Geochemistry of alkaline basalts of Corvo Island (Azores, Portugal): preliminary data

Geoquímica de los basaltos alcalinos de la Isla de Corvo (Azores, Portugal): datos preliminares

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RESUMEN

El vulcanismo de la isla do Corvo (Azores Occidentales, Portugal) comprende diversos episodios eruptivos, desde 1.5 a 1.0 Ma. Los líquidos son mayoritariamente basaltos con una composición modal de olivino, Ti-augita, plagioclasa y Ti-magnetita, existiendo una variedad de litotipos petrográficos según la proporción modal de las fases mayoritarias. La composición geoquímica corresponde a magmas de tipo OIAB, con una fuente mantélica enriquecida próxima a HIMU de origen astenosférico.

Key words: *geoquímica, alcalina, Corvo, Azores*

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Introduction

The Corvo and Flores islands (Western Azores, Portugal) are part of the American Plate, which is separated from the Eurasian and African plates by the Middle Atlantic Ridge (Fig. 1). The main structural directions (WNW-ESE) observed all over the Azores islands are not dominant in the Corvo and Flores islands, where the irregular and asymmetric shapes of the islands are conditioned by approximately N-S fractures, parallel to the M.A.R. direction. General geological data, the preliminary volcanic stratigraphy and radiometric ages are summarized in França *et al*. (2003) and Azevedo *et al*. (2003). Those authors recognized two main volcanic complexes on the island: a) The Basal Complex, the older one associated to proto-island volcanism; b) The Upper Complex (or Central Volcano), that can be divided into three volcanic units (França *et al*., 2003) of pre-, syn- and post-caldera episodes.

This paper deals with the geochemical composition of this volcanism and the definition of the main rock types. The definition of the magmatic affinity of this volcanism will be based on mineralogical and geochemical criteria. Finally, we will suggest the most consistent mantle source for this magmatism, according to the available geochemical data.

Geology of Corvo island

Corvo island (total surface of 17.12 Km^2) has an asymmetric shape. The most relevant geomorphologic feature of Corvo is the «Caldeirão», a subsidence caldera about 2000 m in diameter and 300 m in depth (Fig. 1) at the northern part of the island. Inside this structure several cinder and spatter cones, 20-30 m in height, are emplaced. According to França *et al*. (2003), an area of about 28 Km^2 can be inferred for the initial area of the island, prior to the intense sea erosion that mostly affected its west and north sea cliffs. The caldera (Fig. 1) is on the summit of a 5 km base diameter composite volcano and is affected by three main radial faults, which crosscut secondary cones on the outer slopes of the central volcano (e.g., Cortinhas, Coroa do Pico and Morro da Fonte, Fig.

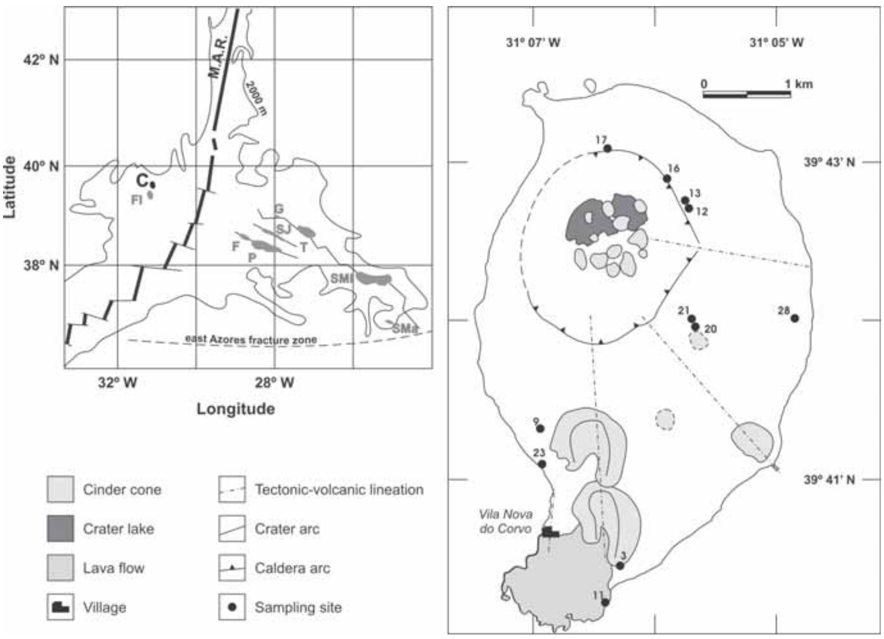

Fig. 1.- Geological map of the Corvo Island indicating sampling sites.

Fig. 1.- Mapa geológico de la isla de Corvo con posición de las zonas de muestreo.

1). On the sea cliffs (e.g. NE and SW sectors) and on the caldera wall, several dykes are exposed, mostly of basaltic composition

Volcanostratigraphy and age of Corvo island

Zbyszewski *et al*. (1967), Azevedo *et al*. (2003) and França *et al*. (2003) studied the geology and volcanostratigraphy of the island. Two main volcanic complexes are usually recognized there:

a) The Basal Complex, the older one associated to proto-island volcanism. This complex includes surtseyan tuffs and basalts and is exposed mainly at the base of the SW and N sea cliffs;

b) The Upper Complex (or Central Volcano), that can be divided into three volcanic units (França *et al*., 2003) of pre-, syn- and post-caldera episodes. While the first and third units are dominated by lava flows and pyroclastic deposits of basaltic composition, the syn-caldera unit is characterized by pumice, surges, lahars and pyroclastic flow deposits, of plinian to sub-plinian type.

Recent formations, have epiclastic deposits, and are found elsewhere in the islands, namely slope deposits bordering the caldera wall, boulder beach deposits around the shoreline and alluvial deposits in many stream valleys of the island.

The initial volcanism of Corvo island could be aged about 1.5-1.0 Ma (França *et al*., 2003) and absolute ages (K/Ar) of 0.7 and 0.4 Ma are reported for younger basaltic episodes on the central volcano (Azevedo *et al*., 2003). Although no isotopic age determinations are available for the more recent volcanic episode, the last eruption took place about 80-100 ka ago in the vicinity of Vila Nova do Corvo village (França *et al*., 2003).

Analytical methods

Forty-nine samples, representative of the three volcanic stages on the island have been studied (Fig. 1). Nine of them were selected for analyses using a CAMEBAX SX-50 electron microprobe at the University of Barcelona, operating in WDS mode at 15 kV accelerating potential, 20 nA beam current, 3 mm beam diameter and 10 s counting time for all the elements except trace elements. The analytical conditions for trace elements were 15 kV accelerating potential, 20 nA beam current, 3mm beam diameter and 20 s counting time. All the results were corrected for inter-elemental effects by

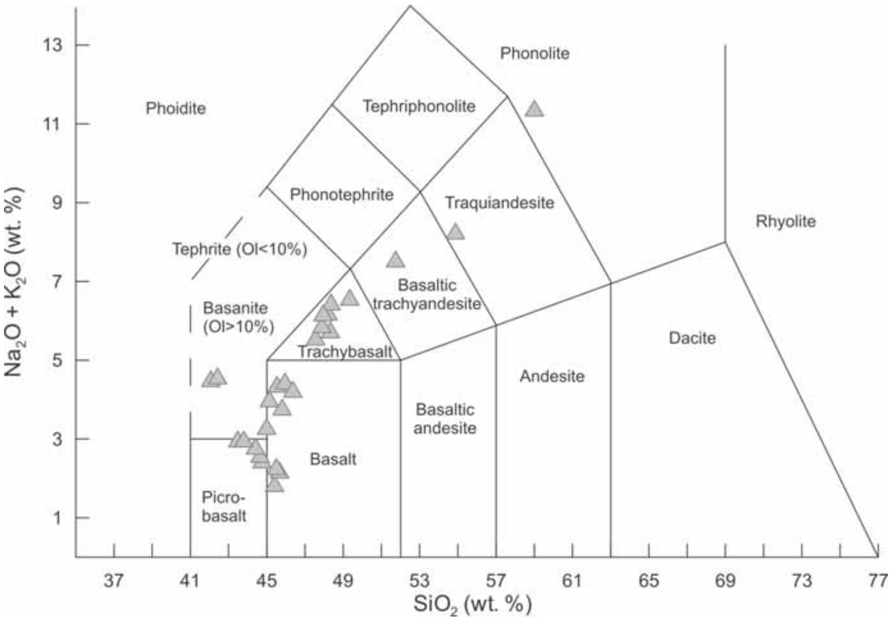

Fig. 2.- TAS diagram for 49 volcanic rocks of the Corvo island.

Fig. 2.- Diagrama TAS de 49 muestras de rocas volcánicas de la Isla de Corvo.

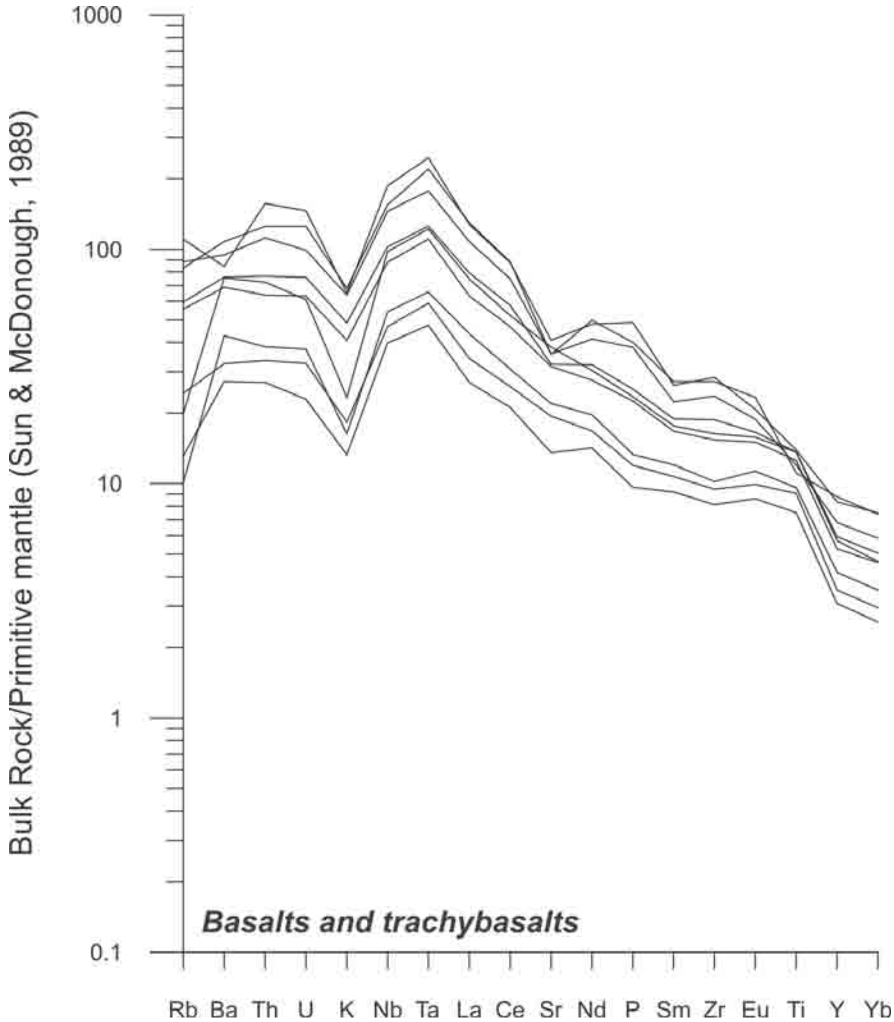

Fig. 3.- Multielemental diagram (normalized with primitive mantle; Sun and McDonough, 1989) of selected basaltic compositions from Corvo island.

Fig. 3.- Diagrama multielemental normalizado con manto primitivo (Sun and McDonough, 1989) de las composiciones seleccionadas en basaltos de la Isla de Corvo.

SAMPLE	COR 17	COR 12	COR 16	COR 9	COR 3	COR 11	COR 23	COR 13	COR 28	COR 20	COR 21
Episode	I	I	I	I	I	I	I	I	II	III	III
SiO_2	45,40	45,49	46,36	43,79	48,58	48,36	51,74	47,94	54,87	44,74	45,13
TiO_2	1,63	1,97	2,72	2,95	2,61	3,02	2,19	2,41	1,19	2,09	2,96
Al_2O_3	10,02	11,86	17,08	18,31	17,22	16,89	17,25	17,48	17,35	13,49	16,73
Fe_2O_3	10,05	10,95	11,35	13,01	11,14	11,70	9,26	11,87	8,68	11,45	12,54
MnO	0,15	0,17	0,18	0,19	0,21	0,23	0,22	0,23	0,27	0,17	0,19
MgO	15,41	13,43	5,32	4,95	4,10	4,08	3,15	2,85	1,61	11,11	5,33
CaO	14,17	13,81	12,76	12,04	8,32	8,01	6,55	7,14	4,00	12,91	11,75
Na_2O	1,47	1,75	3,03	2,30	3,98	4,52	5,07	4,15	5,43	1,98	2,56
K_2O	0,40	0,55	1,23	0,70	1,92	1,96	2,50	2,05	2,85	0,49	1,46
P_2O_5	0,21	0,26	0,49	0,51	0,83	1,06	0,84	0,87	0,50	0,29	0,55
LOI	0,90	<0,06	<0,23	1,34	0,26	<0,07	1,22	1,93	1,66	1,22	0,75
mg*	0,78	0,74	0,52	0,46	0,46	0,44	0,44	0,35	0,30	0,69	0,49
TOTAL	99,83	100,19	100,29	100,17	99,24	99,82	100,09	98,99	98,53	99,97	100,01
Rb	8	15	35	13	56	70	70	53	86	6	38
Cs	B.D.L.	0,14	0,32	0,19	0,48	0,92	0,57	0,46	0,96	0,80	0,36
Be	B.D.L.	B.D.L.	1,00	1,00	2,00	3,00	2,00	2,00	3,00	B.D.L.	1,00
Sr	286	410	667	806	755	865	718	751	611	464	682
Ba	190	227	481	528	660	591	818	753	993	299	531
Sc	50	41	25	21	13	10	8	6	4	35	24
V	235	282	298	345	190	170	105	90	13	272	320
Cr	1250	894	52	B.D.L.	B.D.L.	B.D.L.	B.D.L.	B.D.L.	B.D.L.	787	B.D.L.
Co	65	62	39	44	27	23	12	22	7	58	40
Ni	298	266	74	74	38	32	B.D.L.	29	B.D.L.	212	45
Cu	109	110	168	97	32	15	B.D.L.	14	B.D.L.	125	143
Zn	69	62	88	97	116	128	122	127	119	87	94
Ga	13	15	22	23	24	22	23	25	23	16	21
Y	14,00	16,00	24,00	26,00	31,00	38,00	39,00	40,00	35,00	19,00	27,00
Nb	28,44	33,33	62,63	69,73	103,50	133,04	127,55	110,26	150,79	38,51	73,12
Ta	1,94	2,41	4,53	5,00	7,28	10,08	8,62	9,03	10,25	2,69	5,14
Zr	91	106	172	183	264	317,74	314	305	405	114	209,364
Hf	2,80	3,26	4,78	5,07	6,68	8,60	7,88	7,39	9,34	3,54	5,41
Mo	B.D.L.	B.D.L.	2,20	B.D.L.	2,56	2,37	3,37	2,30	5,61	B.D.L.	2,06
Sn	1,39	1,45	1,76	2,11	2,66	3,61	4,03	2,59	2,49	1,55	1,84
Tl	0,14	B.D.L.	0,08	B.D.L.	0,10	0,07	0,06	1,80	0,12	0,31	B.D.L.
Pb	B.D.L.	B.D.L.	B.D.L.	B.D.L.	B.D.L.	7,40	5,86	B.D.L.	7,20	B.D.L.	B.D.L.
U	0,48	0,68	1,32	1,28	2,08	3,06	2,66	2,63	3,24	0,79	1,59
Th	2,30	2,84	5,42	6,16	9,50	13,33	11,30	10,65	13,77	3,26	6,54
La	18,57	23,54	43,46	51,39	74,02	87,74	90,27	89,02	100,44	29,94	54,48
Ce	37,51	46,02	83,05	92,57	132,90	155,54	162,96	157,23	175,80	54,67	102,21
Pr	4,42	5,31	9,11	10,23	14,17	16,45	17,06	17,19	17,62	6,34	10,76
Nd	19,23	22,76	37,39	41,15	56,03	64,80	65,97	67,37	63,70	26,65	43,54
Sm	4,09	4,75	7,43	7,84	9,91	11,67	11,60	12,09	10,29	5,34	8,38
Eu	1,45	1,66	2,53	2,65	3,17	3,48	3,73	3,92	3,32	1,90	2,78
Gd	3,79	4,30	6,25	6,52	7,64	9,12	9,11	9,95	7,26	4,76	6,66
Tb	0,58	0,67	0,98	1,00	1,18	1,44	1,43	1,49	1,20	0,73	1,05
Dy	3,37	3,76	5,55	5,71	6,81	8,11	8,37	8,82	7,17	4,19	6,12
Ho	0,58	0,65	0,95	1,01	1,17	1,45	1,45	1,52	1,26	0,75	1,05
Er	1,57	1,75	2,65	2,70	3,27	4,09	4,16	4,29	3,69	1,97	2,84
Tm	0,21	0,23	0,37	0,37	0,46	0,58	0,59	0,60	0,55	0,27	0,41
Yb	1,27	1,46	2,27	2,29	2,88	3,69	3,65	3,65	3,59	1,73	2,49
Lu	0,17	0,20	0,31	0,32	0,39	0,48	0,52	0,50	0,51	0,24	0,34
La/Lu_N	10,93	12,10	14,37	16,45	19,06	18,40	17,66	18,06	20,03	12,64	16,18
Nb/Y	2,03	2,08	2,61	2,68	3,34	3,50	3,27	2,76	4,31	2,03	2,71
P_2O_5/Zr	23,08	24,53	28,49	27,87	31,44	33,36	26,75	28,52	12,35	25,44	26,27
TiO_2/P_2O_5	7,75	7,58	5,55	5,79	3,14	2,85	2,61	2,77	2,39	7,20	5,38
Nb/Zr	0,31	0,31	0,36	0,38	0,39	0,42	0,41	0,36	0,37	0,34	0,35
Ti/V	41,50	41,89	54,73	51,29	82,18	106,54	125,29	160,47	539,54	45,99	55,43
Ti/Y	696,59	738,39	679,57	680,55	503,69	476,68	336,89	360,84	204,48	658,39	656,90
Zr/Y	6,50	6,63	7,17	7,04	8,52	8,36	8,05	7,63	11,57	6,00	7,75
Th/Tb	4,00	4,26	5,54	6,17	8,06	9,26	7,91	7,15	11,50	4,44	6,22
K_2O/Yb	0,32	0,38	0,54	0,31	0,67	0,53	0,68	0,56	0,79	0,28	0,59
Nb/La	1,53	1,42	1,44	1,36	1,40	1,52	1,41	1,24	1,50	1,29	1,34
Ta/La	0,10	0,10	0,10	0,10	0,10	0,11	0,10	0,10	0,10	0,09	0,09
Ta/Yb	1,53	1,66	2,00	2,18	2,52	2,73	2,36	2,47	2,86	1,56	2,06
Ta/Hf	0,69	0,74	0,95	0,99	1,09	1,17	1,09	1,22	1,10	0,76	0,95

B.D.L.: Below detection limit

Table I.- Selected compositions of volcanic rocks from Corvo island.

Tabla I.- Composiciones de las rocas volcánicas de la Isla de Corvo seleccionadas.

a ZAF procedure. The standards used were orthoclase (K, Si), wollastonite (Ca), albite (Na, Al), pyrophanite (Mn, Ti), hematite (Fe), strontianite (Sr), Barite (Ba) and synthetic MgO, Cr_2O_3, Rb_2O and NiO.

Whole rock analyses were carried out in the ACTLABS laboratory (Canada) using the WRA + trace 4 Lithoresearch routine. Major elements were analysed by ICP-AES and the trace elements (including REE) were analysed by ICP-MS. Selected representative compositions are given in Table I.

Petrology

The mafic volcanic rocks are porphyritic-hypocrystalline. The primary mineral assemblage is composed of olivine + Ti-augite + plagioclase + Ti-magnetite + glass with different petrographic varieties. Pre- and post-caldera mafic rocks are very similar in composition.

Olivine varies in composition from Fo_{89-85} in phenocrysts to Fo_{85-77} in microcrysts. Clinopyroxene (Ti-augite) phenocrysts are slightly zoned (range: $En_{48}Wo_{46}Fs_6$ to $En_{44}Wo_{46}Fs_{10}$) with increasing TiO_2, Na_2O and FeO contents and descending proportions of MgO and Cr_2O_3 from core to border. Microcrysts of this mineral are homogeneous in composition ($En_{41}Wo_{45}Fs_{14}$). The composition of plagioclase ranges An_{87-82} in phenocrysts and An_{61-51} in microcrysts with high Rb and Ba contents. The K_2O proportion increases during crystallization. The opaque minerals are Ti-magnetite, with notable Al_2O_3 and MgO contents. The composition of the clinopyroxene (high Ti and Na contents) and the plagioclase (high Rb, Ba and progressive increasing of K) are typical of an alkaline affinity of the melt.

Geochemistry

This volcanism is characterized (Table I) by low SiO_2 and Al_2O_3 contents and high values of MgO, TiO_2 and P_2O_5. Na_2O+K_2O increases during fractionation and the K_2O/Na_2O ratio is always less than 0.50, indicating normal alkalinity melts with a K depletion. The *mg#* parameter varies from 0.78–0.70 and Ni decreases with magmatic evolution from 300 to 30 ppm.

The most primitive samples correspond to picrobasalts, basalts and alkali basalts representative of the pre- and post-caldera stages (Fig. 2). The syn-caldera rocks are trachyandesites and phonolites.

The multielement patterns, normalized to primitive mantle (Sun and McDonough, 1989), indicate relative enrichments in the Nb-Ta, U-Th and La-Ce pairs (Fig. 3). These patterns are similar to those of enriched mantle sources. A strong K depletion (and relative depletion in Sr and Rb) is characteristic of HIMU reservoirs (Weaver, 1991).

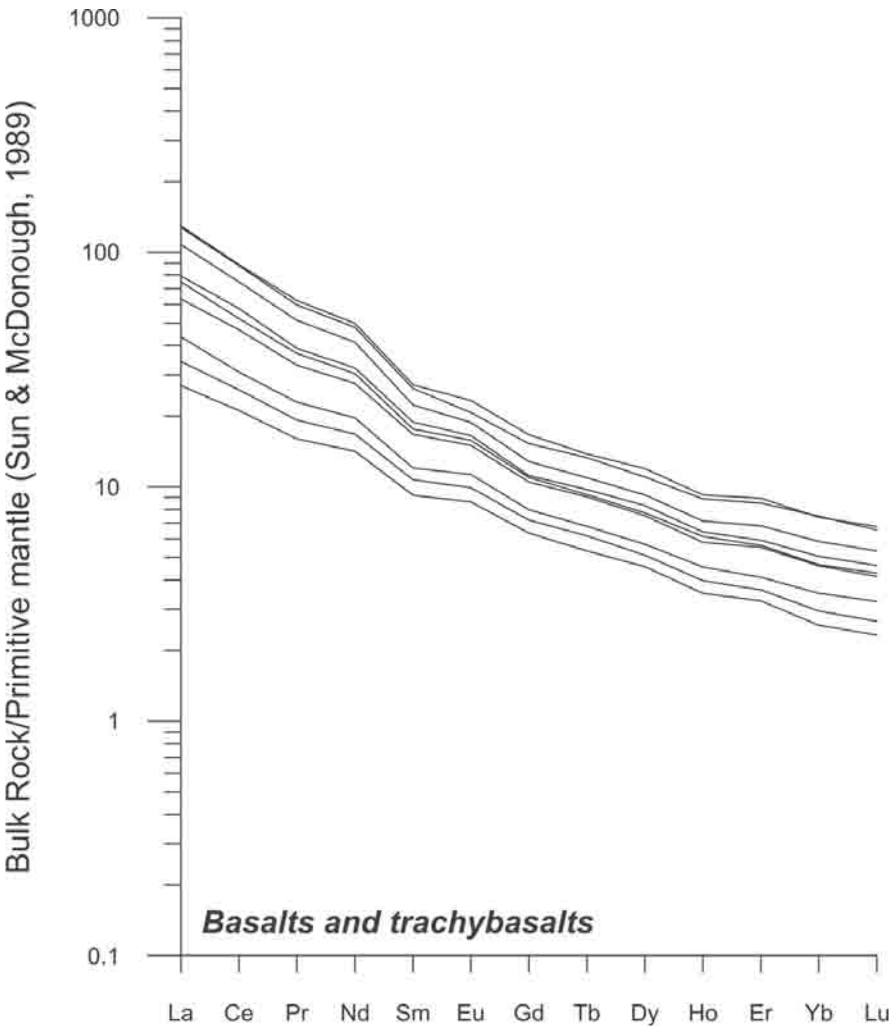

Fig. 4.- REE patterns (normalized with primitive mantle; Sun and McDonough, 1989) of selected basaltic compositions from Corvo island.

Fig. 4.- Pautas de TR normalizadas con manto primitivo (Sun and McDonough, 1989) de las composiciones seleccionadas en basaltos de la Isla de Corvo.

The negative anomalies of K and Sr and the low values for Ti, Y and Yb suggest the presence of potassic amphibole as a melting residual phase. The high P, Ba and Nb contents (Fig. 3) are not compatible with other residual phases as apatite or phlogopite.

The primitive mantle-normalized REE plots indicate an important fractionation from the most primitive rocks to the trachyandesites and phonolites (Fig. 4). The high La/Lu_N slope (Table I) and the REE patterns suggest a continuous fractionation from a common melt with low partial melting rates.

The interelemental ratios (Table I) suggest that the source of these magmas could have been an HIMU-type enriched reservoir with probable participation of an EM II component (Saunders *et al.*, 1988 y Weaver, 1991).

These trace-element geochemical characteristics need to be supported with new Sr, Nd and Pb isotopic data. The available geochemical compo-sitions for the Corvo island rocks are nearly equivalent to those from other Azores islands. Thus, a mantle plume with a significant HIMU contribution could be a reasonable geodynamic scenario for the genesis of the magmas.

Conclusions

The OIAB volcanism from Corvo island probably started at 1.5 to 1.0 Ma (e.g. the Basal Complex). Later subaerial volcanism (e.g. Central Volcano) can be grouped into three volcanic units (França *et al.*, 2003) of pre-, syn- and post-caldera episodes, including 0.7 to 0.4 Ma basaltic events (Azevedo *et al.*, 2003). This volcanism is mainly represented by primitive K-depleted alkali basalts and minor phonolite terms. The geochemical composition of the basalts is characterised by positive anomalies of Nb-Ta and Th-U and notable depletions in K and Sr. These features indicate an enriched HIMU-type source for this volcanism with a possible EM II contribution, consistent with the astenospheric mantle plume model proposed for the Azores archipelago.

Acknowledgments

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