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Rare earth element and thorium distribution in volcanic rocks of the potassio kindred from Procida Island and the Phlegraen Fields, southern Italy

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Petrologia. — *Rare earth element and thorium distribution in volcanic rocks of the potassic kindred from Procida Island and the Phlegraean Fields, southern Italy.* Nota di ANTONIO ALBINI (*), RENATO CRISTOFOLINI (**), PIO DI GIROLAMO (***), GIUSEPPE NARDI (***), GIUSEPPE ROLANDI (***) e DAMIANO STANZIONE (***), presentata (****) dal Socio A. SCHERILLO.

RIASSUNTO. — Vengono riportati i dati relativi all'analisi per Attivazione Neutronica Strumentale di Terre Rare, Th, Sc e Cs, in alcune vulcaniti di serie potassica delle isole di Procida, Vivara e dei Campi Flegrei.

Le rocce analizzate vanno da lati-basalti a trachiti alcaline e fonoliti [2, 6], per le quali si era già suggerita, sulla base di dati petrografici e petrochimici, l'appartenenza ad una serie dominata prevalentemente da cristallizzazione frazionata [2].

L'esame della distribuzione delle Terre Rare e di Th mostra che, per le rocce femiche, le varietà con $SiO_2 > 52\%$ sono da considerarsi distinte dal gruppo delle rocce più basiche ($SiO_2 < 50\%$) le quali mostrano per le Terre Rare composizioni normalizzate alle condriti analoghe a quelle di fusi basaltici originati per grado di fusione piuttosto elevato del mantello superiore (fig. 3) [17, 18, 19, 20]. Le affinità migliori si notano con le rocce potassiche di arco vulcanico (Shoshoniti) [21]. Tali vulcaniti della Campania sono possibilmente contaminate con materiale di provenienza crustale [25, 26].

Per quanto riguarda le varietà più acide, queste non sembrano derivabili dalle rocce basiche per semplici fenomeni di cristallizzazione frazionata, poiché elementi che in tal caso dovrebbero mostrare un comportamento incompatibile, hanno fattori di arricchimento assai diversi fra di loro, ed i rapporti fra coppie degli stessi elementi non si mantengono costanti (Tabella IV, fig. 4).

Pertanto l'intera serie potrebbe derivare da differenziazione complessa, per migrazione di elementi volatili in una camera occupata da un magma a sua volta derivato da cristallizzazione frazionata del lati-basalto originario, o alternativamente le vulcaniti con $SiO_2 > 52\%$ potrebbero avere un'origine indipendente da quella dei tipi più basici.

1. INTRODUCTION

Procida Island is located in the Gulf of Naples, about 20 km south-west of town, and represents the westerly extension of the Phlegraean Fields, where quaternary alkalic volcanics of the potassic suite are characteristically present. These range from rather mafic lati-basalts to trachytes and phonolites; while the Phlegraean volcanics are dominantly trachytes and phonolites, in Procida Is. the more mafic varieties are also common [1, 2, 3].

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A petrologic and geochemical study of the volcanic rocks from this island is then useful in giving us some information about the origin and the evolution of the quaternary magmas in Campania.

In the present paper, on the basis of the REE distribution in a sequence from lati-basalts to trachytes from Procida and in some trachytes from the Phlegraean Fields, preliminary suggestions are given as to the origin and the evolution of the potassic magmas from this area.

2. GEOLOGY AND PETROLOGY

Some geologic and petrologic information about Procida is given here as a framework for the following discussion.

Owing to their structural and petrologic features Procida and the nearby Vivara Is. belong to the Phlegraean volcanic district that is Pleistocene up to Holocene in age, and typically K-rich. This volcanism occurred in a continental environment along the Tyrrhenian edge of the Apennines during a phase when very important tensional movements gave origin to a horst

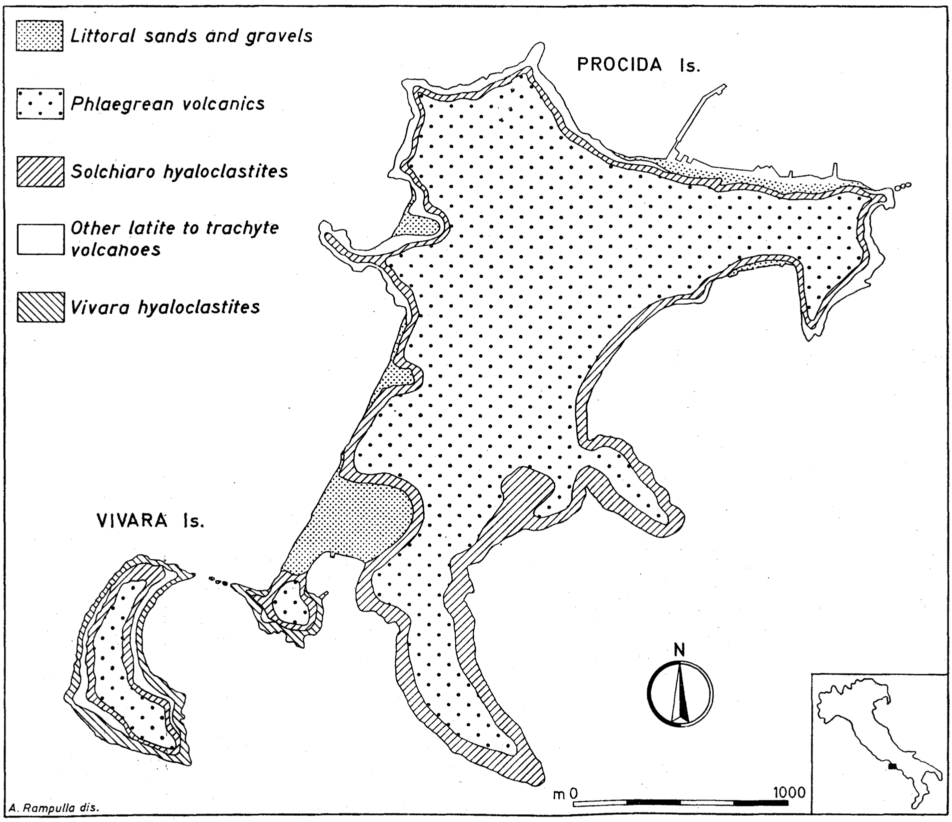

Fig. 1. – Geologic sketch map of the Procida and Vivara Islands.

TABLE I

Major element composition and norms [5] *for the rocks analyzed*

	Procida and Vivara									Phlegraean Fields		
Sample	PS_9	PS_{12}	PS_6'	V_3'	PL_1	PL_{11}	PP_2	PL_3	PL_{12}	CF_{220}	CF_{219}	IC_{351}
SiO_2	47.81	47.54	48.65	47.65	52.46	54.78	59.26	57.20	60.15	55.61	57.95	60.28
TiO_2	1.17	1.22	1.30	1.38	0.50	0.62	0.58	0.59	0.40	0.64	0.45	0.41
Al_2O_3	15.42	16.97	17.66	17.30	16.20	17.34	18.60	17.32	18.79	18.62	17.85	18.41
Fe_2O_3	2.02	2.90	1.53	2.35	3.60	2.92	1.94	2.85	2.11	1.45	1.75	3.21
FeO	5.88	5.32	5.95	6.95	2.39	2.55	2.10	1.97	1.48	3.15	2.17	0.35
MnO	0.10	0.10	0.09	0.15	0.15	0.25	0.20	0.16	0.20	0.08	0.13	0.15
MgO	10.58	6.69	5.72	5.47	5.87	2.56	0.70	2.06	0.70	1.67	0.82	0.69
CaO	11.91	11.49	10.09	10.95	8.37	7.27	2.77	4.92	2.11	4.12	3.10	1.90
Na_2O	2.65	2.70	3.30	3.25	4.59	5.55	4.92	5.22	5.83	4.00	4.99	5.56
K_2O	1.48	2.60	3.49	2.70	3.24	4.00	7.93	6.75	6.68	8.00	7.30	7.11
P_2O_5	0.31	0.50	0.40	0.40	0.26	0.23	0.10	0.14	0.13	0.12	0.14	0.09
Cl_2	0.04	0.05	0.09	*tr.*	0.10	0.28	0.26	0.47	0.06	0.10	0.12	0.06
SO_3	*tr.*	0.04	0.02	0.03	*tr.*	0.02	0.04	0.04	0.03	*tr.*	0.04	0.04
H_2O^-	0.20	0.54	0.42	0.41	0.35	0.18	0.13	0.12	0.19	0.20	1.10	0.80
H_2O	—	1.10	1.45	1.65	1.71	1.06	0.33	0.55	0.90	2.35	2.67	0.94
	99.57	99.76	100.16	100.64	99.79	99.61	99.86	100.36	99.76	100.11	100.58	100.00
Ce	31.3	52.3	55.4	74.1	108.5	130.5	133.1	170.2	173.1	106.5	114.5	179.2
S.I.	47.2	33.6	28.8	26.7	30.4	14.8	4.0	10.9	4.2	9.1	4.9	4.1

Classification after Streckeisen [6]. PS_9: lati-basalt; PS_{12}: lati-basalt; PS_6': phonolite tephrite-latite; V_3': phonolite tephrite-lati-basalt; PL_1: phonolite tephrite-latite; PL_{11}: tephrite phonolite-latite; PP_2: alkali trachyte; PL_3: phonolite; PL_{12}: trachyte; CF_{220}: trachyte; CF_{219}: alkali trachyte; IC_{351}: alkali trachyte.

Major elements in % weight; Ce in p.p.m.; S.I.: Solidification Index: $MgO/(MgO+FeO_t+AlK)$.

Sanidine	8.0	17.2	24.7	18.0	29.6	39.0	83.6	69.7	78.2	69.1	19.4	86.5
Nephelite	4.4	4.5	7.0	8.4	5.5	4.0	1.9	2.0	3.1	6.1	3.6	2.0
Sodalite	—	1.3	1.3	—	1.8	4.8	4.0	7.5	1.1	1.7	2.3	1.7
Plagiocl.	42.6	41.8	36.5	39.6	34.2	31.4	2.4	5.0	10.0	9.8	5.7	3.4
Cl-Pyrox.	28.5	22.7	19.6	23.4	21.4	18.4	5.1	13.4	3.2	7.9	6.8	3.3
Olivine	13.7	8.8	7.3	6.9	4.9	—	—	—	—	—	—	—
Biotite	—	—	—	—	—	—	0.9	—	1.9	3.0	—	1.5
Magnetite	1.1	1.3	1.3	1.6	1.7	1.7	1.4	1.7	2.0	1.6	1.5	1.2
Ilmenite	1.0	1.3	1.4	1.2	0.3	0.3	0.5	0.4	0.2	0.5	0.4	0.3
Apatite	0.7	1.1	0.9	0.9	0.6	0.4	0.2	0.3	0.3	0.3	0.3	0.1

Lava blocks: PS_9, PS_{12} (Procida, Solchiaro) PL_1, PL_{11}, PL_3 (Procida, Punta della Lingua); hyaloclastite grains: PS_6' (Procida, Solchiaro), V_3' (Vivara); lava: PP_2 (Punta Ottimo); vitrophyre: PL_{12} (Procida, Punta della Lingua). References: PS_9, PS_{12}, V_3', PL_{11}, PL_{12}, CF_{219}: this paper. PL_1, PS_6', PL_3, PP_2: [2]. The analyses are arranged in order of increasing Ce content.

and graben structure in the sedimentary basement [2, 3]. Pleistocene calc-alkaline volcanics have been recently found in deep wells underneath the K-rich sequence in the Phlegraean area [4].

The Procida and Vivara rocks are chiefly volcaniclastic and belong to a sequence of seven different, probably monogenic volcanoes (fig. 1). Lavas are present in only one of them, while two are hyaloclastic [1].

According to the Rittmann norm [5] and the Streckeisen classification [6], these rocks are chiefly lati-basalts to latites, near the boundary with phonolite-tephrites ($> 70\%$ vol.), and alkali-trachytes to phonolites (Table I). They have normative nephelite and are not strongly potassic. Occasionally leucite-bearing blocks are enclosed in the volcaniclastic rocks from this area.

The sequence outcropping subaerially at Procida ends with the hyaloclastic low-silica latites ($SiO_2 < 50\%$) from Solchiaro (PS_6'), that enclose blocks of well crystallized massive and older lati-basalts (PS_9, PS_{12}), showing that these rocks are present in the underwater portion of Procida. Lati-basalts have been found at the bottom of the outcropping sequence too, in the hyaloclastic volcano of Vivara (V_3'), while in the remaining subaerial volcanoes high-silica latites to trachytes and phonolites have been found ($SiO_2 > 52\%$).

The samples PS_6', V_3', and PL_{12} are the most glass-rich of the rocks from Procida and Vivara analyzed; the three rocks from the Phlegraean Fields that have been analyzed for comparison are also quite glassy.

The chemical and normative compositions for the rocks that have been analyzed also for REE are given in Table I. In Table II some mineral compositions are shown for rocks from Procida and Vivara.

TABLE II

Phenocryst mineral composition of analyzed volcanics from Procida.

Sample	Clinopyroxene			Olivine % Fa	Plagioclase % An	Alk–Feldspar % Or
	Ca	Mg	Fe			
PS_9	49.4	42.5	8.1	14.5	—	n.f.
PS_{12}	49.1	42.3	8.6	18	82	n.f.
PL_{11}	48.7	43.5	7.8	n.f.	72	n.f.
PP_2	49.2	34.0	16.8	n.f.	60	69
PL_3		—		n.f.	62	59
PL_{12}		—		n.f.	n.f.	57

— : not determined.
n.f.: not found.

The analyzed rocks are not strictly homogeneous with regard to their cooling history and their depositional environment, as shown by their petrographic features.

3. ANALYTICAL RESULTS

Analysis for the REE was performed by Instrumental Neutron activation according to the method suggested by Albini *et al.* [7]. The samples were irradiated twice at different neutron fluxes (0.8×10^{10} n/cm^2 sec for 2 mins and 3.5×10^{11} n/cm^2 sec for 2 hours respectively) by means of the L54 Reactor at the Politecnico in Milan. Radiation counts were read by Ge(Li) γ-ray detectors and a 1024 channel LABEN analyzer 30 mins to 60 days after irradiation.

Accuracy and precision were monitored on some USGS rock standards (BCR-1, AGV-1, GSP-1) (Table III).

The results for the analyzed rocks are shown in Table III with an average composition for the chondrites [8]. These data compare fairly well with those obtained by Capaldi *et al.* [9] for some Phlegraean Fields trachytes.

The REE normalized chondrite patterns are almost linear from La to Tb for the low-silica varieties from Solchiaro and Vivara (fig. 3 C) which are moderately enriched in the light REE (LREE) with respect to the chondrites ($La/La_{ch} = 40–70$) and even less enriched in the heavy REE (HREE) ($Yb/Yb_{ch} = 10–15$). In the more acid types (trachytes) the normalized chondrite values for the LREE are very high ($La_N = 300$), while the HREE are more irregularly distributed and only weakly enriched with respect to the lati-basalts. A distinct negative Eu anomaly is apparent in the high-silica latites. (PL_1, PL_{11}), and is more pronounced in one trachyte and in the phonolite from Procida. Other trachytes from either Procida or the Phlegraean Fields show a very regular REE pattern and low HREE contents (PP_2, CF_{220}, CF_{219}).

Among the other trace elements analyzed Th and Cs behave like the LREE, being strongly enriched in the alkali-trachytes relative to the lati-basalts (Th = 3–57 p.p.m.; Cs = 1–30 p.p.m.; Table III). On the contrary, Sc is strongly depleted in the acid rocks compared with the lati-basalts.

4. DISCUSSION

The narrow range in HREE abundances, which are not as enriched as the LREE from the lati-basalts to the alkali-trachytes, does not agree with a simple crystal fractionation model: this has been suggested on the basis of petrologic data and petrochemical features [2, 3], but it would require for the HREE a bulk partition coefficient between solid and liquid near 1, which is not probable, assuming olivine, augite, and feldspars as the main

TABLE III

Rare earth element, Cs, Sc *and* Th *distribution.*

	PS_9	PS_{12}	PS'_6	V'_3	PL_1
La	12.1 ±1.5	23.1 ±2.7	24.4 ±2.9	22.1 ±2.7	67.9 ±6.8
Ce	31.3 ±1.1	52.3 ±1.5	55.4 ±1.3	74.1 ±1.8	108.5 ±2.3
Sm	4.8 ±0.2	6.8 ±0.3	7.6 ±0.3	7.8 ±0.4	12.9 ±0.5
Eu	1.60±0.10	2.27±0.14	2.38±0.14	2.89±0.16	2.02±0.13
Tb	0.78±0.10	2.01±0.26	1.17±0.16	1.30±0.16	1.83±0.25
Dy	3.05±0.12	4.00±0.24	7.05±0.28	4.80±0.26	7.80±0.27
Yb	1.80±0.47	2.60±0.14	2.05±0.32	1.95±0.29	2.70±0.09
Lu	0.70±0.04	0.85±0.04	0.59±0.03	0.40±0.02	0.70±0.03
Cs	1.5	3.0	5.0	2.5	20.0
Sc	39.6 ±1.2	28.4 ±0.9	23.6 ±0.7	19.5 ±0.7	21.7 ±0.7
Th	3.5 ±0.3	4.4 ±0.3	5.1 ±0.4	3.9 ±0.3	28.2 ±1.0

	PL_{11}	PP_2	PL_3	PL_{12}	CF_{220}
La	81.7 ±8.2	81.0 ±8.1	108.6 ±10.9	93.1 ±9.3	56.7 ±5.7
Ce	130.5 ±2.5	133.1 ±2.4	170.2 ±2.6	173.1 ±2.6	106.5 ±2.1
Sm	14.7 ±0.6	13.0 ±0.6	17.8 ±0.7	17.6 ±0.7	11.4 ±0.5
Eu	2.01±0.13	2.27±0.13	2.23±0.12	1.77±0.12	2.96±0.12
Tb	2.36±0.32	1.30±0.17	2.33±0.33	1.92±0.28	0.81±0.11
Dy	6.85±0.27	6.15±0.25	12.20±0.37	11.90±0.42	5.10±0.28
Yb	3.75±0.13	3.75±0.34	4.80±0.11	5.92±0.33	7.80±0.51
Lu	0.75±0.03	0.52±0.03	1.60±0.06	0.75±0.03	0.40±0.02
Cs	24.0	18.0	20.0	30.0	18.0
Sc	16.4 ±0.7	1.1 ±0.1	9.2 ±0.3	2.5 ±0.2	4.8 ±0.3
Th	33.4 ±1.1	37.7 ±1.2	52.8 ±1.8	56.7 ±1.4	30.5 ±1.0

	CF_{219}	IC_{351}	Average Chondrite (*)	GSP-1 (**)	BCR-1 (**)	AGV-1 (**)
La	63.8 ±6.4	117.8 ±11.8	0.32	188 ±18	21.1±2.5	32.0 ±4
Ce	114.5 ±2.2	179.2 ± 2.9	0.94	385 ±16	53.5±3.2	58.0 ±2
Sm	11.8 ±0.5	17.0 ± 0.8	0.20	26.5± 1.1	6.7±0.3	6.2 ±0.3
Eu	2.19±0.14	1.72± 0.13	0.073	2.7± 0.1	2.5±0.1	2.0 ±0.2
Tb	0.91±0.13	1.90± 0.28	0.050	1.4± 0.2	1.4±0.2	0.5 ±0.1
Dy	5.30±0.32	11.20± 0.56	0.31	5.6± 0.3	7.2±0.3	4.2 ±0.4
Yb	3.30±0.23	6.40± 0.32	0.19	2.2± 0.1	3.3±0.2	1.5 ±0.1
Lu	0.50±0.03	1.15± 0.04	0.031	0.3±0.02	0.5±0.03	0.47±0.03
Cs	14.0	29.0				
Sc	2.3 ±0.2	1.5 ±0.1				
Th	35.6 ±1.1	61.6 ±1.8				

(*) [8], Gordon *et al.*

(**) [7], Albini *et al.*

crystallizing phases [10, 11, 12]. The amount of apatite being fractionated does not look sufficient to explain the low HREE enrichment; on the other hand, the effect of crystallizing apatite should be greater on LREE than on HREE [13]. Very little correlation has been found between REE and Th concentrations and the alteration expressed by % H_2O^+.

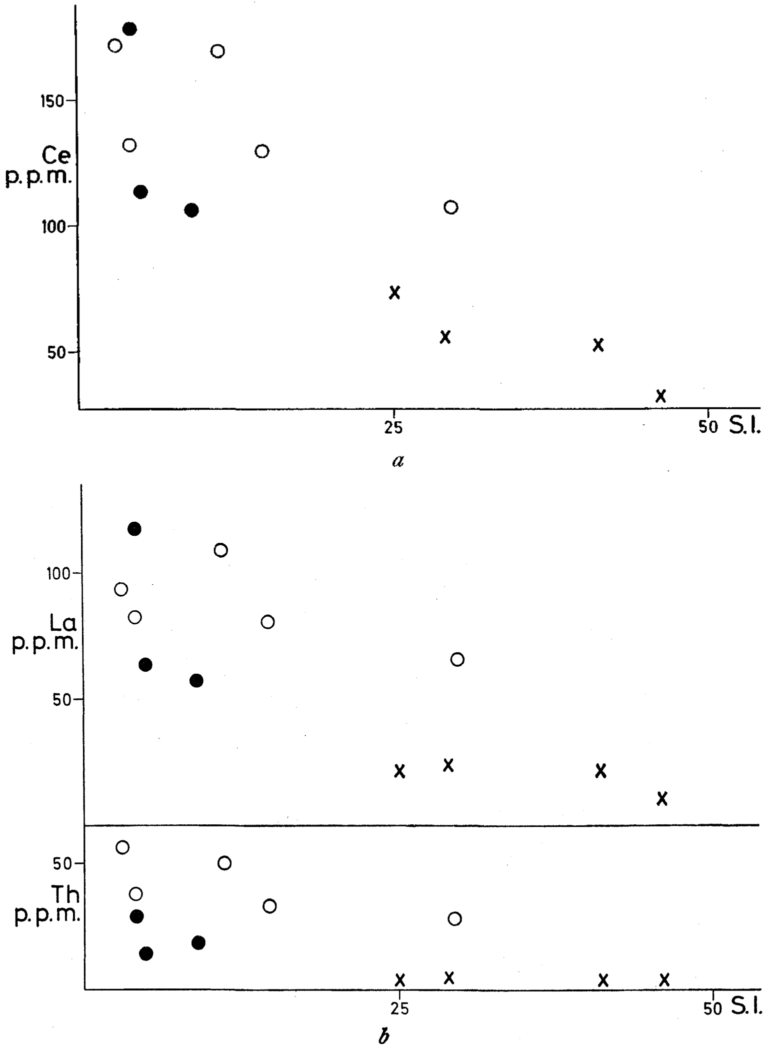

Fig. 2. – The La, Ce and Th contents of the analyzed rocks are plotted against S.I.: it can be seen that the low-silica rocks (×) are aligned following a distinct trend from either the high-silica varieties ($SiO_2 > 52\%$) from Procida (○) or the trachytes from the Phlegraean Fields (●).

In the whole set of data the linear correlation between pairs of elements assumed to behave as incompatible [14] is generally rather high ($r_{Ce-Th} = 0.977$; $r_{Ce-La} = 0.979$; $r_{Ce-Cs} = 0.929$; $r_{Ce-Sm} = 0.986$; $r_{La-Th} = 0.974$). Nevertheless it is to be noted that even if the correlation is significant at the 99 % level,

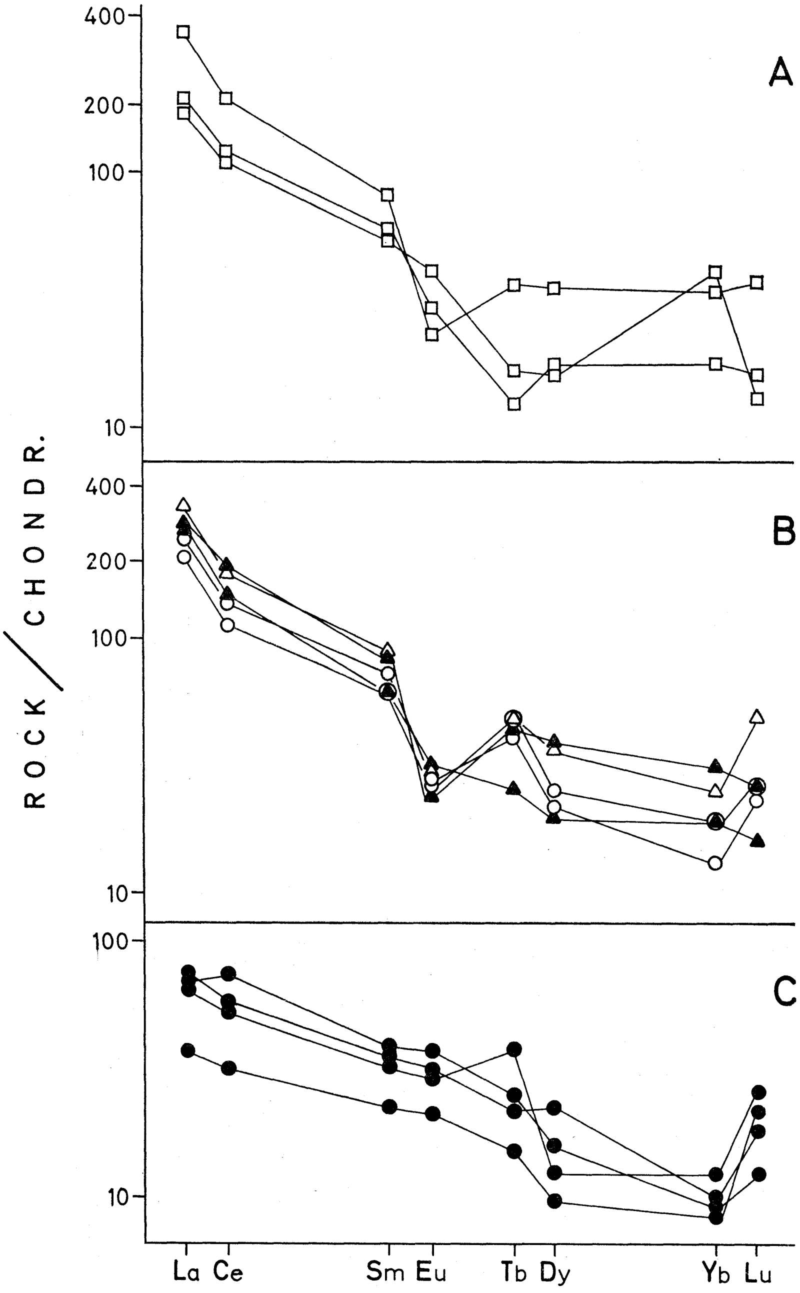

Fig. 3. – Normalized chondrite REE patterns for the analyzed rocks: A: Phlegraen Fields trachytes; B: high-silica latites (○), trachytes (▲), and phonolites (△) from procida; C: low-silica latites and latibasalts from Procida.

the intercept of the regression line falls off the origin by a significant value. Moreover, the enrichment factors for different elements are not similar, being 3.7 for Sm, 5.5 for Ce, 9.0 for La, and 16.2 for Th. On further examining the relationship between pairs of elements, according to the suggestions of Treuil & Toron [15], it can be shown that their ratios (Table IV) change by a factor of about two from the lati-basalt and low-silica latite group on the one side to the high-silica latites and trachytes on the other side.

TABLE IV

Ratios between pairs of trace elements analyzed.

	La/Ce	La/Sm	La/Tb	Th/La	Th/Ce	Ce/Dy	Ce/Sm
PS_9	0.387	2.52	15.51	0.289	0.112	10.20	6.52
PS_{12}	0.442	3.40	11.49	0.190	0.084	13.10	7.69
PS'_6	0.440	3.21	20.85	0.209	0.092	7.86	7.29
V'_3	0.298	2.83	17.00	0.176	0.053	15.43	9.50
PL_1	0.626	5.26	37.10	0.415	0.260	13.91	8.41
PL_{11}	0.626	5.56	34.62	0.409	0.255	19.05	8.88
PP_2	0.609	6.23	62.31	0.465	0.283	21.64	10.24
PL_3	0.638	6.10	46.61	0.486	0.310	13.95	9.56
PL_{12}	0.538	5.29	48.49	0.609	0.328	14.54	9.84
CF_{220}	0.532	4.97	70.00	0.538	0.286	20.88	9.34
CF_{219}	0.557	5.41	70.11	0.558	0.311	21.60	9.66
IC_{351}	0.657	6.93	62.00	0.523	0.344	16.00	10.54

These facts should not occur, given that these elements are incompatible and that their distribution depends mainly on crystal fractionation processes [15, 16].

The LREE and Th are systematically less abundant in the more basic rocks than in the more acid latites to trachytes: plotting the La, Ce and Th contents against S.I., two distinct alignments can be recognized for the two groups (fig. 2).

Considering in detail the lati-basalts and the low-silica latite from Vivara and Solchiaro, these form a rather homogeneous group, with the sample PS_9 systematically depleted in Th, Cs and REE (except Lu) with respect to the other three samples; PS'_6 shows the most regular REE pattern, while PS_{12} exhibits the largest anomalies for Tb and Dy.

The available data suggest that the low-silica rocks ($SiO_2 = 47\text{–}50\,\%$) form an independent group, where the REE content does not reflect rather large variations in the overall major element chemistry (Table I; fig. 2). In the diagrams of fig. 4 this group does not show any clearly defined trend, and clusters in a rather small field, distinct from that of the more acid latites to trachytes ($SiO_2 > 52\,\%$).

On the average the REE abundances for the basic rocks are slightly in excess with respect to those reported for the ocean island tholeiites [17, 18, 19], and about in the same range as the Hawaiian alkali basalts [17]; the LREE are not as abundant as in the average alkali basalt [20]. In particular, also the German continental tholeiites, alkali basalts and phonolites are reported [20] as showing a distinct Dy anomaly, which is also shown by minerals like plagioclase and pyroxene from the same rocks, and could be explained on the basis of a different crystal-chemical behaviour of the REE with the decreasing ionic radius. The REE coordination should also be controlled by other factors like total pressure [19] and possibly by volatile activity in the melt [17]: considering that most of the analyzed rocks have been erupted as tephra, some of the scatter of their REE content could be accounted for by diffusion in a separate gaseous phase before the eruption. This is particularly important for elements like Eu, which is affected by oxi-reduction reactions [15], or Tb and Dy, which possibly change their coordination under varying pressure [19], thus being differently distributed in the various solid and fluid phases.

Examining then the more acid varieties, from the latite (PL_1) to the phonolite and the trachytes, they show a regular increase of La, Ce, Sm, Yb, and Th toward the most silica-rich rocks, with some minor inconsistencies for the HREE; the Eu anomaly is shown by most of the rocks, being more pronounced in the more acid trachytes (PL_{12}, IC_{351}) but is very weak or even absent in PP_2, CF_{219}, and CF_{220}. In the first approximation this could be taken as evidence of the important rôle that feldspar fractionation played in the origin of this rock suite.

On the other hand, some of the ratios between pairs of incompatible elements increase gradually with the evolution of this group of rocks from Procida (fig. 4), while others show a more irregular behaviour: Th/Ce and Th/La show the former trend, and La/Ce on the contrary decreases in the most acid varieties. This should indicate that La and Ce have been removed from the melt at a higher rate than Th, and further, that La has been more efficiently removed than Ce in the last stages of the evolution.

The three rocks from the Phlegraean Fields show a rather wide range in the LREE and Th, with Th/Ce and Th/La almost constant.

Again also for this salic group the irregular distribution of the HREE could suggest control by factors other than crystal fractionation alone.

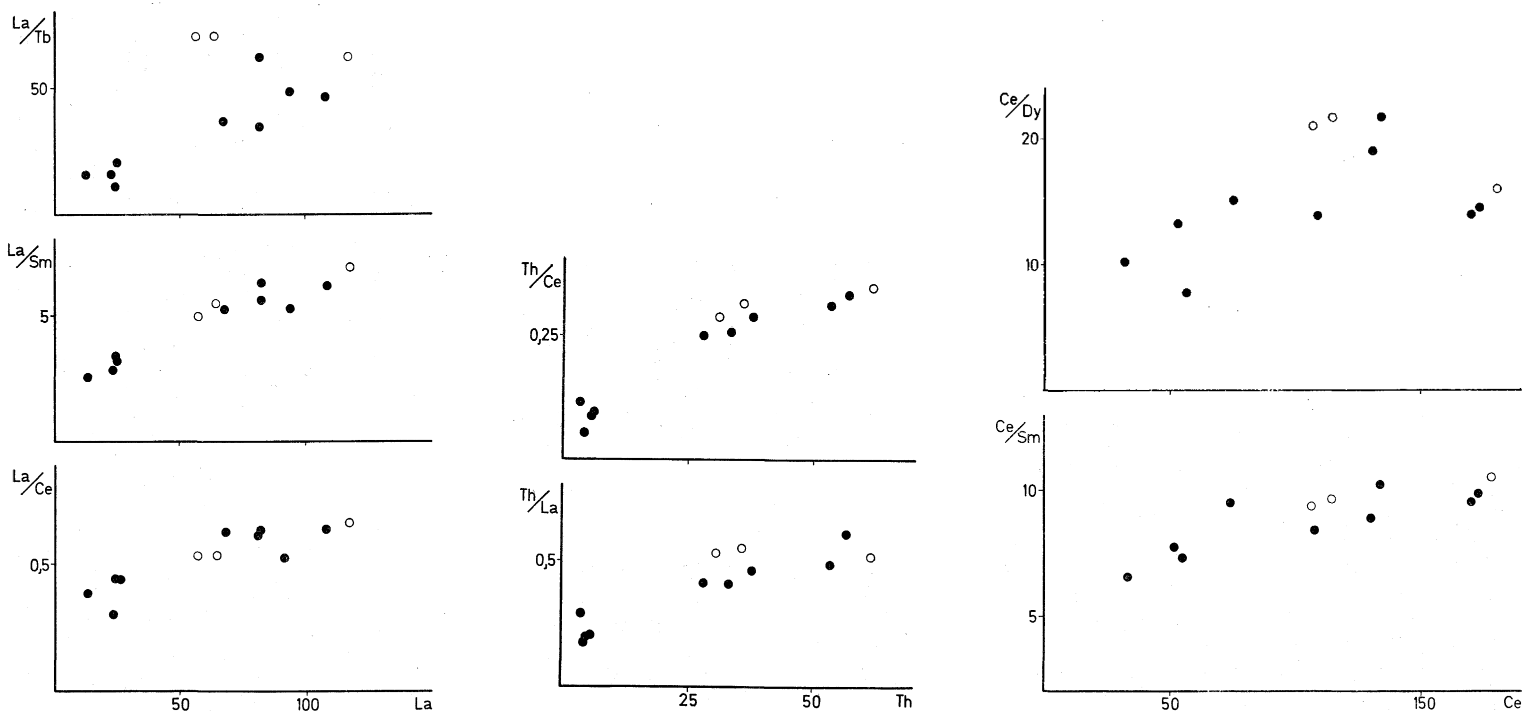

Fig. 4. – In the diagrams drawn according to [15] there is no clear alignment of the analyzed rocks. Given that the elements considered have an incompatible behaviour a simple crystal fractionation should yield constant ratios between pairs of these with an increasing evolution: on the contrary, the lati-basalt group shows distinctly lower ratios than the latite-trachyte sequence. ●: Rocks from Procida; ○: rocks from the Phlegraean Fields.

The REE distribution in the trachyte PP_2 is significantly different than in PL_{12} (Table III; fig. 4): its departure from the regular trend of evolution could be accounted for by K-feldspar accumulation into a melt with a composition near to that of PL_{12}.

5. CONCLUSIONS

The present data do not allow us to give a rigorous model of the processes of origin and evolution of the analyzed rocks, but can be a basis for their qualitative evaluation.

The overall major element chemistry and the REE distribution in the low-silica rocks show that they could represent compositions not far from that of a primary magma from high mantle material. This looks consistent with their REE composition as compared to that of other basaltic rocks derived by a fairly high degree of partial melting [17, 18, 19, 20]. In particular, chemical affinities can be observed with mafic K-rich volcanics (shoshonites) [21, 22] from folded but almost aseismic areas, generally distant from active subduction zones [23], while some differences can be observed with mafic K-rich volcanics from West African Rift Valleys [24].

Taking into account also recent Sr and O isotope compositions [25, 26] for rocks from the same volcanic district, contamination from deep crust material should be considered important in the origin of these volcanics.

The petrography is not consistent with an origin of the basic rocks from a more acid melt by accumulation of mafic phenocrysts [27, 28], as large amounts of crystals should have accumulated to produce the observed compositions, while the analyzed rocks always show rather few phenocrysts, and are often even largely glassy [2]. Furthermore, the phenocryst cores show lower temperature compositions in the latites and the trachytes than in the lati-basalts.

The mixing of a lati-basalt and a trachyte magma should be rejected as a possible origin of the sequence on the basis of the recognized non-linear REE variation trends (fig. 2).

Even a simple crystal fractionation model [2] does not conform in detail either with the observed REE distribution, as stated in the above discussion, or with some of the major element variation (Na_2O/K_2O; $S.I./SiO_2$). However, an open system crystal fractionation with addition of mobile elements into a high-level magma chamber could account for the observed evolution. In other words the lati-basalt magma that occasionally erupted at a barely differentiated stage underwent crystal fractionation processes (suggested by the negative Eu anomaly and by the gradually changing composition of some phenocryst minerals) while the mobile elements were mobilized by volatile compounds migrating in the magma toward the low pressure levels. This process could have been particularly effective at the latite stage, and could account for the marked increase of the LREE and Th contents observed between the low- and high-silica latites, and for the irregular distribution of some of the HREE. In the most differentiated varieties (alkali-trachytes and phonolites) the REE mobilization could also control their departure from the incompatible element behaviour.

Finally, the migration of trace elements in different amounts and at varying rates could also be consistent with the different REE distribution between the Procida and the Phlegraean volcanics.

Due to the chemical features of the high-silica latite (PL_1), as compared to the more basic rock types (Table I, fig. 2), also a two source origin could be suggested for the sequence analyzed. According to Cundari & Le Maitre [30] the Phlegraean trachytes should have a source other than that of the mafic rocks from Vesuvius, and Marinelli [29] states that " the rare trachybasalts " of this region are not related to the trachyte series. So far, on the basis of the presently available data, the hypothesis that the latibasalts had a different source than the high-silica latites leaves the question of the origin of the latter unanswered, while it could easily account for the large difference in the LREE and Th contents in terms of a different composition and/or phsyco-chemical environment at the source. The evolution from the high-silica latites to the trachytes could then be controlled mainly by crystal fractionation.

More data on carefully selected samples from a wider area are needed to trace with greater detail the complex history of the origin and the evolution of the Quaternary potassic magmas in the region around Naples.

The present data show that no simple model conforms to the observed compositions, and that more geologic, volcanological, petrologic, and geochemical information is to be considered in order to interprete the origin and the evolution of these volcanics.

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