of minerals. If needed, the concentrates were then 95–99% purified by hand-picking.

Basalt samples were crushed to 3–5 cm, washed in cold 0.1 N HCl to get rid of surface contaminants, and then pulverized in an agate mortar to 200 mesh grain size.

He was extracted from rocks and minerals by the melting techniques [*Kamensky et al.*, 1990] and by crushing the samples [*Ikorsky and Kamensky*, 1998] at the Laboratory of Isotopic Geochronology of the Institute of Precambrian Geology and Geochronology, Russian Academy of Sciences. The crushing technique makes it possible to selectively extract gases from fluid inclusions and thus to minimize the effect of radiogenic gases accumulated in the crystal structure of minerals [*Kaneoka et al.*, 1980]. To extract gases, 0.16–2.25 g of the material and steel rolling crushers were placed in a glass ampoule, which was then evacuated and welded. The material was crushed due to vibrations of the ampoule. The He isotopic composition and concentration were measured on a MI-1201 no. 22–78 mass spectrometer with a He detection limit of 5×10^{-5} A/torr. The concentrations were calculated from the height of the peak accurate to $\pm 5\%$ ($\pm 1\sigma$), and the errors of the measured isotopic ratios were $\pm 20\%$ at $^3He/^4He = n \times 10^{-8}$ and $\pm 2\%$ at $^3He/^4He = n \times 10^{-6}$. The blanks were conducted after reloading the cassette under the same conditions as the analyses of the samples.

Sm, Nd, Rb, and Sr were extracted for isotopic analysis at the same institute in compliance with the method described in [*Richard et al.*, 1976]. The blanks were 0.003 ng for Rb, 0.2 ng for Sr, 0.03 ng for Sm, and 0.08 ng for Nd. The isotopic composition of these elements was determined on an Finnigan MAT-261 8-collector mass spectrometer in static mode, with the simultaneous recording of the ion currents of various isotopes of elements.

The chemical composition of the samples was analyzed by XRF with the application of an original analysis technique development at Sevzapgeologiya. The analytical XRF setup consisted of a 1000-channel pulse analyzer, spectrometric amplifier, and a Si(Li) detector with 25 mm^2 sensitive area and an energy resolution (5.9 keV) of 210 eV.

The material to be analyzed (20 g, 200 mesh) was placed into specialized trays. The characteristic radiation was excited by (i) an X-ray tube with an intermediate Ag target and (ii) the Am-241 radioactive isotope source. The XRF analyses were carried out with the VM, SGD-1A, SG-1A, ST-1A, SA-1, TV, and SGKHM-3 certified standards.

Samples

Our xenoliths can be classified into two groups according to their morphology and the age of their host basalts. The first group comprises xenoliths in basalts from Montana Tamia and Ermita de la Magdalena volcanoes belonging to suite 3, which was dated at the Early Quaternary [*Sagredo*, 1969]. Xenoliths of this group usually have geometric ellipsoidal morphologies and are up to 20 cm long (Figure 2a).

The second group consists of xenoliths from basalts and cinders at the Timanafaya volcanic field, which were produced by the 1730–1736 fissure eruptions. The xenoliths of this group are also large but are angular and covered with rinds of cinder or vitreous basaltic lava. It can be seen at contacts of the xenoliths with host rocks that the basalt melt penetrated into the xenoliths, although the contacts are usually sharp.

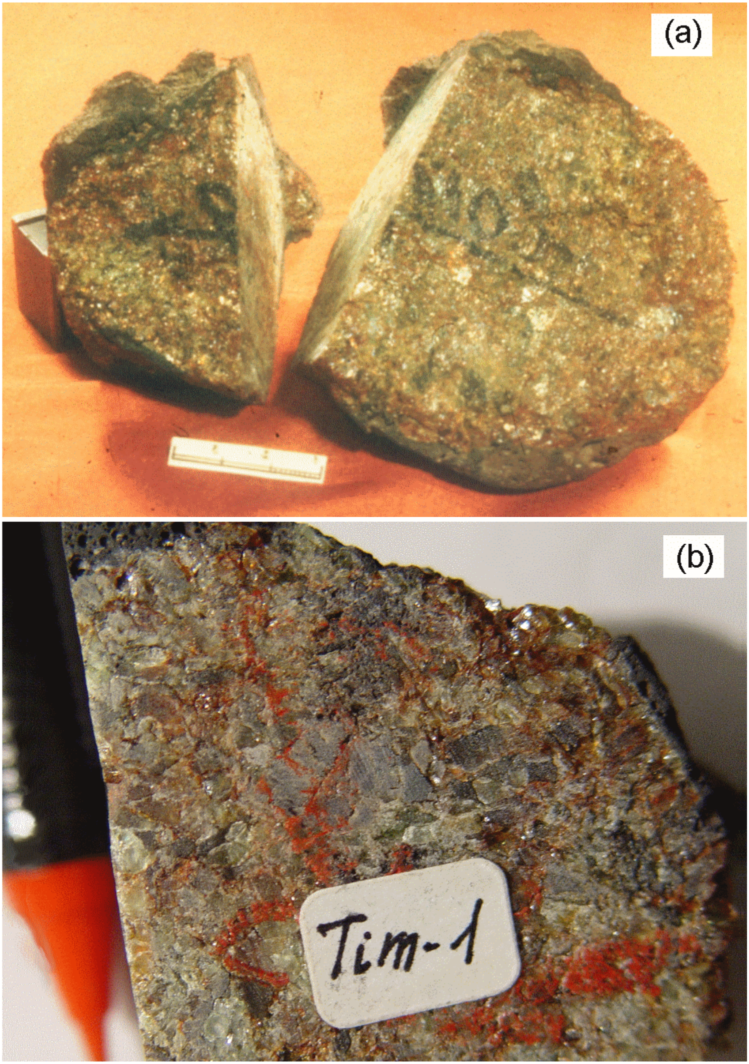

Figure 2. (a) – Typical rounded shape of mantle xenoliths (sample L-88-1), (b) – red-color type of xenolith (sample Tim-1).

Another, although fairly rare, type of the xenoliths can be distinguished thanks to their reddish coloration (Figure 2b). Color changes are clearly pronounced along the boundaries of olivine grains and often affect much of some individual grains. The origin of the red suite is explained by mantle metasomatism and resultant changes mainly in the Fe, Mg, concentrations in the margins of olivine grains [*Grachev*, 2000]. These elements are concentrated within zones 50–150 μm thick (Figure 3). Zones of intense color changes are often related to partial melting. The occurrence of melt films along grain boundaries, where incompatible elements are concentrated, in mantle peridotites was first pointed out in [*Suzuki*, 1987], and this effect is pronounced in the xenoliths of the red suite in a change in their color.

The xenoliths have porphyroclastic textures with pronounced olivine porphyroblasts and neoblasts (Figure 4a).

Practically all olivine grains are deformed and contain kink bands (Figure 4b). The rocks also contain domains with traces of melting [*Koreshkova*, 1994].

In terms of chemical composition (Table 1, Figure 5), all of the xenoliths affiliate with the strongly depleted mantle with high contents of MgO (45–48%) and low contents of CaO (0.4–1.4 wt%), and Al_2O_3 (0.5–1.5%).

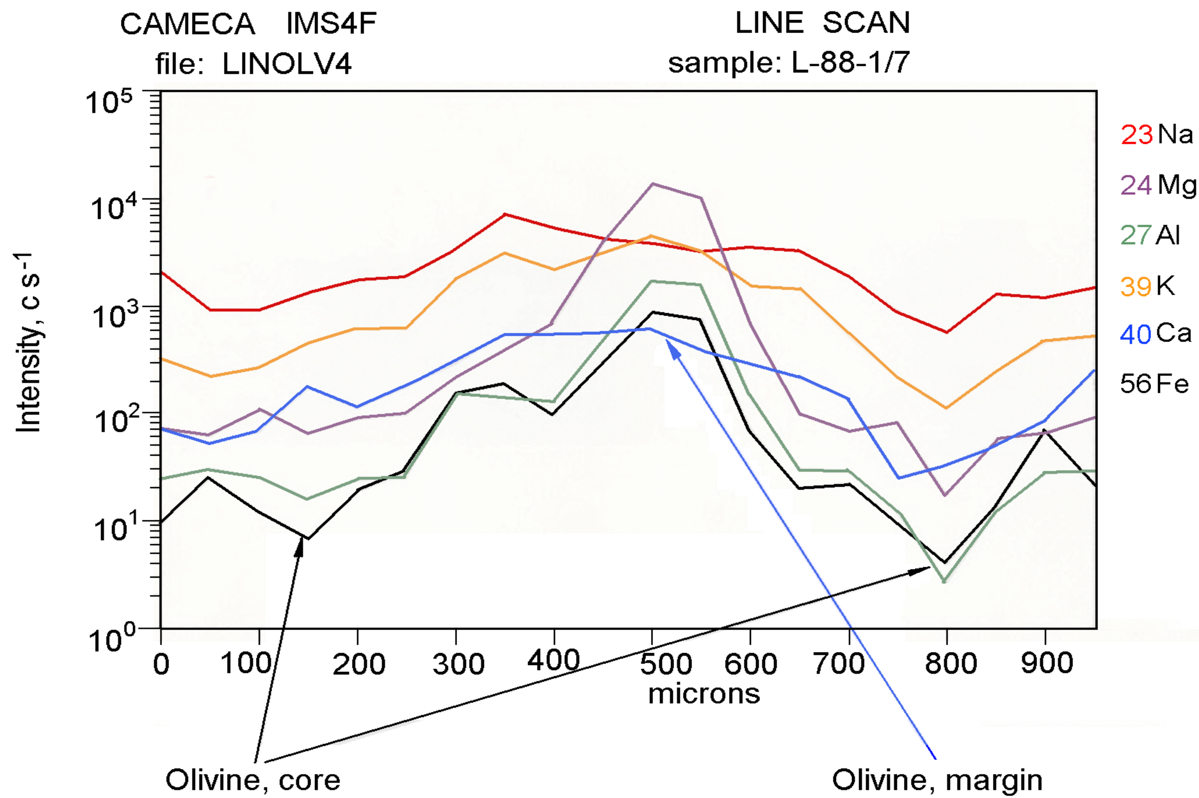

Figure 3. Changes of trace elements abundances from centre to margin of olivine grain (sample L-88-1/7).

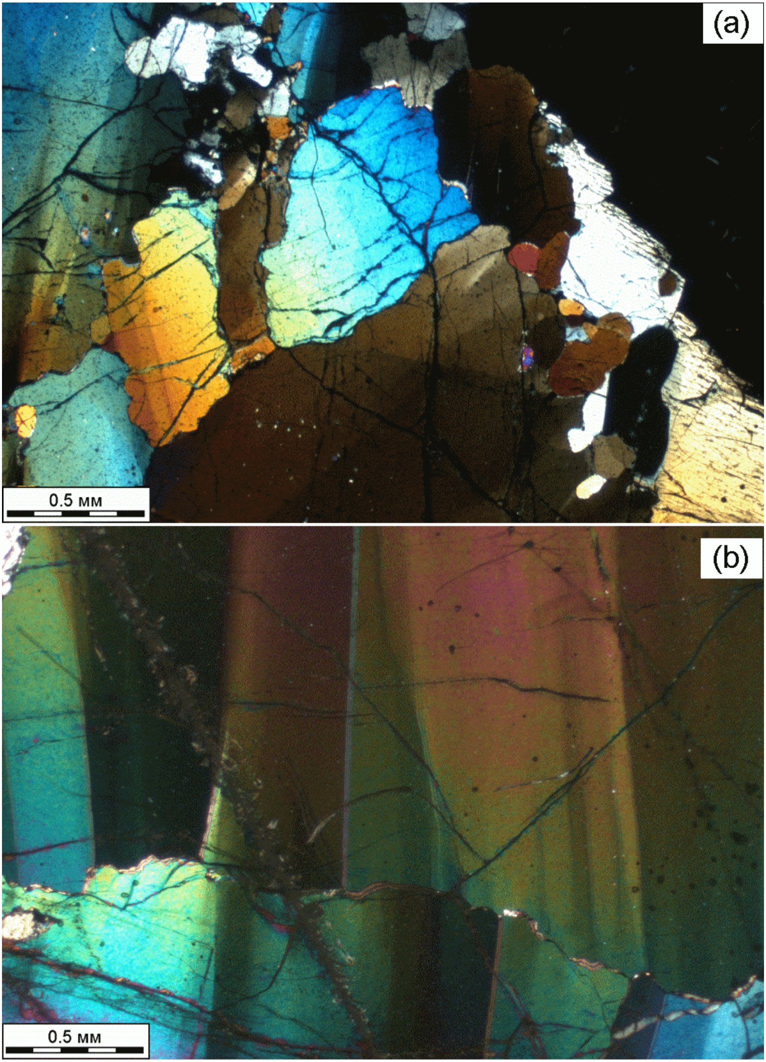

Figure 4. (a) – Olivine porphyblasts and neoblasts, (b) – kink bands (sample Tim1-1, thin section, cross-polarised light).

Table 1. Chemistry (wt. %) of ultramafic xenoliths of the Lanzerote Island

Element	L88-1	L88-2	L88-3	Tam-1	Tam-2	Tim-1	Tim-2	EN-4x	GC-1
	1	2	3	4	5	6	7	8	9
SiO_2	43.14	42.40	43.14	42.32	40.56	41.41	41.46	42.16	43.11
TiO_2	0.16	0.04	0.28	0.09	0.05	0.04	0.04	0.05	0.19
Al_2O_3	1.09	1.48	1.12	1.28	0.61	0.48	0.50	0.82	1.60
FeOt	7.79	7.55	7.86	8.84	9.63	9.12	9.03	8.84	8.48
MnO	0.25	0.25	0.24	0.11	0.13	0.12	0.13	0.12	0.13
MgO	46.09	45.12	45.29	46.62	47.70	47.39	48.45	46.10	44.56
CaO	0.60	1.45	0.63	0.58	0.52	0.49	0.43	0.89	1.20
Na_2O	0.20	0.20	0.24	0.36	0.31	0.29	0.46	0.29	0.58
K_2O	0.09	0.05	0.09	0.13	0.06	0.04	0.38	0.02	0.10
P_2O_5	0.07	0.11	0.09	0.01	0.01	0.01	0.06	0.01	–
Cr_2O_3	0.27	0.40	0.32	–	–	–	–	–	–
NiO	0.13	0.11	0.14	–	–	–	–	–	–

Note: 1 – dunite, Ermita de la Magdalena, 2, 3 – harzburgite, Pico Partida, 4, 5 – harzburgite, Tamia, 6–8 – harzburgite, Timanafaya, 9 – harzburgite, caldera Vandama, Gran Canaria.

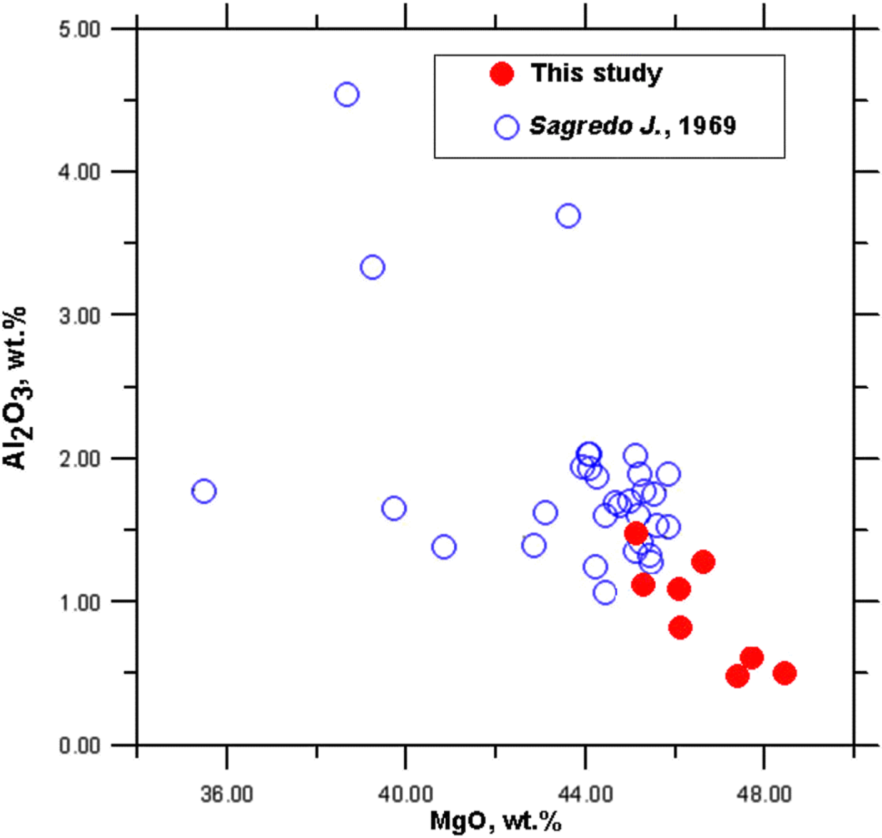

Figure 5. MgO-Al_2O_3 diagram for the studied xenoliths.

He and Ar Isotopic Composition

Table 2 and Figure 6 and Figure 7 present our data on the He and Ar isotopic composition of the xenoliths, which were examined by the melting and crushing techniques. All of our xenolith samples, except for only two of them from Tamia volcano (samples Tam-2 and Tam-3), which were hosted in Quaternary basalts, have ^{3}He/^{4}He ratios (R) much higher than the atmospheric ones ($R_a = 1.39 \times 10^{-6}$).

Regardless of the technique utilized to extract He, the xenoliths from lavas of the 1734 eruption have R/R_a ratios within the range typical of MORB ($R/R_a = 8 \pm 1$) [*Kaneoka et al.*, 1980]. This means that the content of the cosmogenic component in xenoliths from the young lavas is so low [*Dunai and Wijbrans*, 2000] that it does not any appreciably influence the results obtained by the melting and crushing techniques (Table 2).

The host basalts are strongly degassed and have R/R_a ratios much lower than those of he xenoliths. It can be readily seen in the $R/R_a -^{40}$ Ar/^{36}Ar diagram (Figure 7) that the ^{40}Ar/^{36}Ar ratio of the basalts is close to the atmospheric one, whereas this ratio of the xenoliths varies from 1000 to 4000. The degassing of

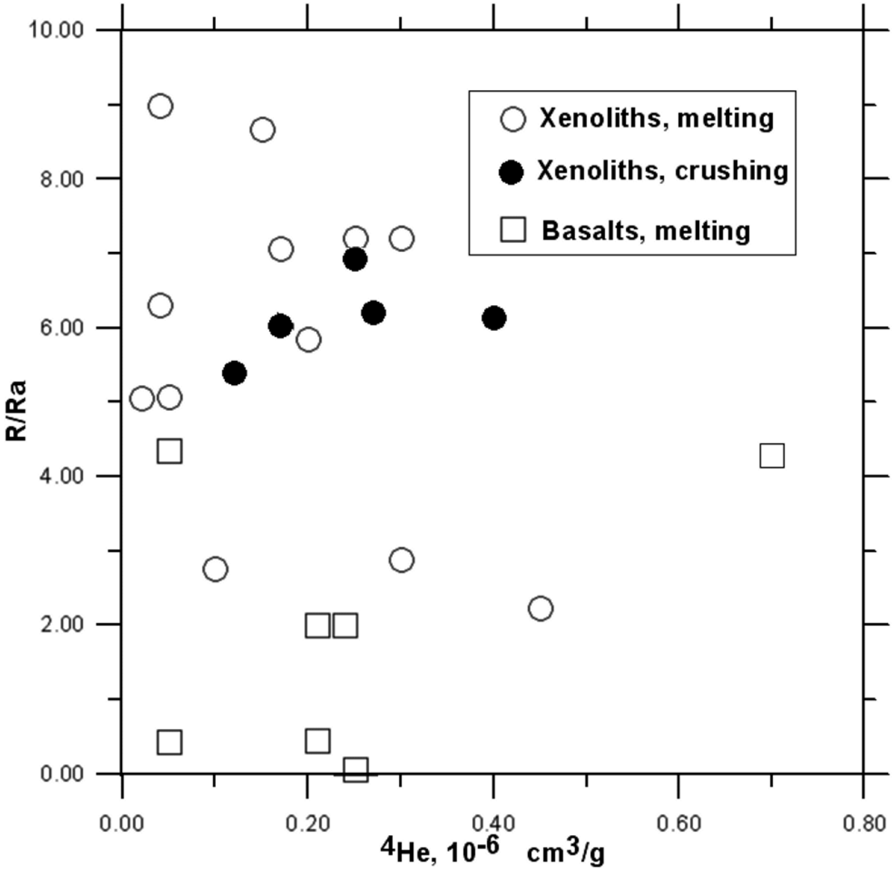

Figure 6. $^3He/^4He$ (R/R_a) – ^4He diagram for xenoliths and basalts. Open circles and squares for gas released by melting procedure, close circles refer to crushing method data.

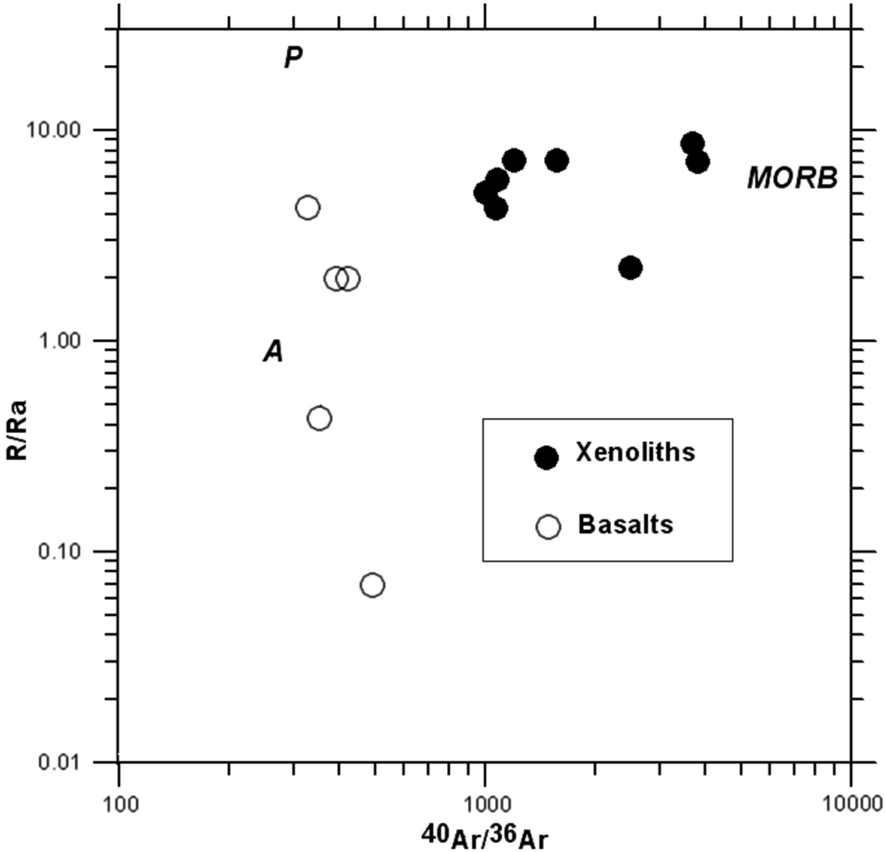

Figure 7. ^{3}He/^{4}He (R/R_a) – ^{40}Ar/^{36}Ar diagram for xenoliths and basalts. A – Atmosphere, M – MORB, P – Plume [*Kaneoka*, 1983].

Table 2. He-Ar isotopes of ultramafic xenoliths and basalts of the Lanzerote island

Sample	Rock, mineral	Weight, g	^{4}He (10^{-6} cm^3/g)	^{3}He/^{4}He	^{40}Ar (10^{-6} cm^3/g)	^{40}Ar/^{36}Ar	R/R_0	Method
				Xenoliths				
L-88-1	Hrzb.	0.3731	0.20	8.1	0.89	1080	5.85	melting
L-88-1/2	Dunite		0.45	3.1	2.18	2500	2.23	melting
L-88-1/3	Hrzb.		0.25	10	6.6	1200	7.22	melting
L-88-1/3 Harz.	Ol		0.02	7.0		1000	5.06	melting
L-88-1/4	Dunite		0.17	9.8	3.0	3800	7.08	melting
L-88-2/1	Dunite		0.30	10.1	0.55	1560	7.21	melting
L-88-2/4	Dunite		0.15	12	3.13	3680	8.67	melting
Tim-1	Ol	0.4296	0.04	12.6			9.0	melting
Tim-1	Opy	1.45	0.27	8.7			6.21	crushing
Tim-1	Ol	1.43	0.12	7.5			5.4	crushing
Tim-2	Ol	0.5126	0.05	7.02			5.07	melting
Tam-1	Ol	0.4745	0.04	8.74			6.31	melting
Tam-2	Ol	0.3062	0.10	3.84			2.77	melting
Tam-3	Ol	0.5250	0.30	3.98			2.88	melting
Lanz560	Cpy	1.05	0.25	9.70			6.93	crushing
Lanz560	Opy	0.40	0.40	8.60			6.14	crushing
Lanz560	Ol	2.00	0.17	9.70			6.93	crushing

Table 2. (Continued.)

Sample	Rock, mineral	Weight, g	^{4}He (10^{-6} cm^{3}/g)	^{3}He/^{4}He	^{40}Ar (10^{-6} cm^{3}/g)	^{40}Ar/^{36}Ar	R/R_0	Method
				Basalts				
L-88-1 bas	Ol		0.70	6.0	2.05	1070	4.28	melting
L-88-1/2 bas			0.05	6.1	1.21	325	4.35	melting
L-88-1 bas			0.24	2.8	1.03	420	2.0	melting
L-88-1/2 bas			0.21	2.8	1.4	390	2.0	melting
L-88-1/3 bas			0.05	0.6	0.6	352	0.43	melting
L-88-1/3 bas			0.21	0.6	1.68	409	0.43	melting
L-88-1/4 bas			0.25	0.1	1.13	491	0.07	melting

the basalts in the course of their melting accounts for their high CO_2 concentrations (> 3 ncm^3/g), whereas the analogous concentrations in the xenoliths never exceed 1 ncm^3/g [*Lokhov and Levskii*, 1993].

As can be seen in the Sr-Nd diagram (Figure 8, Table 3), the xenoliths and basalts define a compact group of their data points with typical MORB ^{87}Sr/^{86}Sr and ^{143}Nd/^{144}Nd ratios, but these ratios are not correlated with the he isotopic composition.

Our results are in good agreement with data on the He isotopic composition of olivine phenocrysts in basalts from the islands of La Palma [*Grachev*, 2001a, 2001b; *Hilton et al.*, 2000] and Tenerife.

Discussion

Our data on the He, Sr, and Nd concentrations and isotopic composition in xenoliths from basalts from Lanzerote Island testify to a strongly depleted type of the mantle, and these mantle xenoliths should be regarded as such of refractory residual material after the derivation of basalts.

The alkali basalts of Lanzerote Island have a He isotopic composition principally different from that of the typical plume basalts of Hawaii and Reunion Island,

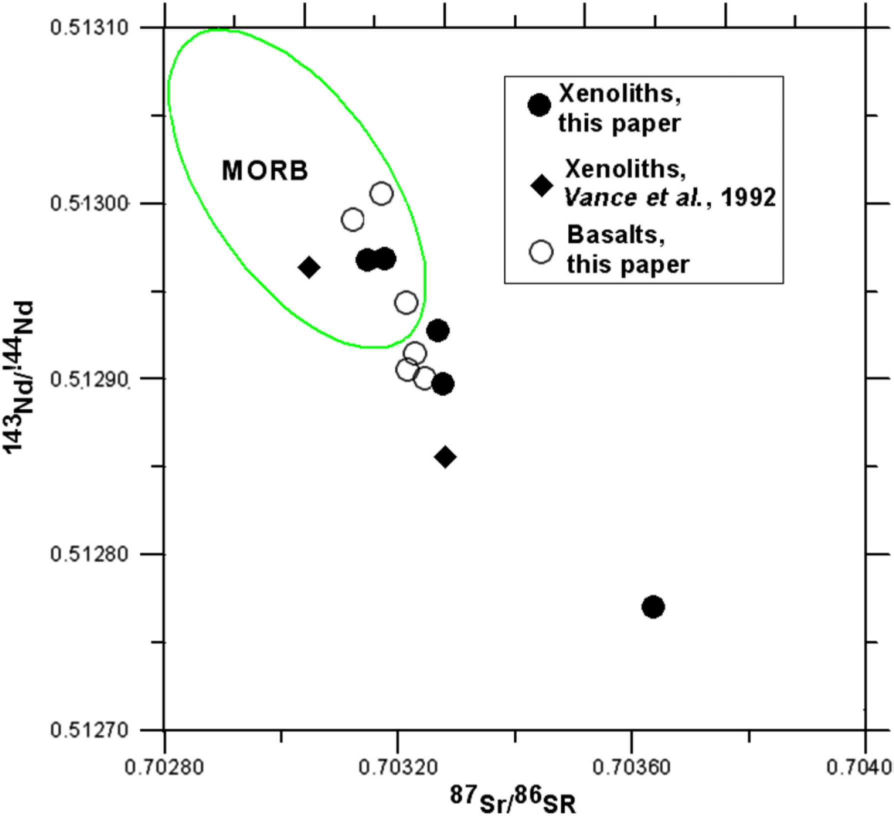

Figure 8. Sr-Nd diagram for the studied xenoliths and basalts.

Table 3. Sm-Nd and Rb-Sr isotopic systematics of ultramafic xenoliths and basalts of the Lanzerote Island

N	Sample	Sm	Nd	Rb	Sr	$^{147}Sm/^{144}Nd$	$^{143}Nd/^{144}Nd \pm 2\sigma$	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr \pm 2\sigma$
						Xenoliths			
1	Tam-1, Di	2.161	16.37	0.864	270.4	0.08007	0.512928±27	0.00924	0.703267 ± 14
2	Tam-2, Di	3.747	22.66	0.582	407.6	0.10028	0.512968 ± 16	0.00413	0.703147 ± 12
3	Tam-3, Di	0.814	5.662	0.668	192.7	0.08717	0.512897 ± 21	0.01002	0.703275 ± 21
4	Tim-1, Di	2.024	13.54	0.586	434.9	0.09065	0.512969 ± 12	0.0390	0.703175 ± 16
5	Tim-2, Di	8.688	36.13	2.648	285.3	0.14584	0.512770 ± 42	0.02684	0.703636 ± 283
6	Tim-3, Opy1	0.014	0.058			0.143672	0.512100 ± 35		
7	Tim-3, Opy2	0.028	0.129			0.129453	0.512858 ± 29		
8	Tim-3, Di	0.579	2.293			0.119727	0.512716 ± 17		
9	L-88-1, wr	0.060	0.190	1.243	1.277	0.19022	0.512587 ± 16	2.81983	0.706367 ± 21
10	L-88-3, wr	0.720	1.491	4.754	5.964	0.29177	0.513095 ± 21	2.30788	0.715833 ± 22
11	GC-1, wr	0.008	0.054	0.034	1.381	0.09420	0.512820 ± 120	0.07070	0.704016 ± 40

Table 3. (Continued.)

N	Sample	Sm	Nd	Rb	Sr	$^{147}Sm/^{144}Nd$	$^{143}Nd/^{144}Nd \pm 2\sigma$	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr \pm 2\sigma$
						Basalts			
12	L-89-3 wr	6.84	27.18	14.73	397.9	0.15218	0.5129017	0.10298	0.703244 ± 9
13	L-88-1/1 wr	6.50	25.70	14.26	391.8	0.15299	0.5129065	0.10256	0.703213 ± 19
14	L88-1/2 wr	6.77	26.88	13.98	399.3	0.15235	0.5129156	0.10127	0.703277 ± 14
15	ND-6 wr	7.99	39.31	nd	nd	0.12283	0.51300612	nd	0.703212 ± 13
16	ND-7 wr	9.03	45.65	33.52	730.2	0.11950	0.5129448	0.13273	0.703212 ± 13

Note: Sm, Nd, Rb and Sr concentrations in ppm (isotope dilution, precision is about 0.5%), error estimations on $^{147}Sm/^{144}Nd$ and $^{87}Rbr/^{86}Sr$ are $\pm 0.3\%$ and 0.5% respectively. During the period of analytical work the weighted mean of 10 La Jolla Nd standart runs yielded 0.511852 ± 4 (2δ), using 0.241579 for $^{143}Nd/^{144}Nd$ to normalize; and NBS-987 standard yeilded 0.710255 ± 15 (2δ), using 8.375210 for $^{87}Sr/^{86}Sr$ to normalize. Total procedure blanks for Nd and Sm are 0.08 and 0.03 ng respectively, and for Sr and Rb are 0.3 and 0.4 ng respectively. All isotopic analyses were carried out on the Finningan MAT-261 solid source machine under multicollector static mode. Chemical preparation of rock samples and elements separation were done using standart procedure similar to [*Richards et al.*, 1976] in the Precambrian Geolody and Geochemistry Institute (St. Petersburg) and in the Geological Institute of the Kola Scientific Centre of the Russian Academy of Sciences.

whose R/R_a ratios are greater than 20 [*Kaneoka et al.*, 1980]; although xenoliths (predominantly dunites) in tholeiite basalts at Oahu Island are also of residual nature [*Jackson and Wright*, 1970], they have R/R_a ratios typical of MORB [*Kaneoka et al.*, 1980]. Recent studies at Oahu Island resulted in the discovery of nodules with garnet, and moreover, the xenoliths were determined to contain nanodiamonds, which suggests that the xenoliths were formed under pressures higher than 50–60 kbar [*Keshav et al.*, 2007].

The He-Ar isotopic composition of xenoliths from Lanzerote Island is closely similar to that of xenoliths from seamounts in the northwestern Pacific Ocean with typically MORB signatures [*Yamamoto et al.*, 2009].

It follows that the isotopic parameters of both the xenoliths and the basalts from Lanzerote Island do not show any indications of a mantle plume. With regard for data on other islands of the Canary Archipelago [*Day and Hilton*, 2011; *Grachev*, 2001a, 2001b; *Grachev et al.*, 1992; *Vance et al.*, 1992], this led us to conclude that no mantle plume occurs beneath all of the Canary Islands.

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