

Petrological features of picrobasaltic melts on Lanzarote, Canary Islands

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Abstract: The paper discusses issues related to the petrology of picrobasaltic melts forming lava flows on Lanzarote, Canary Islands. During a scientific and educational expedition on the aforementioned island, lava flows of picro basalt of the third phase of the 1731-1732 eruption were studied and tested. Preference was given to the well-preserved streams in the west and south of the island that are accessible for direct study. Volcanogenic-sedimentary associations were identified in the studied outcrops and described, the structural and textural features of the flows were characterized, and samples with mantle rock xenoliths were taken for petrological reconstructions. New geochemical data on rocks and minerals are presented. It was established that the temperature of the initial melt was 1100–1180°C. Large harzburgite phenocrysts in picro basalt are xenocrysts formed as a result of melting and disintegration of mantle xenoliths.

1 Introduction

The presence of basic magmatism is characteristic of various geotectonic settings [1]. For volcanic islands, main magmatism is predominant (over 95% of the volume), whereas the generation of melts occurs at mantle levels under the influence of thermal anomaly (plume). The presence of xenoliths in basalts makes it possible to identify the composition of the mantle beneath the region and estimate the contribution of mantle rocks to the formation of basaltic melts.

The intense magnetic activity on the Canary Islands, as well as the young age of magmatism, i.e., during the past 500 years according to [2] makes the Canary archipelago one of the crucial objects for studying oceanic island magmatism. The islands of the Canary archipelago have a highly dissected relief and are often eroded and brought to the surface near coastal deposits, which makes these sites attractive for geological study.

Over the past two decades, deposits of the islands of the Canary archipelago have been extensively studied and characterized by a complex of geological and geophysical methods [2, 3, 4, 5, 6, 7, 8]. Thus, today, the Canary archipelago is one of the best-studied

volcanic chains in the world. The origin of melts from the islands of the Canary archipelago is widely discussed in the world literature [5, 9, 14, 16, 18, 19].

This article is devoted to the study of the evolution of melts of the third phase of the eruption of Lanzarote Island, represented by picrobasalts containing xenoliths of mantle rocks.

2 Geological position

The Canary Archipelago is formed of 7 islands and several smaller erosive remains. Tectonically, the islands are located near the margin of the northwestern African continental shelf. Moreover, the composition of xenoliths found on all islands suggests the presence of an oceanic type of crust below the archipelago, whose age is estimated as 60 Ma [20]. The above circumstances indicate its formation due to the mantle thermal anomaly located inside the lithosphere plate, which is a source of magmas that feed the active volcanoes of the islands.

Lanzarote is the easternmost island (Fig. 1). Its tectonic position is an intra-plate area located on the North African plate that encompasses both the oceanic and the continental crust.

The island stretches in a northeasterly direction and is parallel to the continental margin of Africa. It rises about 2500 m from the seabed, whereas most of the volcanic structure is submerged. It is connected in its underwater part with the island of Fuerteventura, as indicated by the same type of volcanism and identical equalage composition of sedimentary rocks, and the thickness of the water between the islands does not exceed 40 m [11]. The base of the island was formed during the Oligocene over oceanic deposits with an age of approximately 65-55 Ma and is composed of material from underwater volcanic eruptions and plutonic rocks.

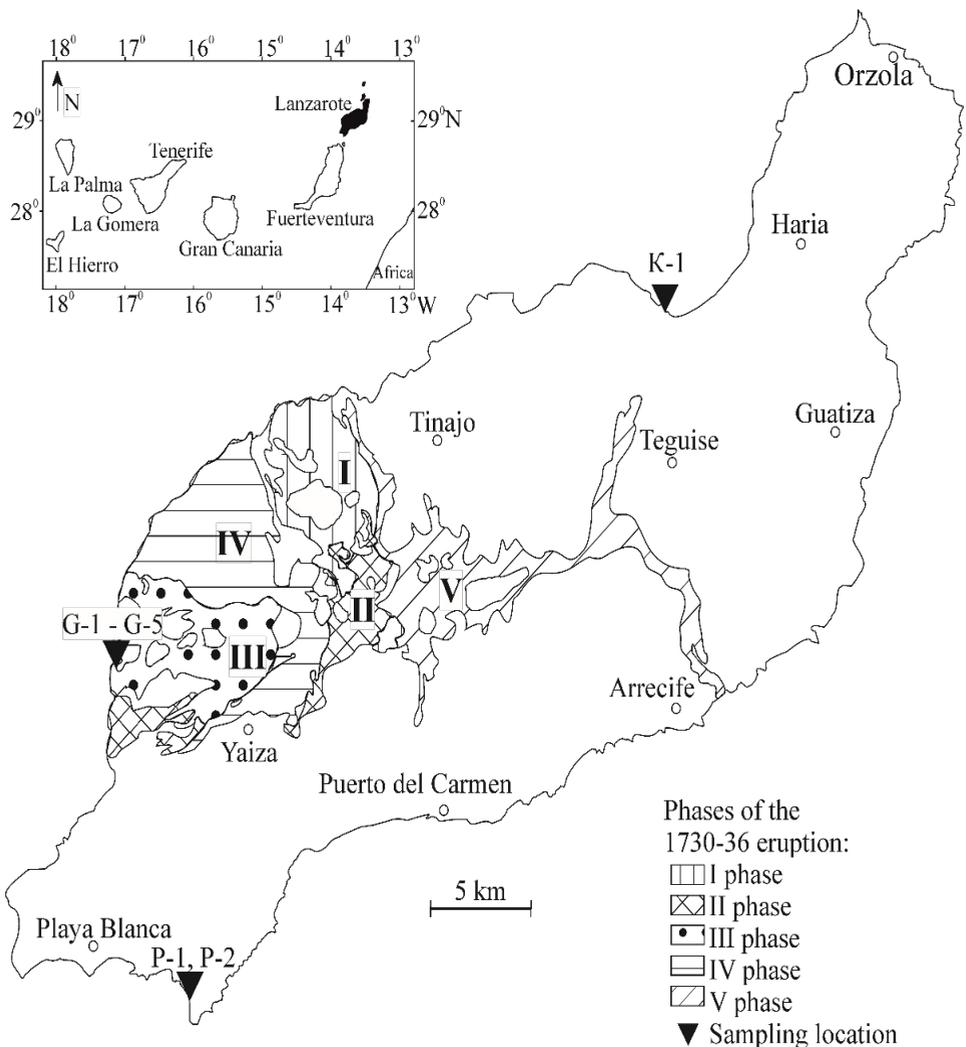


Fig. 1. Map of Lanzarote showing the distribution of products of the five eruptive phases on the island (after Carracedo & Troll 2016) with sampling points.

Recent volcanoes are grouped in a central rift zone from northeast to southwest, with 1730-1736 vents and deposits that are an expression of the “active” volcanic status of the island [2]. The 1730-1736 eruption is divided into 5 phases (Fig. 1). The composition of magma during the initial phase gradually changed from melanepheline sites through basanites to alkaline basalts. In the remaining 4 phases of the eruption, magma evolved from basanites to olivine tholeiites.

The object of the study was microbasalt, attributed [12] to the third phase of the volcanic eruption (July 1731 – January 1732). The studied samples were selected from recent, well-preserved lava flows with primary textural, structural, and mineralogical features in the south-west of the island near the El Golfo village. These rocks contain xenoliths of various compositions: (1) mantle xenoliths according to [21, 22] may be fragments of the old suboceanic mantle subjected to metasomatism and partial melting; (2) xenoliths of

sedimentary rocks (calcareous-silicate and siliceous rocks, subordinate to limestones, clay, and sandstones), most of which are metamorphosed and metasomatized[10].

3 Methods of research

For petrological study, 8 rock samples were taken from different points on Lanzarote island. Of particular interest were rocks with large and numerous mantle xenoliths. Thus, 5 samples of picrobasalts were taken near the El Golfo village. To compare the composition of rocks, 2 samples of basalts in the south of the island at Playa Papagayo and 1 sample in the north at Caleta de Famarawere taken.

The mineralogical composition of the rocks was studied in 8thin sections. The composition of rock-forming minerals was determined in the laboratory for mineral matter analysis at IGEM RAS using a JEOL (JXA-8200) electron probe analyzer equipped with 5 wave spectrometers at an accelerating voltage of 20 kV, a Faraday cup current of 20 nA, and a beam diameter of 1 μm. Exposure times for all elements measured in olivine, pyroxene, and plagioclase were 10 s at the peak and 5 s on the background on both sides. Forty mineral composition analyses were performed.

The content of major and trace elements on 3 samples was determined by X-ray fluorescence analysis (XRF) using an S4 Pioneer spectrometer (Bruker, Germany) with a 4 kW rhodium tube and a 75 μm beryllium window. Sample preparation for analysis was carried out according to the method described in [23]. The microelement composition of rocks was determined by inductively coupled plasma mass spectrometry (ICP-MS) on a Thermo Fisher Scientific 2 apparatus at the GIN RAS. These samples were prepared for analysis by acid decomposition according to the procedure described in. The accuracy of the analysis was monitored by measuring samples of the international standard MUH-1 and WG-1. A geothermobarometry[24] was used to determine the crystallization temperature of the melt. Calculation of temperature parameters was carried out according to equation 32.

4 Petrogeochemical characteristics of picrobasalt

On the west coast of Lanzarote, outcrops are extended; almost black streams of chilled magma, in the roof of which the structures of quenching zones with pahoehoe and numerous lava breccias are often preserved. Clumps of basalts of various sizes containing large xenoliths of mantle rocks of 10 cm in size were observed everywhere along the coast. Powerful pyroclastic flows are located in close proximity to the outcrops and are composed of tuffs with numerous volcanic bombs and lapilli.

According to petrochemical characteristics (Table 1), picrobasalts correspond to low potassium tholeiitic basalts with the predominance of Na over K ($K_2O / Na_2O = 0.3-0.4$). According to the TAS classification, the volcanic compositions are located in the field of basalts, less frequently, basanites.

(MORB) of normal (N-) and enriched (E-) types, island arcs (IAB) and oceanic islands (OIB). The rocks are normalized to a primitive mantle according to [29].

Table 1. Whole-rock composition of 3rd eruptive phase on Lanzarote

Sample	K-1	P-1	G-4	M-42	M-11	Sample	K-1	P-1	G-4	M-42	M-11
Major elements, wt%						Trace elements, ppm					

SiO ₂	46.05	42.43	47.94	46.85	47.5	Cs	0.3	0.3	0.3	-	-
TiO ₂	2.62	4.61	2.88	2.51	2.59	Ba	257	422	183	316	284
Al ₂ O ₃	12.46	11.23	12.77	13.26	13.48	Y	18	23	19	20	18
Fe ₂ O ₃	12.2	12.84	13.26	11.49	10.95	Zr	195	390	192	190	179
MnO	0.19	0.17	0.17	0.17	0.17	Nb	41	85	35	36	32
MgO	11.73	7.11	8.18	10.6	10.07	La	28	43	19	27	19
CaO	9.44	12.99	9.88	9.61	9.71	Ce	58	91	42	47	34
Na ₂ O	3.02	2.54	2.83	3.2	3.23	Pr	7	11	5	-	-
K ₂ O ₅	0.78	1.12	0.77	0.72	0.75	Nd	29	45	23	-	-
P ₂ O ₅	0.38	0.48	0.27	0.37	0.42	Sm	6	8.9	5.4	-	-
LOI	0.8	4.15	0.8	0.9	0.8	Eu	2	2.8	1.9	-	-
Total	99.67	99.68	99.75	98.78	98.87	Gd	5.7	7.8	5.4	-	-
Mg#	63	50	52	63	63	Tb	0.8	1	0.8	-	-
Trace elements, ppm						Dy	4	5.3	4.1	-	-
V	196	345	221	282	287	Ho	0.7	0.9	0.7	-	-
Cr	699	160	439	527	460	Er	1.7	2.2	1.8	-	-
Sc	19	23	22	-	-	Tm	0.2	0.3	0.2	-	-
Co	58	39	51	41	44	Yb	1.3	1.6	1.3	-	-
Ni	558	85	285	290	245	Lu	0.2	0.2	0.2	-	-
Cu	69	75	83	68	71	Hf	4.2	8.3	4.3	-	-
Zn	107	98	117	-	-	Ta	0.7	0.7	0.5	-	-
Ga	17	22	20	-	-	Th	2.8	4.2	1.9	8	6
Rb	16	20	16	17	16	U	2.9	5.6	2.5	-	-
Sr	514	757	427	480	396	Pb	2.7	2.1	1.8	-	-

* The total content of iron oxides. Samples M-42, M-11 are picrobasalt of the volcanoes El Quemado and Mña. Rajada[2]

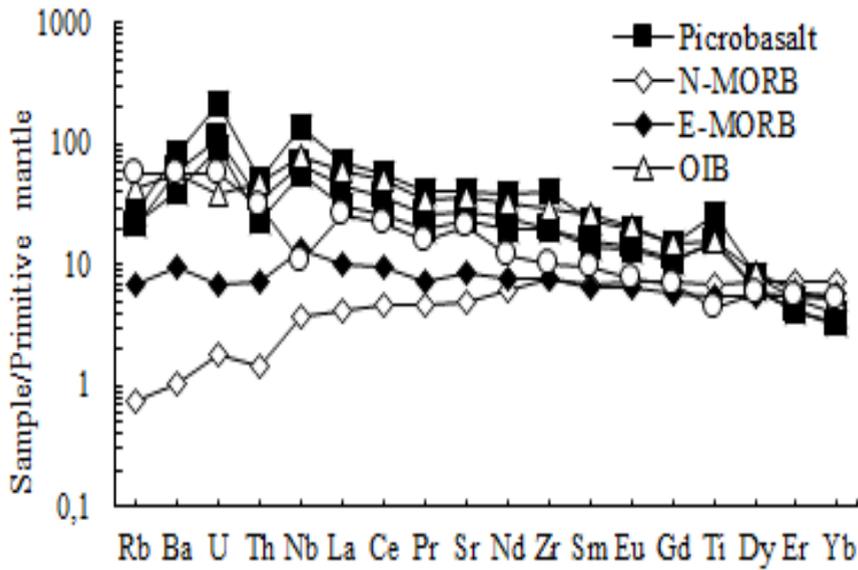


Fig. 2. Multi-element variation diagram for picrobasalt of the third phase of the eruption on Lanzarote and basalts of different geodynamic settings (according to Sun & McDonough 1989): mid-ocean ridges

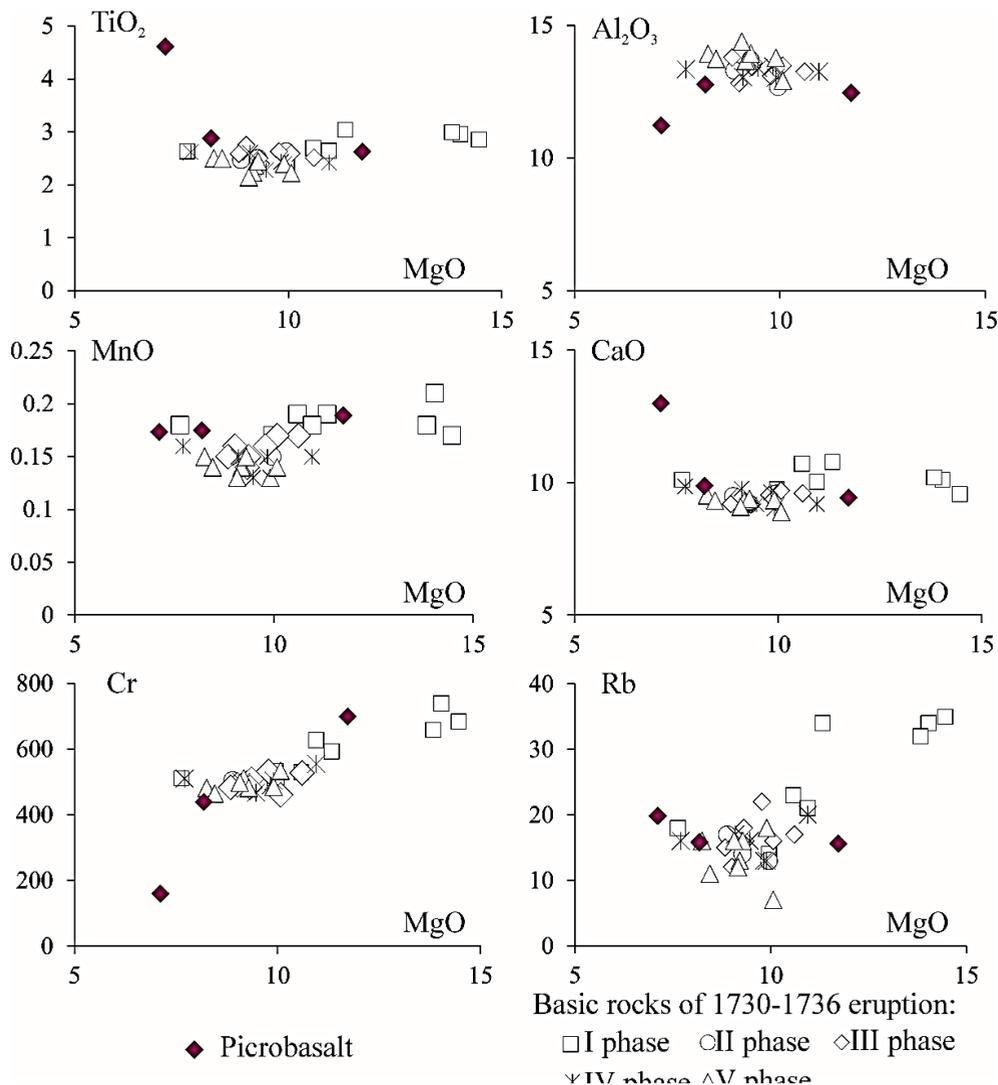


Fig. 3. Variational diagrams MgO - rock-forming oxide (wt.%) and MgO - microelements (ppm) for the studied picrobasalt and mafic rocks of different phases of the 1730-1736 Lanzarote eruption (Carracedo et al. 1990).

The studied rocks in terms of the content of all major elements are comparable with the known compositions of picrobasalt of the third phase of the eruption (Fig. 3). At the same time, rocks of all phases of eruptions on Lanzarote as a whole have similar variations in the contents of major and trace elements forming a trend of changes in their compositions with MgO variations from 7 to 12 wt.% on binary diagrams. The decrease in the contents of MgO in rocks from 12 to 8 wt. % is accompanied by a decrease in the concentrations of TiO₂, MnO, Cr, Ni, and Rb and an increase in Al₂O₃ contents. Inflection of the trend at the level of 8 wt. % MgO is accompanied by a smooth increase in the concentrations of TiO₂, MnO, CaO, and Rb and a decrease in Al₂O₃ contents.

The multi-element trace of the distribution of rare-earth elements (REE) of the studied rocks is weakly fractionated and are characterized by enrichment of light ([La/Sm]_N = 1.7-

2.3) and heavy ($[\text{Gd/Yb}]_N = 3.3\text{-}3.9$) REE and positive anomalies of Nb ($\text{Nb/Nb}^* = 1.7\text{-}2.2$) and Ti (Fig. 2). The REE trace of picobasalts is similar to those for basalts of oceanic islands (OIB, Fig. 2).

Picobasaltare dark gray rocks with an almond-stone, porous texture and contain large (4-5 cm) peridotite xenoliths. The porphyry structure of microbasalts is formed by olivine phenocrysts (30-35 vol.%). They are embedded in fine-grained olivine-pyroxene-plagioclase bulk rocks.

Olivine phenocrysts (Ol-Ph) form large (0.3-0.5 mm) resorbed grains of angular and irregular shape (Fig. 4). The central parts of the grains are homogeneous and characterized by high Mg # 89-91 ($\text{Mg \#} = \text{Mg} / (\text{Mg} + \text{Fe}) * 100$), Ni and Cr concentrations and low concentrations of incompatible elements (Al, Ti, Mn) (Table 2). The core sections are surrounded by a narrow (less than 0.005 mm) rim of less magnesian composition (Mg # 85), characterized by a low Ni content and higher contents of incompatible elements. The Ol-Ph rims contain spinel inclusions with chromium number Cr # 25-45 ($\text{Cr\#} = \text{Cr} / (\text{Cr} + \text{Al} + \text{Fe}) * 100$).

The groundmass of porphyry picobasalt has a gabbro structure and consists of olivine (10 vol.%), pyroxene (45 vol.%), plagioclase (35 vol.%), and magnetite. Olivine forms small (up to 0.05 mm) isometric grains with Mg # 84-85 and is comparable in composition to the rim parts of Ol-Ph (Table 2).

Pyroxene forms prismatic grains up to 0.3 mm in elongation, most often smaller (less than 0.05 mm) hypidiomorphic grains, and is represented mainly by diopside with Mg # 68-76 ($\text{Wo}_{51\text{-}54}\text{En}_{34\text{-}40}\text{Fs}_{9\text{-}11}$) (Table 2). More rarely diopside is surrounded by narrow (less than 0.005 mm) Ol-Ph rims. Magnetite is present as inclusions in pyroxene-forming veins along cleavage cracks. The interstices filled with plagioclase are represented by labrador ($\text{An}_{62\text{-}69}$). Magnetite forms rounded grains in the bulk of the rock. Amphibole reaction fringes that surround olivine and pyroxene grains are rare.

Table 2. Composition of olivine (Ol) and pyroxene (Px) from picobasaltic lavas and xenolith of harzburgite (in mas. %)

Type	Groundmass			Phenocrystal					Xenolith		
	Core	Core	Rim	Core	Rim	Core	Rim	Core	Core	Rim	Core
SiO ₂	40.36	40.03	39.74	41.52	39.92	41.21	40.57	41.12	40.86	41.30	41.65
TiO ₂	0.05	0.05	0.12	0.03	0.04	0.01	0.01	0.01	0.02	0.01	0.01
Al ₂ O ₃	0.03	0.06	0.06	0.01	0.03	0.02	0.03	0.00	0.01	0.01	0.00
Cr ₂ O ₃	0.04	0.01	0.00	0.04	0.06	0.02	0.00	0.03	0.01	0.01	0.01
FeO	13.91	14.79	16.10	9.12	14.32	10.08	13.70	8.22	8.49	8.54	8.33
MnO	0.15	0.23	0.30	0.04	0.20	0.20	0.21	0.12	0.12	0.13	0.13
MgO	44.76	44.04	42.76	48.39	44.08	47.89	44.77	48.38	49.26	48.85	48.45
NiO	0.20	0.25	0.20	0.36	0.24	0.39	0.31	0.37	0.41	0.41	0.40
CaO	0.24	0.21	0.35	0.05	0.22	0.04	0.09	0.11	0.05	0.06	0.05
Total	99.74	99.67	99.63	99.55	99.09	99.86	99.70	98.36	99.24	99.32	99.02
Mg#	85	84	83	90	85	89	85	91	91	91	91

Type	Groundmass						Xenolith	
	Diopside	Diopside	Diopside	Diopside	Diopside	Diopside	Estatite	Enstatite
SiO ₂	47.96	41.97	46.74	42.42	41.31	47.27	57.01	56.94
TiO ₂	2.83	5.64	3.32	4.68	5.65	3.13	0.02	0.02
Al ₂ O ₃	6.01	10.21	6.21	8.50	10.65	5.79	2.36	2.32

Cr ₂ O ₃	0.01	0.04	0.00	0.10	0.02	0.04	0.39	0.41
FeO	7.10	8.25	7.57	8.36	8.43	7.45	5.43	5.37
MnO	0.12	0.12	0.12	0.14	0.10	0.18	0.15	0.18
NiO	0.00	0.00	0.04	0.01	0.01	0.00	0.10	0.12
MgO	12.77	10.04	12.39	10.79	10.35	12.61	33.30	33.38
CaO	22.84	22.59	22.47	22.25	22.39	22.56	0.56	0.55
Na ₂ O	0.49	0.55	0.46	0.47	0.56	0.45	0.02	0.01
K ₂ O	0.00	0.01	0.01	0.01	0.02	0.02	0.00	0.00
Total	100.11	99.42	99.32	97.74	99.47	99.50	99.35	99.29
Mg#	76	68	74	70	69	75	92	92

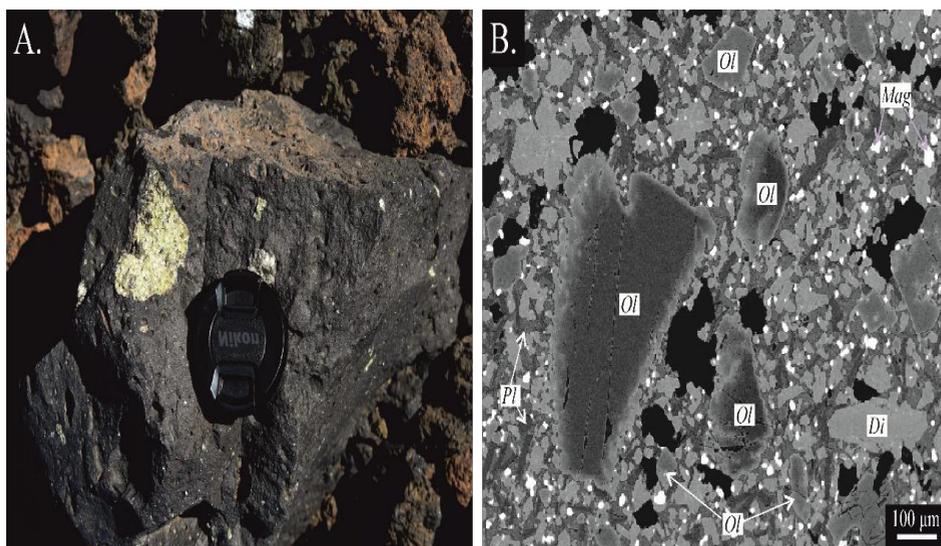


Fig. 4. Picrobasalt of Lanzarote. (A) Photograph of picrobasalt. The rock contains large xenoliths (light green) of mantle rocks. (B) Microphotography of picrobasalt. The porphyry structure is formed by large phenocrysts of olivine (Ol). The groundmass of the rock is composed of small grains of olivine and clinopyroxene (Di), interstices filled with plagioclase (Pl) fills the interstitium. The image in backscattered electrons.

Mantle xenoliths in picrobasalts are mainly represented by pyroxenites and dunites [2, 9, 12, 15, 21], harzburgites are less common. Harzburgite xenoliths of a harzburgite composition composed of large (4-5 cm) grains of olivine (60 vol.%) and orthopyroxene (40 vol.%) were studied. Large hypidiomorphic grains of olivine with Mg # 90-91 are characterized by a high Ni content and low concentrations of incompatible elements (Table 2).

According to the content of trace elements, xenolithic olivines are comparable with the central parts of Ol-Ph on picrobasalt.

Inclusions of chrome spinel (Al₂O₃ 33 wt.%) with Cr # 36 are present in some grains. At the contact of harzburgite olivine with the host picrobasalt mass, its dissolution is substantiated by the formation of diopside (Mg # 85-86, Wo₄₈En₄₄Fs₈). Orthopyroxene forms large hypidiomorphic grains and is represented by enstatite (Wo₁En₈₇₋₈₈Fs₁₁) with Mg# 92 (Table 2).

5 Discussion

The porphyritic texture of microbasalt indicates that the melt which formed lava flows contained crystalline mineral phases. This can often indicate the existence of an intermediated magmatic chamber in which crystallization of phenocryst minerals could occur [18, 26]. At the same time, phenocrysts can be xenocrysts, melt fragments of the disintegration of rocks trapped by the melt during ascent (Larrea et al. 2013). In any case, phenocrysts are an indicator of events in the formation of the initial melt for volcanic rocks and their study allows us to draw conclusions about the previous evolutionary stages of the initial magma.

Recent studies [14, 16, 23] have shown that olivine is an important petrogenetic indicator. Reliable data on the distribution of trace elements have been established for some elements (e.g., Ni, Co, Mn, Cr) of olivine phenocrysts from basalts formed in different tectonic settings [27, 28], separated by trace elements and dispersed through olivine into three groups, whose distribution depends on (1) the ionic radius close to Mg (Ni, Mn, Co, Cu, Zn, Li); (2) melt composition (Ti, Zr, Nb, Y, P); (3) controlled by temperature during equilibrium crystallization of the mineral (Cr, Al, V, Sc, Ca, Na), which revealed systematic differences between mantle substrate compositions, element distribution mechanisms in olivine, and their potential for use in geobarometry and interpretation of mantle processes. Generalized information on the concentrations of trace elements in olivine from different basaltic melts revealed patterns of their distribution depending on the source of melting.

In microbasalts, Ol-Ph has a sharp and clear boundary between the homogeneous central part and the narrow marginal zone. Assuming the distribution coefficient K_D^{Fe-Mg} olivine-melt = 0.3 ± 0.03 [25], Mg# of the central parts of Ol-Ph is excessive with respect to the contained melt, which may indicate its crystallization from a more primitive melt. However, in terms of magnetism and the content of trace elements, such as Ni, Ca, and Ti, the central parts of Ol-Ph differ from the marginal parts and are comparable with the olivine of harzburgite xenoliths. On the variation diagrams (Fig. 5), the compositional points of the central parts of Ol-Ph and olivine from harzburgite xenolith form a local area of points with Mg # from 89 to 92 located in the region of olivine compositions of dunite and harzburgite xenoliths.

Mg# of the olivine in the bulk corresponds to Mg# of the surrounding melt. According to the content of trace elements, the olivine of the groundmass is similar to the compositions of the Ol-Ph rims. This olivine enriched of incompatible elements Al, Ca, and This likely to indicate an enriched source of the melts.

Given The significant differences in the content of trace elements between Ol-Ph and groundmass olivine, as well as the geochemical similarity of olivine in harzburgite xenoliths and central parts of the Ol-Ph, we can assume that Ol-Ph is most likely a product of harzburgite xenoliths disintegration, which was accompanied by the resorption of xenolithic olivine which affected its morphology. During crystallization from a melt of liquidus olivine (groundmass olivine), the central parts of Ol-Ph were surrounded by narrow rims. This mechanism explains the geochemical similarity of the bulk olivine and the Ol-Ph rim.

The presence of rare inclusions of low-chromium spinel and magnetite in the Ol-Ph and groundmass olivine boundaries and at the same time their more frequent occurrence in inclusions in pyroxene indicate that crystallization of spinel and magnetite occurred at the final stage of olivine fractionation, probably synchronously with the crystallization of large grains of groundmass pyroxene. Plagioclase was the last to crystallize from the melt.

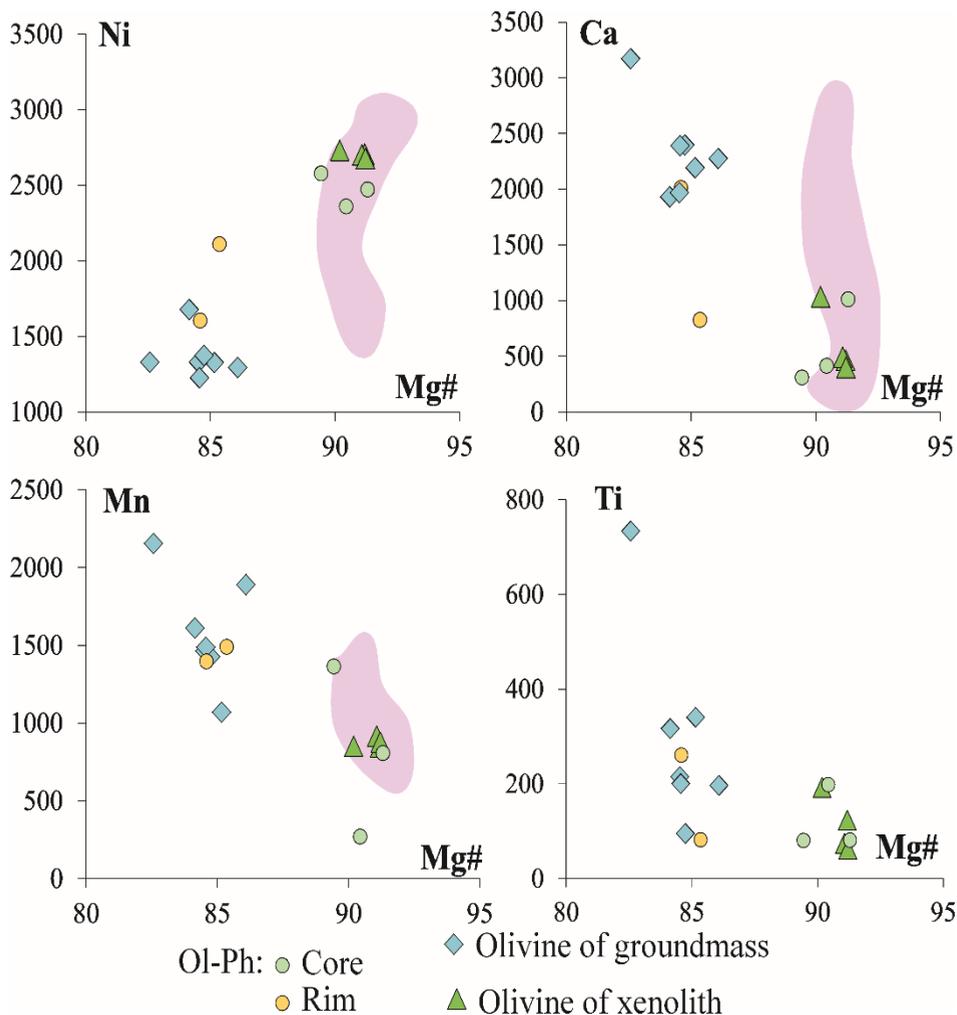


Fig. 5. Variational diagrams Mg# vs microelements in olivine from picobasalt. The composition field of olivine of dunite and harzburgite xenoliths in alkaline basalt from Lanzarote is plotted (Neumann et al, 1995).

The temperature of crystallization of clinopyroxene obtained using a geothermometer [24] varies in the range of 1100–1180°C. It is established that the equilibrium temperature of mineral paragenesis in xenoliths of harzburgite composition varies from 1170 to 870 °C. The higher temperature of the initial melt compared to mantle rocks trapped during its ascent could lead to melting and disintegration of the mantle xenoliths. (Aparicio et al. 2006) found in their work that the initial melt could have a basaltic composition and temperature ~ 1200°C, at which the calcium-siliceous and siliceous sedimentary rocks trapped at a depth of 4-5 km acquired tholeiitic structure. Thus, the calculated temperature is in good agreement with the data of previous researchers.

6 Conclusion

Based on the study of picobasaltic lavas on Lanzarote and the peridotite xenoliths contained in them it was found that (1) the rocks studied belong to the third phase of the eruption (1731 - 1732); their geochemical composition supplements the existing data on the

geochemistry of rocks of this phase; (2) olivine phenocrysts are xenocrysts and conventionally originated from the disintegration of mantle xenoliths formed in the high-temperature initial melt (more than 1100°C); (3) the initial melt could have a basaltic or basanitic composition.

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