Geochemistry of Some Volcanic Rocks from South-eastern Sicily: Rare Earth and Other Trace Element Distribution [1]

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ABSTRACT

Some trace element data for volcanic rocks found at different levels, from Tertiary to Holocene, in south-eastern Sicily (Iblean Plateau and Mt. Etna) are presented and discussed in the present paper in order to better the information about the origin and relationships of the various rock types.

Four groups of volcanic rocks have been recognized on the basis of their major element chemistry: 1) low-K tholeiites, 2) associated alkali basalts to nephelinites of the Iblean Plateau (Upper Pliocene to Lower Pleistocene), 3) the basal subalkaline lavas of Mt. Etna, and 4) the alkalic suite rocks that make up the bulk of the volcano.

The distribution of Rb, Sr, Ni, Cr, Co, Cu, REE, Th and Sc suggests:

i) an origin of the Iblean magmas by a different degree of partial melting of a Rb-poor and possibly slightly hetereogeneous mantle;

ii) quite distinct source compositions for the Etnean magmas, relative to those of the Iblean area, on the basis of their Rb and Sr contents;

iii) an origin of the alkalic rocks of Mt. Etna from independently generated magma(s) rather than by crystal fractionation of the Etnean subalkaline magmas or of a magma having the geochemical features of the Iblean alkali basalts; evidence for this is given by the distribution features of the incompatible elements showing an origin for these rocks from compositionally different parent magmas and/or an evolution under widely variable environmental conditions;

iv) the primary character for the chemical differences observed in some of the Etnean subalkaline rocks that can be accounted for by different physico-chemical conditions at their source rather than by crystal fractionation processes.

INTRODUCTION

Several episodes of volcanic activity occurred in South-eastern Sicily from Upper Trias to Pleistocene, with dominantly basaltic features. The volcanic rocks, either subaqueous or subaerial, are linked to important tensional episodes (BARBERI et al., 1974a; CRISTOFOLINI et al., 1977a), and are found in the Iblean area and at Mt. Etna.

In the Iblean area different volcanic levels have been recognized in the upper triassic sedimentary sequence from deep oil wells (CRISTOFOLINI, 1966a, 1966b), and others, liasic in age, are known at the southern-most portion of Sicily, near Pachino, and along the eastern coast between Augusta and Catania (BARBERI et al., 1974b; DI GRANDE, 1972; PONTE, 1916). The bulk of the outcropping Iblean volcanic rocks (Miocene - Lower Pleistocene) is found at the northern edge of the at present uprising Plateau where it grades to the subsiding trough of the Catania Plain, through two main fault systems that have been active since Upper Miocene (DI GRANDE, 1972). Here low-K tholeiites have been recognized in the Upper Pliocene - Lower Pleistocene series among mainly subaerial lavas, associated with decidedly alkalic products (basalts to nephelinites). The same varie-
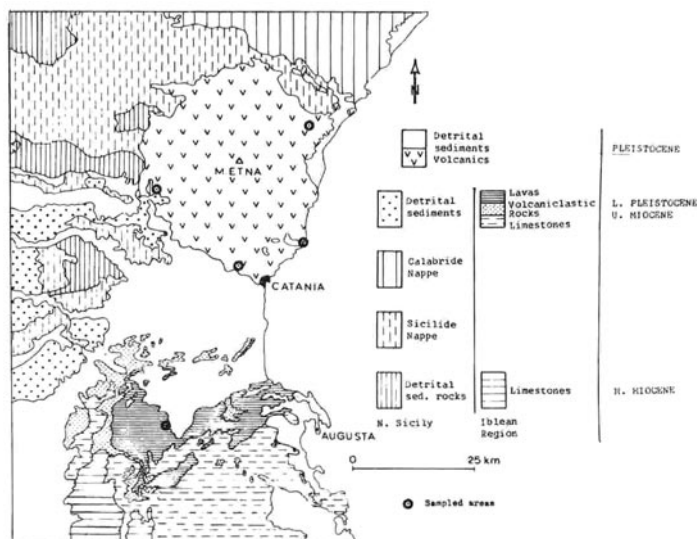
FIG. 1 – Geological sketch map of south-eastern Sicily.

ties are probably present also in the suba-queous levels (hyaloclastites) of the older phases, where they cannot easily be recognized because of their high degree of alteration (CRISTOFOLINI and BATTAGLIA; 1975; BARBERI et al., 1974b; BATTAGLIA et al., 1976; CRISTOFOLINI, 1973; ROMANO and VILLARI, 1973).

Mt. Etna is located to the north of the Catania Plain trough, where an E-W trending structure intersects several fault systems at the southern margin of the Nebrodi-Peloritani overthrust chain that overlays the downwarped Iblean sequence (CRISTOFOLINI et al., 1977a; OGNIBEN et al., 1974). Here the volcanic activity started in Pleistocene times with subalka-line basalts, overlain by a conspicuous succession of alkaline eruptions from different centres whose chemistry ranges mainly from hawaiites l.s. ($SiO_2 = 45\%$) to mugearites l.s. ($SiO_2 = 60\%$). The composition of the Etnean volcanic rocks shows no linear evolution with time (CRISTOFO-LINI, 1973; CRISTOFOLINI et al., 1977b), the historic lavas being among the most mafic in the alkalic sequence.

An analysis of the main petrologic features and of the major element chemis-try of these volcanic rocks shows signifi-

cant differences among them: the Iblean tholeiites are generally oversaturated in silica, K-poor, and with rare bronzite phenocrysts, while the subalkaline rocks from Mt. Etna are slightly richer in alka-lies and magnesia, generally undersatu-rated in SiO_2, and with olivine pheno-crysts. The alkalic rocks of the Iblean area are mostly basalts to nephelinites ($SiO_2 < 48\%$), with rare hawaiites; on the contrary the alkalic suite rocks at Mt. Etna are chiefly intermediate ($SiO_2 = 45 - 60\%$), richer in alkalies and less mafic than basalts (Fig. 2).

The samples analyzed in this paper were taken from the upper levels of the Plio-Plei-stocene sequence of the Iblean Plateau (except MI91, probably Upper Miocene in age; see CRISTOFOLINI and BATTAGLIA, 1975), and from both the subalkaline and the alkalic suites of Mt. Etna[1]

On the basis of the major and trace elements chemistry it has been proposed that the Iblean tholeiites and alkalic suite

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[1] Even if rather rare, aphyric varieties of the Etnean alkalic rocks have been preferred for the analysis in order to avoid the influence of possible cumulus phases on the trace elements distribution.
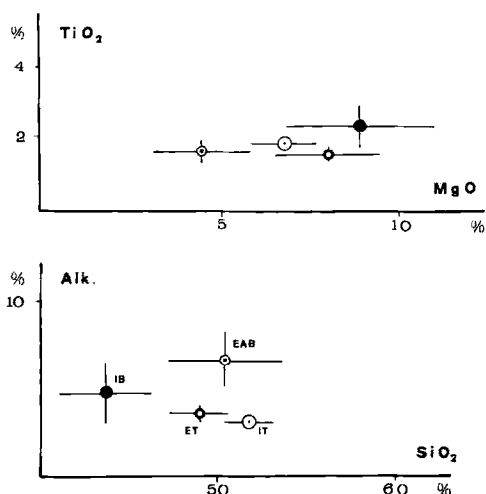
FIG. 2 - SiO_2/Alk and MgO/TiO_2 diagrams, showing the average values for the Etnean tholeiites (ET), the Iblean tholeiites (IT), the Etnean alkali basalt suite (EAB), and the Iblean basaltic rocks of the alkalic series (IB). Bars represent ± 1σ values. The diagram shows a fairly good discrimination of the different groups also on the basis of their major element chemistry.

rocks are independent in their origin (CRISTOFOLINI and BATTAGLIA, 1975; BATTAGLIA et al., 1976), and the same has been suggested for the subalkaline and alkaline volcanic products of Mt. Etna (CRISTOFOLINI, 1971, 1973). Recent isotope data strongly support these views (CARTER and CIVETTA, 1977), and further indicate that each of the four groups should have been originated from independent mantle sources.

RESULTS

REE, Th, and Sc have been determined in 24 lavas from Mt. Etna and in 8 lavas from the Iblean Plateau Rb, Sr, Ni, Cr, Co, and Cu have been determined for the Etnean rocks. The data on these elements for 13 Iblean rocks have been published elsewhere (BATTAGLIA et al., 1976). Five of such rocks were analyzed also for REE, and are reported here for comparison.

REE, Th, and Sc have been analyzed by Instrumental Neutron Activation Analysis (INAA) at C.I.S.E., Milan, after irradiation of the samples at the reactor of the Polytechnic (Milan), according to the

TABLE 1 – List of the analysed samples and respective literature.

Iblean Plateau

Tholeiites:	FR14, FR45, FR56, FR38, FR2, FR13. LE3 (Plio-Pleistocene); MI91 (probably Upper Miocene)	BATTAGLIA et al. (1976; same symbols)
Alkalic rocks:	FR25, FR1, FR5, FR4, PE4	BATTAGLIA et al. (1976; same symbols)

Mt. Etna

Tholeiites:	VC1, A15, A28, A34, A53	CRISTOFOLINI (1972; an. 1, 2, 3, 7, 4)
	AT1a, AT8, AT13, AT20	CRISTOFOLINI (1975; an. 1a, 8, 13, 20)
	A2, A3	CRISTOFOLINI & PUGLISI (1975; same symbols)
Alkalic rocks:	A21, A5	CRISTOFOLINI & LO GIUDICE (1969; an. 10, 9)
	FE25, FE34, FE43, SP10, SV22	CRISTOFOLINI & SPADEA (1975; an. 6, 1, 15, 16, 12)
	12, 13, 14	CRISTOFOLINI & PUGLISI (1976; same symbols)
	Pd3, Pd12	PUGLISI & TRANCHINA (1977; same symbols)
	ET74	[no major element analysis for this sample; see composition of lavas of the first eruptive stage of the 1974 eruption (BOTTARI et al., 1975)].

TABLE 2 – Trace

Etnean alkalic suite lavas.

	Fe34	SV22	ET74	A5	A21	12	14	15	Pd3	Pd12	SP10	Fe43	Fe25
Rb	40.40	31.20	40.85	40.85	40.40	44.55	44.55	46.00	34.50	48.40	56.40	51.10	56.40
Sr	1200	975	975	987	825	975	1050	1012	1037	1000	875	1112	1062
Cu	81	104	146	55	12	21	39	36	106	132	43	55	43
Ni	32	75	39	14	21	24	40	40	12	46	50	24	34
Cr	73	132	122	45	40	89	63	65	86	83	76	63	63
Co	28	49	38	34	19	28	40	42	21	31	47	29	34
Sc	16.5	31.6	32.9	13.2	10.8	15.12	15.8	15.2	13.5	12.2	17.8	12.6	13.3
Th	14.69	8.36	7.60	14.81	18.25	19.19	20.24	20.74	20.75	17.73	17.10	19.12	18.09
La	90.27	67.13	56.63	85.39	121.57	121.00	120.62	127.55	107.07	114.82	104.96	108.66	110.27
Ce	146.54	108.58	103.87	139.07	213.20	199.19	194.94	207.79	192.51	184.71	159.21	176.05	183.22
Sm	12.14	7.40	8.34	13.19	18.49	12.14	11.84	9.96	11.83	13.34	12.41	15.71	17.50
Eu	3.44	2.93	3.26	3.53	4.58	4.56	4.40	4.67	4.21	3.99	3.63	4.15	5.17
Tb	0.86	1.06	1.27	1.10	1.55	1.35	1.20	1.55	1.33	1.36	1.09	1.3	1.45
Yb	2.6	2.5	4.1	2.4	4.5.	4.0	2.6	3.2	3.0	3.0	2.0	2.3	3.8
Lu	0.33	0.29	0.25	0.28	0.55	0.53	0.58	0.48	0.39	0.45	0.31	0.23	0.52
K %	1.33	1.29	1.61	1.95	2.36	1.89	1.83	1.88	2.03	2.19	1.91	2.03	1.84
K /Rb	328	412	394	477	584	424	410	409	589	453	338	398	327
K /Sr	11.07	13.20	16.52	19.76	20.58	19.41	17.39	18.62	19.61	21.92	21.82	18.29	17.35
S.I.	26.33	32.80	26.64	16.96	14.32	14.71	15.37	15.25	16.05	15.18	16.71	15.00	17.56
M.L.I.	0.50	-2.08	-2.56	2.89	5.33	3.25	3.17	3.42	3.76	3.85	3.43	3.54	3.43

Iblean alkalic suite rocks.

	FR25	FR25	FR1	FR5.	LE4	FR49
Rb	4.68	4.95	4.95	5.50		4.29
Sr	109*	1241	2000	841		684
Cu	111	141	119	92		73
Ni	283	269	246	201		112
Cr	410	475	460	227		160
Co	35	35	47	31		33
Sc	n.d.	29.7	n.d.	23.4		24.0
Th	n.d.	8.48	n.d.	7.41		7.29
La	79.6	100.37	141.1	82.97		49.76
Ce	160.9	176.57	249.5	130.57		85.92
Sm	12.6	12.05	20.0	10.18		8.61
Eu	4.29	4.89	4.20	3.63		3.79
Tb	1.84	1.56	2.27	1.41		1.42
Yb	4.9	3.2	4.4	1.6		2.3
Lu	0.75	0.36	0.90	0.28		0.34
K %	0.44	0.52	0.61	0.66		1.21
K / Rb	1600	991	1059	1258		1198
K /Sr	4.03	4.21	3.03	7.90		17.72
S.I.	45.61	44.59	44.13	34.52		26.63
M.L.I.	-9.60	-8.64	-11.76	-5.14		-2.15

Notes

S.I.: Solidification Index $(MgO / (MgO + FeO_t + Na_2O + K_2O))$.

M.L.I.: Modified Larsen Index $(\frac{1}{3} Si + K - (Ca + Mg))$.

* Values revised relative to those previously reported (Battaglia et al., 1976), after refinement of the technique of reading and correction of the data.

1) Analytical errors are less than 10% for INAA determinations (15% for Yb), and less than 8% for AAS data.

method suggested by ALBINI et al., (1976). Rb, Sr, Cr, Ni, Co, and Cu have been determined by Atomic Absorption Spectrophotometry (AAS) at the Institute of Mineralogy, University of Naples.

Some of the samples from the same areas were analyzed by CARTER and CIVETTA (1977), DUNCAN (1976), and POLI et al., (1977) for elements determined also by us. Their results are generally in good agreement with our data.

The four previously mentioned groups can easily be discriminated also on the basis of their trace element distribution.

There is no evidence for any genetic links between them in the plots of Figs. 3

element data.

	U.S.G.S. rock standards				Iblean tholeiites							
	BCR-1	GSP-1	AGV-1	G-2	MI91	FR14	FR45	FR56	FR38	LE3	FR2	FR13
Rb					2.70	2.70	2.75	2.20	2.75	2.70	2.70	2.70
Sr					506	149	149	182	145	200	136	162
Cu					83	121	110	92	89	92	101	101
Ni					152	185	162	156	177	145	148	161
Cr					190	175	200	310	360	245	165	275
Co					34	25	35	35	30	38	30	34
Sc					20.5	n.d.	23.8	n.d.	24.0	22.6	n.d.	26.1
Th					3.09	n.d.	n.d.	n.d.	-	-	n.d.	0.30
La	25.22	184.17	39.47	96.75	33.18	8.0	9.52	6.6	9.86	11.50	5.4	8.95
Ce	52.49	402.73	62.48	154.54	54.09	21.6	17.86	11.9	22.80	20.83	15.6	24.03
Sm	6.18	24.32	5.77	7.47	5.14	4.2	3.14	3.6	3.35	3.59	3.1	3.23
Eu	2.20	2.66	1.79	1.62	1.96	2.38	1.49	1.61	1.83	1.53	1.24	2.02
Tb	1.15	0.98	0.89	0.41	0.80	0.76	0.69	0.53	0.88	0.93	0.63	0.58
Yb	4.9	1.3	1.1	1.7	2.8	0.8*	2.1	2.2*	2.5	2.9	0.9*	1.8
Lu	0.50	0.23	0.36	-	-	0.50	0.34	0.37	0.18	0.32	0.09	0.26
K%					0.10	0.16	0.16	0.12	0.19	0.22	0.12	0.17
K/Rb					369	584	573	566	694	830	461	615
K/Sr					1.97	10.58	10.58	6.84	13.17	11.21	9.15	10.25
S.I.					38.43	32.78	32.43	32.31	31.89	30.74	28.71	26.84
M.L.I.					-3.27	-1.51	-2.00	-2.31	-1.75	-1.87	-1.25	-1.16

	Etnean tholeiites										
	VC1	A15	A28	A34	A53	A2	A3	AT1a	AT8	AT13	AT20
Rb	7.08	4.45	7.60	7.60	10.08	10.75	14.80	11.26	7.60	10.75	9.00
Sr	325	362	425	440	287	500	500	325	450	537	350
Cu	66	35	48	46	73	83	70	80	107	66	95
Ni	132	175	143	107	143	136	115	166	156	70	101
Cr	203	145	205	175	190	147	125	345	195	105	145
Co	47	59	53	51	51	42	41	47	56	34	36
Sc	26.5	28.0	25.5	29.6	27.9	25.4	27.0	30.6	24.1	29.8	33.1
Th	1.20	1.89	0.47	1.51	2.13	2.75	2.84	1.25	1.84	1.89	1.19
La	18.45	15.50	20.12	22.74	13.84	27.85	26.63	17.32	25.21	47.99	16.03
Ce	36.72	38.01	44.95	49.42	34.25	46.67	50.86	37.56	51.84	76.98	31.25
Sm	4.29	3.88	4.76	5.01	3.72	4.82	4.91	4.03	4.40	6.70	4.15
Eu	2.02	1.59	1.89	2.10	1.75	1.99	2.22	1.87	2.55	2.93	2.10
Tb	1.01	0.91	1.08	0.98	1.03	0.94	1.11	0.55	0.83	1.25	0.84
Yb	2.0	2.4	1.8	2.2	2.7	2.7	2.0	2.5	2.0	1.8	2.9
Lu	0.30	0.27	0.28	0.30	0.27	0.27	0.17	0.43	0.43	0.44	0.29
K %	0.17	0.22	0.25	0.22	0.11	0.52	0.58	0.27	0.27	0.51	0.33
K /Rb	246	503	338	294	107	486	392	243	360	471	368
K /Sr	5.36	6.19	6.06	5.09	3.75	10.46	11.62	8.43	6.09	9.42	9.49
S.I.	37.56	42.10	39.16	34.50	33.10	31.54	32.04	43.70	35.91	30.21	37.12
M.L.I.	-4.23	-6.08	-3.87	-3.93	-3.08	-1.83	-2.11	-4.89	-3.02	-2.83	-4.09

and 4, where they are clearly separated and do not show common trends to different groups.

i) The group of the Iblean tholeiites, with S.I. between 30 and 32, has very low Large Ion Lithophile (LIL) element contents (Light REE included), and abundant transition elements (Ni = 150 − 170 p.p.m.).
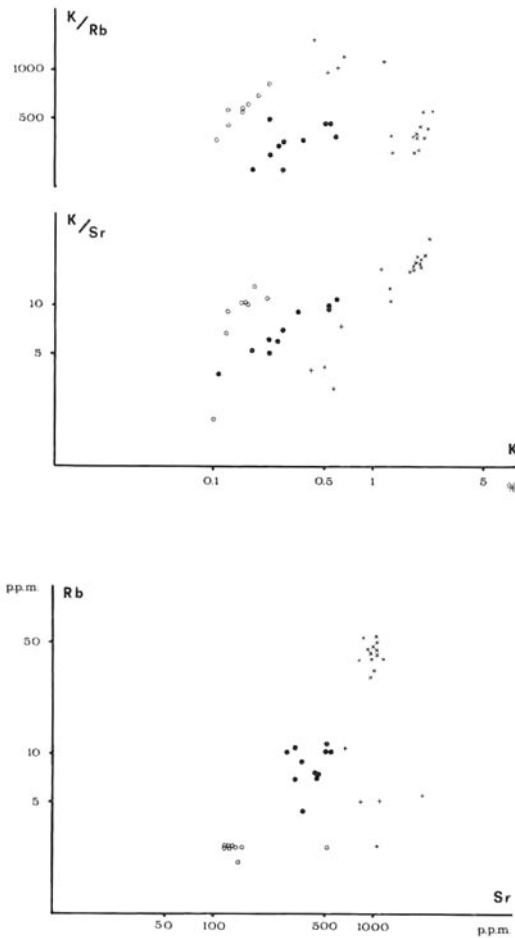
30 up to 45, and show the highest LREE (La = 50-140 p.p.m.) and transition element abundances (Ni = 200-300 p.p.m.).

iv) The Etnean volcanic materials of the alkalic suite have generally low S.I. (< 20) and show high values of LIL element contents (La = 60-120 p.p.m.; Rb = 30-56 p.p.m.) and low contents of transition elements (Ni ≅ 50 p.p.m.).

Iblean Tholeiites.

Some of the geochemical features of these rocks have extensively been examined in a previous paper (BATTAGLIA *et al.*, 1976) pointing out their geochemical homogeneity, with the only exception of sample MI91. This rocks group has very low LIL element abundances (Rb mean value = 2.7 p.p.m.; La = 9 p.p.m.), and shows similarities with some of the Tyrrhenian abyssal plain basalts (BARBERI *et al.*, 1977; DIETRICH *et al.*, 1977). In this group the chondrite norma-
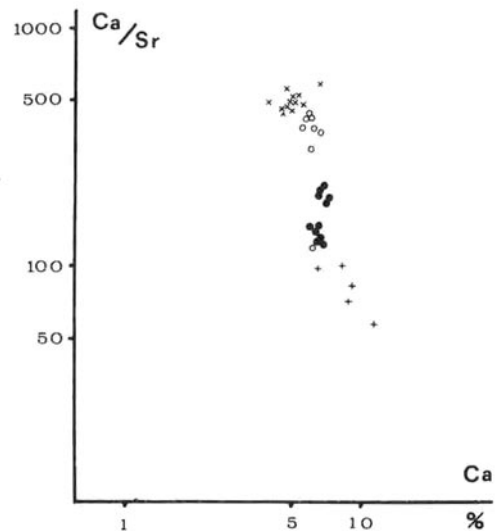
FIG. 3 – The K, Rb, and Sr distribution shows no evidence of a common parent magma for the analyzed rocks, but rather indicates an independent origin for each of the groups.
O: Iblean tholeiites; +: Iblean alkalic rocks; ●: Etnean tholeiites; x: Etnean alkalic suite.

FIG. 4 – In the Ca/Sr vs. Ca diagram the four groups fall in distinct fields not showing obvious genetic relationship among them.
Same symbols as in Fig. 3.

ii) The Etnean subalkaline basalts, with S.I. ranging from 30 to 43, show more abundant LIL elements (especially LREE; La ≅ 20-40 p.p.m.), and slightly lower transition element contents (Ni = 110-150 p.p.m.) relative to the first group.

iii) The Iblean alkaline volcanic rocks are rather heterogeneous, with S.I. from

lized REE distribution patterns (Fig. 6D) show that the LREE contents are intermediate between those of the abyssal and of the ocean island tholeiites ($Ce_N / Yb_N = 2$-3; GAST, 1968). A significant positive Eu anomaly ($Sm_N / Eu_N = 0.6 - 1$) and a rather irregular HREE distribution can also be observed. The transition elements show a limited variation interval in the basaltic compositional range (PRINZ, 1967), displaying a rather weak correlation among each other (Fig. 5; $r_{(Ni/Cr)} = 0.19$), and K/Rb values which are well correlated with K ($r = 0.95$). The Upper Miocene lava (MI91) is less LIL elements depleted than the other Iblean tholeiites and shows affinities with the Etnean subalkaline basalts.

Etnean Subalkaline Basalts

They are distinct from those of the Iblean area chiefly because of their higher LIL element contents – notably LREE (Rb mean value $= 8$ p.p.m.; La $= 30$ p.p.m.). Their chondrite normalized distribution patterns are like those of the ocean island tholeiites (Fig. 6C), but displaced toward alkali basalt patterns ($Ce_N / Yb_N = 3$-6; SCHILLING and WINCHESTER, 1969), generally displaying a positive Eu anomaly ($Sm_N/Eu_N = 0.6 - 1$). The correlation of K/Rb with K is not very high ($r = 0.66$) and anyhow along a trend different from that of the Iblean tholeiites (Fig. 3). K/Sr behaves similarly to K/Rb, but with a much higher correlation with K ($r = 0.93$), while the correlation of Ca/Sr is poor (Fig. 4). Also if the other diagrams are considered (Fig. 5) the analytical data for this group do not show clear trends: the rocks with the most evolved major element chemistry (A2, A3) are nevertheless the richest in LIL and LRE elements, but one sample (A53), which seems rather evolved on the basis of its %SiO_2 and S.I.

FIG. 5 – The La distribution vs. Sm, Ce, Th, and Tb allows define some details of the origin and evolution of the analyzed rocks. See text for discussion.

Same symbols as in Fig. 3.
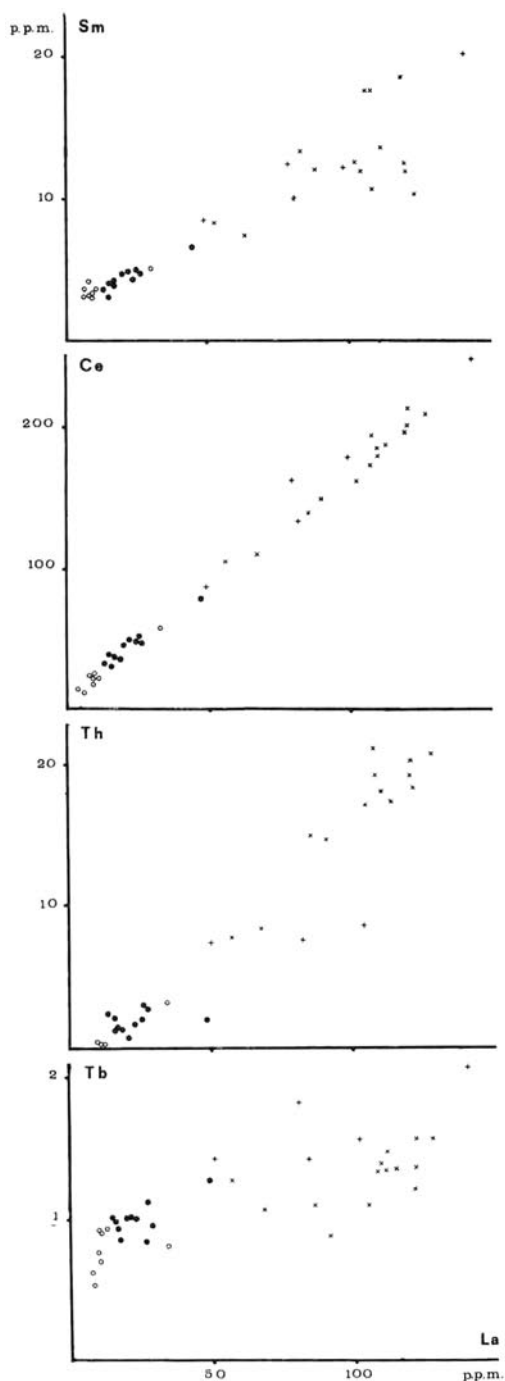
values, is on the contrary among the most depleted in K, La, Sr and fairly rich in Cr and Ni. Another sample (A15), although poor in silica and enriched in magnesia, is significantly richer in some LIL elements and slightly depleted in Cr, with respect to A53.

An analcite dolerite sample (AT13) (CRISTOFOLINI, 1975) shows fairly high concentrations of LIL elements and low Ni and Cr contents; its chondrite normalized REE pattern is intermediate between those of the Etnean subalkaline basalts and of the alkalic suite (Fig. 6).

Iblean Alkalic Rocks

This is not a homogeneous group as these volcanic rocks range from basanites-nephelinites to alkali basalts and hawaiites (CRISTOFOLINI and BATTAGLIA,

1975; ROMANO and VILLARI, 1973), and are dispersed over a wide compositional interval with reference either to their major element chemistry or to their geochemistry. The new REE data agree with those previously known (BATTAGLIA et al., 1976), showing the strongest LREE enrichment in the most undersaturated varieties, while the basaltic types show REE contents in the alkali basalts range ($La_N = 250 - 300$; $Ce_N = 130 - 170$) (GAST, 1968; HUBBARD, 1969).

The Alkalic Suite Rocks from Mt. Etna

The analyzed aphyric lavas are fairly homogeneous with reference to their major element chemistry ($SiO_2 \cong 52$-53%; S.I. $\cong 15$-16), but some trace elements show a rather wide range of their abundances (La = 100-127 p.p.m.; Ni = 40-12

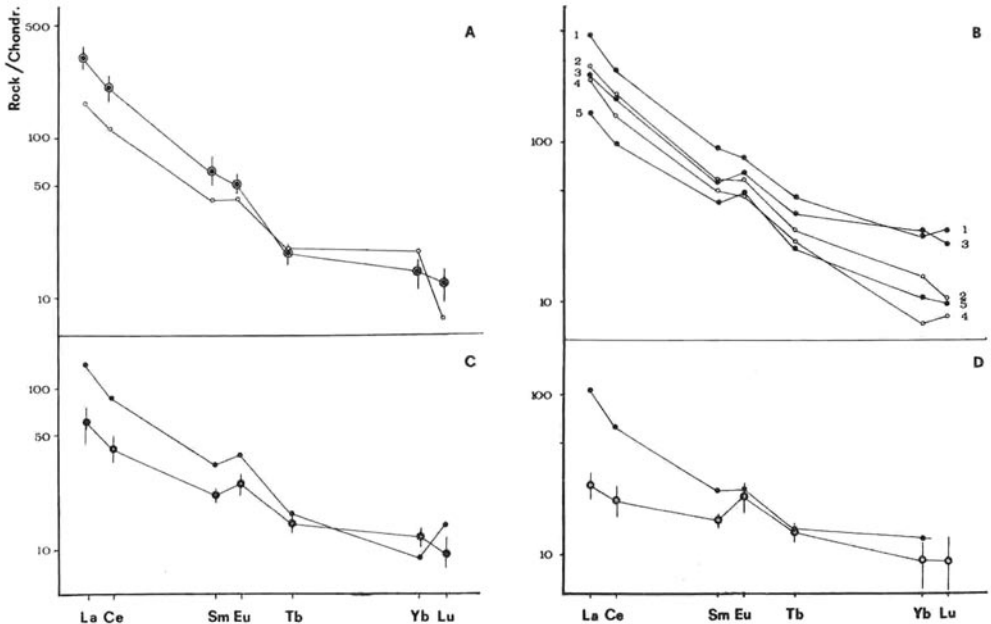
FIG. 6 – Chondrite normalized (NAKAMURA, 1974) REE patterns: A - Etnean alkalic suite; ○ ET74, ● Average values of 12 analyses (bars represent ± 1σ). B - Iblean alkalic rocks; 1 = FR5, 2 = FR1, 3 = LE4, 4 = FR25, 5 = FR49. C - Etnean subalkaline rocks; ● AT13, ● Average of 10 analyses. D - Iblean tholeiites; ● MI91, ● Average of 7 analyses. See text for discussion.

p.p.m.). The LIL elements (LREE included) are concentrated in these rocks, but quite often their binary correlation is not very high ($r_{La/Sm}$ = 0.51; $r_{La/Tb}$ = 0.56 for the whole set of analyzed rocks) and further the computed regression line does not project through the origin. A positive Eu anomaly is apparent in several of the chondrite normalized patterns (Fig. 6A) and the HREE abundances are about in the same range of the other more basic rocks with $Ce_N / Yb_N \cong$ 10-30.

The transition element contents (Ni = 70-10 p.p.m.) are the lowest among those of the other rocks analyzed here, but on the average are higher than in volcanic rocks with a similar major element chemistry (PRICE and CHAPPEL, 1975). Moreover, their abundances are weakly correlated with each other and with %SiO_2, %MgO, and Σ%alk, ($r_{Cr/Ni}$ = 0.62; $r_{S.I./Ni}$ = 0.60).

LREE are as abundant as in the Gough I trachyandesites (FREY et al., 1968), but on the average are more concentrated than in similar rocks from Hawaii (SCHILLING and WINCHESTER, 1969) or from Reunion I (ZIELINSKI, 1975). They are clearly more concentrated in the SiO_2 - enriched rocks (La = 110-120 p.p.m.) than in the most basic rocks (La = 54-64 p.p.m.), while this is not so much clear for HREE (Tab. 2).

DISCUSSION

The trace elements behaviour in the analyzed rocks is particularly relevant for interpreting the relationship within and among the different groups according to the models of the incompatible elements distribution suggested by various authors (GAST, 1968; SHAW, 1970; TREUIL and VARET, 1973). However, no detailed and quantitative interpretation of the data is presented here, owing to the characters of the incompatible element distribution and to the inadequacy of very simplified models to fit the complex nature of actual processes (OTTONELLO and RANIERI, 1977; O'NIONS et al., 1976; YODER 1976). In fact there are instances where contrasting interpretations have been given, even

on the basis of data from the same rocks (KEMPE and SHILLING, 1974; SHILLING, 1973a, 1973b; SHIMIZU and ARCULUS, 1975; TREUIL and JORON, 1975).

It has already been shown that the Iblean volcanic rocks can be interpreted as originated chiefly through different degrees of partial melting of a heterogenous mantle (BATTAGLIA et al., 1976), and that chemical variations within the alkalic suite cannot be on the whole accounted for by fractional crystallization processes. The present data are discussed to show which relations can exist among the volcanic rocks in south-eastern Sicily.

In both the subalkaline suites, K/Rb is correlated with K along two separate subparallel trends. If the incompatible behaviour of these elements in basaltic melts is taken into account, this distribution does not conform either with a crystal fractionation model from a single parent magma, or with different degrees of partial melting from a common source. In the former case the ratio K/Rb should be constant, and in the latter it should change linearly along the same trend in both the suites (TREUIL and VARET, 1973). The actual distribution points toward an origin of the two suites from a heterogeneous mantle, which is also shown by the strong Rb depletion in the rocks of both the Iblean suites (Rb < 10 p.p.m.), contrasting with the higher Rb contents either in the subalkaline (Rb = 10 p.p.m.) or in the alkaline volcanic rocks (Rb > 30 p.p.m.) from Mt. Etna.

Sr behaves like Rb in both the subalkaline suites, but contrary to Rb is definitely more concentrated in the Iblean alkalic rocks, where it attains the highest concentrations (= 2000 p.p.m.) in the strongly undersaturated basanites.

With respect to the REE distribution, the HREE abundance ranges of the different groups overlap widely, showing no systematic variation among them, while the LREE are progressively enriched from the low-K Iblean tholeiites to the alkalic suites of both the Iblean area and Mt. Etna. This again is not suggestive of any unequivocal and simple genetic model that can account for the overall geochemical variation among the analyzed volcan-

ics. The LREE fields of both the alkalic suites form a single trend, and fall in the same area (La/Ce; Fig. 5), but in the Iblean rocks the LREE are increasingly enriched with the silica undersaturation, while in the Etnean lavas their content is positively correlated with the silica content.

The subalkaline basalts from the SW sector of Mt. Etna (Adrano area) do not follow any clearly defined low pressure crystallization path (CRISTOFOLINI, 1972). This has been shown on the basis of their major element chemistry and appears confirmed in the present paper. In these rocks La/Yb spans over a range from 16 to 12, with values mainly clustered between 12 and 14. The average Yb concentration is around 2 p.p.m. According to FREY et al., (1974) this distribution is not consistent with an olivine controlled fractionation. Also, high pressure fractionation with removal of garnet and pyroxene, invoked to explain their major element variation (CRISTOFOLINI, 1972), is severely limited for these lavas if one takes into account the narrow range of Sc contents (= 26 p.p.m.).

Some incompatible elements are distributed in few of the subalkaline volcanic rocks from the SW slopes of Mt. Etna (A15, A53, VC1) with a negative correlation between Ce, La, K, Sr on one side, and Th and Rb on the other which cannot be explained by either crystal fractionation processes, or different degrees of partial melting (GAST, 1968; TREUIL and VARET, 1973). In other subalkaline rocks from Mt. Etna the correlation among all the above mentioned elements tends to be weakly positive: in particular the few samples from the SE sector (Acitrezza), even if showing features that do not allow a detailed interpretation, appear to have been originated by crystal fractionation at shallow depth. Among them the analcite dolerite (AT13) displays a geochemistry intermediate between that of the subalkaline and the alkaline rock suite: on the basis of the geological and petrological data, it could be interpreted as derived from the Acitrezza subalkaline magma through complex differentiation and interaction of magmatic fluids with solutions derived from sea water or wet sediments (CRISTOFOLINI, 1975; WELLS, pers. comm., 1976).

All these facts suggest complex processes for the origin and fractionation of the subalkaline magmas in this region and do not appear conform with the views expressed by TANGUY (1978), who considers all the Etnean volcanic rocks as originated from one single parent magma (olivine tholeiite) through low and/or high pressure crystal fractionation.

The analyzed rocks of the Etnean alkalic suite cannot be taken as representative of the whole series, because of the low number of the mafic highly porphyritic varieties considered in this paper. Nevertheless again the evidence for their derivation from the «olivine tholeiites» (TANGUY, 1978) appears very poor on the basis of the Ca, K, Rb, and Sr distribution (Figs. 3 and 4). In this group the aphyric varieties represent a fairly homogeneous cluster, but many of the LIL elements appear to be weakly correlated in many of the diagrams, and there are some suggestions for the presence of distinct trends. These facts imply that the chemical variation among the various rocks cannot be accounted for by crystal fractionation under constant conditions, as far as the known partition coefficients for the main phases in equilibrium with a basaltic melt are correct also here (DRAKE and WEILL, 1975; HIGUCHI and NAGASAWA, 1969; SCHNETZLER and PHILLPOTS, 1970). Besides, the transition element abundances in these rocks show a poor correlation with any of the common indicators of the fractionation degree (%SiO_2, S.I., La, etc.).

Even the often well defined positive Eu anomaly in relatively fractionated rocks does not indicate a simple model of crystal factionation for interpreting their origin (Fig. 6A). In other volcanoes lavas with similar %SiO_2 and S.I., interpreted as falling along liquid lines of descent (SHILLING and WINCHESTER, 1969; ZIELINSKI, 1975), do not display this feature, and further show a lower LREE content. The Eu abundance is not obviously correlated with Sr and La, inside the group of the Etnean alkalic rocks, even though it is

distinctly higher than in the subalkaline volcanics.

There is no evidence that the Etnean alkalic suite originates from any of the Iblean alkali basalts (see Figs. 3 and 5; *cfr.* La/Sm and La/Tb). An independent mantle source for this group appears then consistent with the present data.

CONCLUSIONS

The trace element data presented here confirm that in south-eastern Sicily four distinct group of volcanic rocks are found: the Iblean low-K tholeiites and alkali basalts to nephelinites, Upper Miocene to Lower Pleistocene in age, on one side; and, on the other, the Quaternary Etnean tholeiites and alkalic volcanic rocks.

The present data show no clear evidence that these rocks have been generated or have evolved from a common source, but rather that they are derived from differerent parts of a heterogeneous mantle. The features of the trace element distribution inside each of the groups do not indicate a simple and detailed model that can account unequivocally for the overall chemical variation.

As far as the Iblean volcanic rocks are concerned no interpretation alternative to that previously suggested (BATTAGLIA *et al.,* 1976) is offered here: a different degree of partial melting of a Rb poor, slightly heterogeneous mantle conforms to the observed trace element distribution and is consistent with the results of Sr isotope analysis (CARTER and CIVETTA, 1977).

Quite distinct source compositions are suggested for the Etnean rocks, compared to those of the Iblean Plateau, by systematically different Rb and Sr abundances and related ratios (Figs. 3 and 4). Our data offer very little support to the idea of an origin of the alkalic Etnean rocks by crystal fractionation either of the subalkaline volcanic rocks of the same region (TANGUY, 1978), or of an alkali basalt magma like those of the Iblean region (Fig. 5).

The correlation of some LIL elements in the subalkaline volcanic rocks from Mt.

Etna could indicate for them an origin from low volume batches that should have been generated under slightly different conditions, and reached the surface through deep tensional fractures during Lower Pleistocene.

In the analyzed Etnean alkaline rocks the weak correlation of many incompatible elements (Fig. 5), the positive Eu anomaly, and the irregular HREE enrichment do not indicate an origin from one definite magma through crystal fractionation under regularly varying conditions along a strictly defined liquid line of descent. The Etnean alkalic suite could have been generated from a set of compositionally different parent magmas, and/or have evolved in a widely variable environment.

The complexity of the geochemistry of the Etnean alkalic rocks reflects that of the tectonic framework in south-eastern Sicily. As a consequence, more data from well defined sections of their sequence are needed for a more detailed petrogenetic model of these magmas.

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