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ΓΕΩΛΟΓΙΑ. – The genesis of the eruptive peraluminous rocks in Greece and their volcanological significance, *by Dem. A. Kiskyras**. Ἀνεκοινώθη ὑπὸ τοῦ Ἀκαδημαϊκοῦ κ. Λουκᾶ Μούσουλου.

ABSTRACT

The building of volcanic peraluminous rocks in Greece is connected with a strong differentiation in small and shallow magma chambers, isolated from the asthenosphere. As a result of such differentiation a residual magma low in Ca, Mg and Fe ($MgO < FeO$) and considerably lower in feldspar content is developed, which with a sediment-water assimilation, essential for the building of hydrous minerals, gives the said peraluminous rocks. The occurrence of peraluminous alkali rhyolites (Antiparos, Kos, Patmos, Samos, Chios, Mytilene etc.) may be considered as the last stage of magma differentiation making the residual magma unable to undergo new eruptions. The finding of some peraluminous dacites with tendency to rhyolite in the area of Methana, Santorini and Nisyros signifies the beginning of the end of these volcanoes.

INTRODUCTION

By the petrochemical analyses of Greek volcanic rocks after the Sawarizki system it is found that 115 samples out of 540 contain an excess of alumina expressed in moles $Al_2O_3 > Na_2O + K_2O + CaO$. According to Niggli, de Lacroix and C.I.P.W.— systems usually applied in the Greek

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papers this alumina excess is as normative corundum reported. This is the case of some samples of rhyolite and dacite of the islands Milos, Chios, Antiparos and Santorini (Ktenas 1935), dacite of Krommyonia (Papastamatiou 1937) rhyolite of Samos (Karageorgiou 1944) rhyolite and dacitoide of Mytilene (Georgalas 1949) dacite of Imbros (Georgalas 1950) rhyolite of Evros (Rentzeperis 1956) dacite of Methana (Davis 1957) andesite of Thessaly (Georgiades 1958) liparite of Nisyros (Davis 1967), liparite of Rhodope (Soldatos 1961) and perlites of Thrace (Vgenopoulos 1977). Such alumina excess is also in eruptive ophiolitic rocks of Pindos establisched by Papayannopoulou (1971) who used the Sawarizki system.

The present study examines the petrochemical differences between peraluminous and non peraluminous rocks and is aiming at the knowledge of the conditions of the peraluminous rocks formation, and the Greek volcanoes future in association with the differentiation process in the magma chambers. For this purpose the Sawarizki system has been chosen instead the other systems because, on the basis of the chemical composition of the volcanic rocks, the mineralogical constitution and its changes during the magma differentiation are graphically presented.

The chemical analyses of the Greek peraluminous Plio-Quartenary rocks used in this paper are listed in table A, whereas table B gives the principal numeral features of the chemical composition of these rocks a, c, b, and s[1] and the magmatic parameters f', m', a', n and q calculated[2], according to Sawarizki system, on the basis of the table A.

The chemical composition of the eruptive rocks is presented graphically in the forme of two vectors projected in the adjoining planes ASB and CSB (rectangular coordinates) of diagramme Fig. 1. The main petrochemical features of the rocks are recognized by the position of the vectors' top point in the plane ASB with coordinates a (abscissa) and b (ordinate) and in the plane CSB with coordinates c (abscissa) and b (ordinate). The secondary features of the rocks are related to the length and the direction of the

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[1] Corresponding to the molar percentage of $2(Na_2O+K_2O)$, CaO, $2(Al_2O_3 - Na_2O - K_2O - CaO) + 2Fe_2O_3 + FeO + MnO + MgO$ and (SiO_2+TiO_2) respectively.

[2] By the formulas $f'=100(2Fe_2O_3+FeO+MnO)/B$, $m'=100MgO/B$, $a'=200(Al_2O_3 - Na_2O - K_2O - CaO)/B$, $n = 100\,Na_2O / Na_2O+K_2O$ and $q = s - (3a+2c+b)$, where $B = 2(Al_2O_3 - Na_2O - K_2O - CaO) + 2Fe_2O_3 + FeO + MnO + MgO$.

TABLE A.

Chemical analyses of the Greek volcanic peraluminous rocks.

	Locality	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O
1	Antiparos Despotico	73.92	0.10	13.08	0.76	0.85	0.07	0.15	1.15	4.01	3.81
2	» Stroggylo	75.83	0.13	12.69	1.03	0.24	0.14	0.14	0.83	4.18	4.22
3	» »	74.00	0.11	11.70	1.16	1.06	0.09	0.28	0.70	2.59	4.08
4	» M. Spyridonisi	74.08	—	11.87	0.16	1.11	0.04	0.08	0.64	3.26	3.72
5	Milos	74.56	0.10	13.47	0.20	0.06	—	0.08	1.47	3.76	3.51
6	»	67.10	0.20	13.40	1.45	0.15	—	1.52	1.86	2.90	4.30
7	»	72.10	0.15	14.25	0.65	0.10	—	0.06	0.37	3.20	4.40
8	» Bombarda	76.56	0.10	13.47	0.20	1.01	0.06	0.08	1.47	3.76	3.51
9	» Kastanas	75.64	0.42	12.81	1.35	0.43	—	0.12	1.68	3.30	3.32
10	Krommyonia Kolantziki	67.34	—	15.96	3.38	0.80	—	0.88	2.38	4.12	1.66
11	» Kalamaki	69.95	—	15.00	1.06	1.45	—	1.25	3.10	3.20	2.85
12	Samos Platanos	78.23	—	11.17	0.26	1.63	—	0.15	0.23	4.12	2.74
13	Chios Ag. Paraskevi	73.92	0.10	13.74	0.62	1.37	0.06	0.61	1.14	3.84	3.91
14	» Pr. Ilias, Emborios	72.80	0.08	15.78	0.10	0.72	0.20	—	0.86	4.69	4.10
15	Patmos Prasovouno	74.70	—	12.38	0.37	0.38	—	0.77	0.86	3.85	3.83

Table A (continued)

	Locality	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O
16	Patmos Cape Tripiti	61.46	0.32	17.88	2.48	1.91	0.14	1.36	2.30	4.01	6.77
17	Kos Coccino Nero	81.72	—	8.51	1.07	0.41	—	0.36	0.38	2.88	2.79
18	» Mt. Latra	74.98	—	11.51	0.37	0.80	—	0.86	0.30	4.03	3.79
19	» Mt. Chephalo	70.08		12.63	0.42	0.96	—	0.43	1.38	3.28	4.26
20	» Mt. Thimiano	75.10		13.08	0.88	0.71	—	0.21	0.96	3.12	5.48
21	Patmos Lefkes	63.25	0.87	16.62	3.96	0.45	0.07	1.39	1.82	3.28	3.45
22	Kalymnos Calino	67.27		16.31	3.13	1.15		0.84	3.48	3.61	2.91
23	Nisyros Perigusa	61.03		20.30	2.03	2.15		2.42	6.41	3.56	1.63
24	W. Thrace Tavri	76.09	0.22	12.45	0.77	0.30	0.04	0.21	0.97	4.25	3.25
25	» Ag. Konstantinos	68.75	0.18	14.83	2.10	1.75	—	0.20	0.20	1.80	7.95
26	» Kayia Dadias	70.13	0.16	12,73	0.52	0.17	0.08	0.40	1.43	2.93	5.45
27	» Madem Levkimi	77.88	—	11.57	0.52	0.13	0.05	0.29	0.71	2.70	3.74
28	Santorini 1925 eruption	65.84	0.83	16.46	1.39	3.80	0.08	0.91	3.50	4.81	1.90
29	» Therasia	65.91	1.03	16.96	1.36	3.47	—	1.13	2.42	4.60	3.08
30	» Pal. Kammeni	65.14	1.12	17.67	1.59	3.33	—	0.95	2.96	5.41	2.18
31	» Georgios Kamm.	64.87	1.02	16.65	1.46	4.21	—	1.42	2.88	5.09	1.87

Table A (continued)

	Locality		SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O
32	Methana	Kosona	62.90	—	18.29	1.79	4.00	—	1.61	5.62	2.91	1.48
33	Mytilene	Kalloni	67.65	—	15.90	1.40	1.60	—	0.85	2.13	2.10	4.40
34	»	Polychnitos	63.98	—	16.70	1.76	0.57	—	1.44	2.80	2.72	4.50
35	»	Daphia	59.10	—	18.37	2.60	3.20	—	3.00	5.50	3.47	1.70
36	Imbros	Arassia	60.33	—	17.60	3.38	2.00	—	2.75	4.30	3.50	2.96
37	Thessaly	Porphyrion	55.36	0.58	19.10	1.76	4.20	0.02	4.44	6.10	2.36	3.64
38	W. Thrace	Levkimi	62.29		16.00	1.66	1.70	0.07	2.95	3.23	2.92	3.74
39	»	Mavropetra Kirki	59.64		16.42	3.07	2.69	0.09	4.11	4.88	2.22	2.93
40	»	Trifili	57.55		17.43	1.87	4.50	0.03	5.19	6.54	2.17	1.40
41	»	Kila-Fere	54.10	0.90	18.65	4.75	2.90	0.06	6.95	5.50	2.35	0.80
42	Patmos	Ag. Thomas	64.20	0.60	17.20	3.0	0.5	0.02	0.7	0.4	2.5	9.6
43	»	Vounari	67.5	0.6	15.3	2.5	0.7	0.03	0.5	0.4	1.9	9.0
44	»	Chondrovouno	69.5	0.3	15.4	1.2	0.2	—	—	0.3	1.5	10.6
45	»	Thermia	69.0	0.3	15.2	1.9	0.2	0.07	—	0.4	0.3	12.3
46	»	Ai Nicolas	65.3	0.7	15.4	3.5	0.4	0.24	1.7	1.4	3.1	5.3
47	»	Prasovouno	71.5	0.3	14.8	0.2	1.8	0.01	—	0.5	3.8	6.3

Table A (continued)

	Locality		SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O
48	Patmos	Vouno tai Giorgi	72.0	0.6	14.6	0.5	0.6	0.02	—	0.5	2.5	7.5
49	»	Apokalypsi	67.0	0.6	16.3	2.5	0.3	0.03	0.6	0.3	2.1	8.3
50	»	Skala	73.0	0.3	14.0	1.2	0.2	0.02	—	0.4	1.4	9.0
51	»	Chochlacas	66.8	0.6	15.0	2.8	0.9	0.02	1.2	0.7	1.7	7.1
52	»	Kastelli	64.2	0.7	15.9	3.6	0.9	0.06	1.1	0.9	2.0	8.4
53	»	Ai Dimitris	67.5	0.3	13.9	3.3	0.4	0.8	0.7	0.6	0.9	8.3
54	»	Evagelistria	65.0	0.6	16.2	3.5	0.4	0.04	0.8	2.1	3.1	5.8
55	»	Panagia Germanou	72.2	0.3	13.3	1.3	0.3	0.02	0.1	0.4	0.4	10.6
56	Samos	Kaminia	78.54	0.62	10.7	0.4	1.9	0.05	0.13	0.10	4.2	2.6
57	»	Pr. Ilias	78.12	0.55	11.5	0.35	1.8	0.05	0.12	0 08	4.65	2.95
58	Milos	Sta Nychia	76.3	0.18	12.75	1.27	—	—	0.26	1.18	3.66	3.18
59	»	»	76.13	0.18	12.95	1.28	—	—	0.26	1.19	3.71	3.33
60	»	»	76.45	0.18	13.0	1.28	—	—	0.27	1.17	3.22	3.29
61	»	»	76.45	0.18	13.0	1.28	—	—	0.27	1.17		
62	»	»	76.35	0.17	12.70	1.25	—	—	0.27	1.15	3.61	3.20
63	»	»	76.24	0.17	12.81	1.26	—	—	0.26	1.20	3.44	3.20

Table A (continued)

	Locality	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O
64	Milos, Demenagaki	76.28	0.22	13.08	1.62	—	—	0.34	1.48	4.20	3.00
65	Patmos, Mt. Giorgios	63.25	0.87	16.62	3.96	0.45	0.07	1.39	1.82	3.28	5.45
66	» Lefkes	63.70	0.56	17.84	2.59	0.80	0.07	1.13	2.09	3.50	5.50
67	» Gheranou	56.48	0.91	19.65	1.29	0.29	0.13	1.57	3.55	1.91	8.96
68	» Mt. Vath (Ag. Ant.)	73.96	0.22	13.40	0.09	0.47	0.08	0.24	0.09	1.53	9.05
69	» Meloi	73.65	0.34	13.05	1.25	0.22	0.10	0.20	—	1.75	7.80
70	» Chondrovouno	66.48	0.35	16.49	1.03	0.83	—	0.31	0.15	1.83	11.05
71	» Meloi	64.31	0.59	16.81	2.46	0.85	—	0.78	0.39	2.02	8.59
72	» Chiliomodi	76.68	0.20	11.80	0.06	0.80	—	0.33	0.70	3.43	4.49
73	» Prassovouno	62.25	0.68	18.36	2.95	0.47	—	0.39	1.39	4.89	6.22
74	Evros, Dhadhia	64.20	0.42	15.54	0.78	0.57	—	0.73	1.28	1.65	4.41
75	» »	65.02	0.18	14.51	0.94	0.64	—	0.73	1.46	2.36	3.58
76		68.24	0.25	13.79	1.00	0.73	—	0.27	1.55	0.63	5.29
77	» »	65.7	0.27	12.6	1.20	0.82	—	0.80	1.64	0.90	4.40
78	» »	68.73	0.28	13.87	0.79	0.56	—	0.37	1.13	1.69	5.09
79	» »	70.01	0.18	14.10	0.84	0.47	—	0.47	0.94	1.78	4.89

Table A (continued)

	Locality		SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O
80	Rhodope		69.03	0.33	14.46	1.24	1.15	0.07	0.94	2.54	3.46	3.86
81			69.12	0.45	14.37	1.39	1.44	0.07	0.92	2.26	3.33	4.00
82	Milos,	Trachylas	75.1	0.08	12.4	0.5	0.3	0.09	0.14	0.8	3.5	4.5
83	»	Phyriplaka	75.3	0.12	12.6	0.4	0.7	0.06	0.8	1.2	4.0	3.0
84	»	Isthmus	70.5	0.2	14.9	1.0	0.9	0.06	0.4	2.5	4.2	3.0
85	»	Chalakas	68.1	0.32	15.2	2.5	0.4	0.02	1.8	1.7	3.2	5.2
86	»	»	61.4	0.5	17.9	3.5	1.2	0.05	1.7	5.4	3.5	1.2
87	Santorini,	Akrotiri	67.74	0.35	14.45	1.07	1.45	0.07	0.89	3.09	2.90	3.19
88	»	»	68.2	0.45	15.10	1.3	1.49	0.07	1.3	2.9	4.2	2.5
89	»	»	69.5	0.45	15.7	1.3	1.56	0.08	1.2	2.9	4.59	2.32
90	»	»	69.2	0.36	13.2		1.42	0.03	0.17	1.47	2.7	3.9
91	»	»	71.7	0.78	13.7		4.47	0.08	0.31	1.40	4.6	2.7
92	»	»	73.6	0.78	14.6		3.22	0.04	0.29	0.96	3.0	2.5
93	Mytilene,	S of Stipsi	75.42	0.22	12.0	0.83	0.70	0.04	0.10	1.30	1.85	5.40
94	»	Ag. Paraskevi	69.65	0.25	15.15	1.35	0.55	0.05	0.35	0.90	3.90	5.70
95	»	Polychnitos	64.55	0.32	15.85	1.85	0.85	0.08	1.40	2.05	3.70	5.15

vectors. The construction of the vectors into the right part is made on the basis of parameters m′ (vertically) and a′ (horizontally in left direction). The vectors into the left part of the diagrammes have been constructed on the basis of the parameter n (vertically) and the number 100-n (horizontally in left direction).

SAWARIZKI'S PETROCHEMICAL DIAGRAMMES

Diagramme Fig. 1, based on Sawarizki's petrochemical data of the table B, refers to all known Greek peraluminous volcanic rocks, whereas diagramme Fig. 2 concerns only the Patmos eruptive rocks independently of peraluminous or non peraluminous rocks. Peraluminous rocks are characterized by the presence of parameter a′, resulting in the left direction of the vectors into the right part (ASB) of the diagrammes Fig. 1 and Fig. 2. Parameter a′ indicates the presence of aluminiferous femic minerals (biotite and amphibole). In the case of non peraluminous rocks parameter a′ nulifies and an other one, the parameter c′ appears, resulting in the right direction of the vectors, see the right upper part of the diagramme Fig. 2. Parameter c′ indicates the presence of calciferous femic minerals.

As the plot of the top point of the vectors depends on the chemical composition of the volcanic rocks, we can on the basis of diagramme Fig. 1 classify the Greek peraluminous rocks among (1) acid andesites and trachyandesites. These are projected into the section laying between the horizontal lines 10 and 20 (2) dacites round the line 10 and (3) trachytes and rhyolites projected into the upper part of the same diagramme above the line 10, i.e. in the space, where rocks more saturated in silica are plotted. Peraluminous rocks are not found among intermediate and basic volcanic rocks, like andesites and basaltes. This is in agreement with the fact that in the peraluminous rocks of the table B, except one, the magmatic number q shows positive values, i.e. non bound SiO_2. This exception regards a sample (No 16) of mica-pyroxene trachyte from Patmos with $q = -0,5$ due to its high alkali content. The acidity of the peraluminous rocks, associated with the lack or at least with the small share of the calciferous molecule in feldspars, resulting in a decrease of the feldspar percentage in the peraluminous rocks, is evident in the indicative plotting of the vectors in the left part (CSB) of the diagrammes Fig. 1 and Fig. 2. The rocks with less calcic feldspar (An) are plotted close to the axis SB.

The plotting of the vectors with the bigger deviation from the vertical direction into the upper part of the ASB diagramme Fig. 1 shows that the more peraluminous rocks are also more acid. This is more evident in the diagramme Fig. 2 (ASB part) where the vectors due to the increase of the alumina excess (high values of parameter a′) are very large and show a remarkable change from the SW to W direction on account of a considerable decrease of the MgO-content. Most of the acid peraluminous rocks are also rich in alkali as indicated by being plotted into the ASB part far from the axis SB

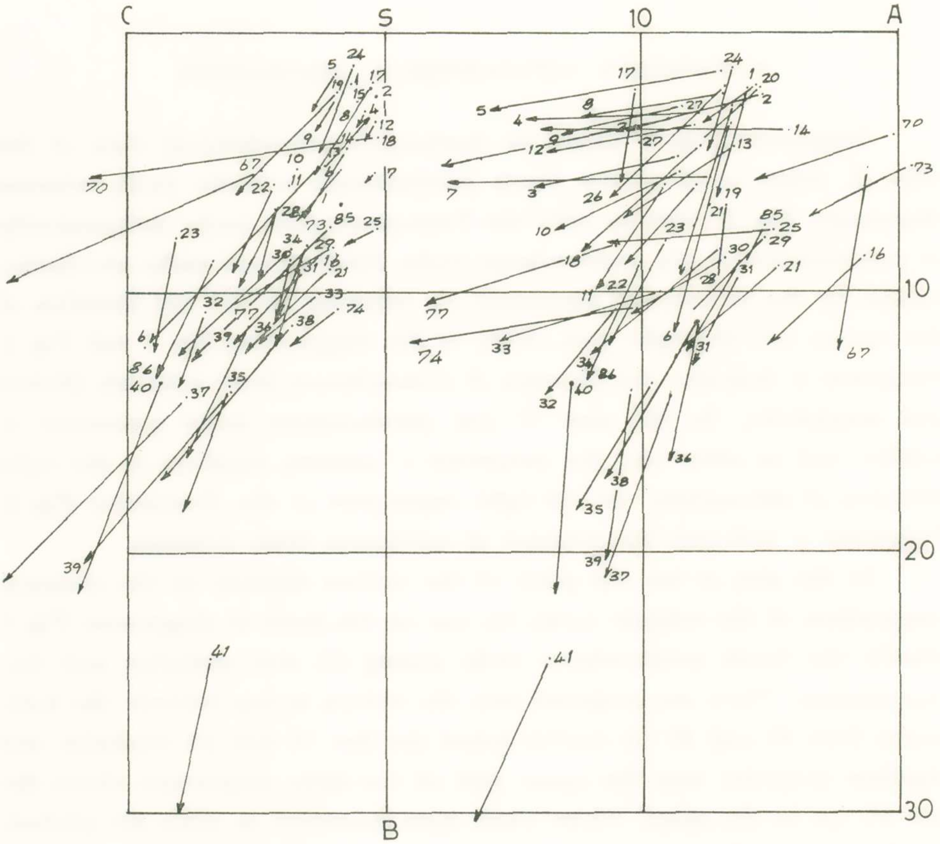

Fig. 1. Petrochemical diagramme (after the Sawarizki system) of the Plio-Quartenary calc-alkalic peraluminous rocks of Greece.

(high values of the magmatic feature a). Some of them contain more potassium than sodium indicated by the bigger deviation of the vectors in the left (CSB) part of the diagrammes Fig. 1 and Fig. 2.

It is of interest to notice that the vectors into the uppermost right part of diagramme Fig. 2, presenting the petrochemical data of the Patmos volcanic rocks, show a right direction, which indicates non peraluminous rocks. This change of the vector direction, associated with saturation of the early existing alumina excess (normative corundum) is due to the presence of calciferous femic minerals, and may be attributed to a small change in the chemical composition of the magma which reflects to the biotite composition.

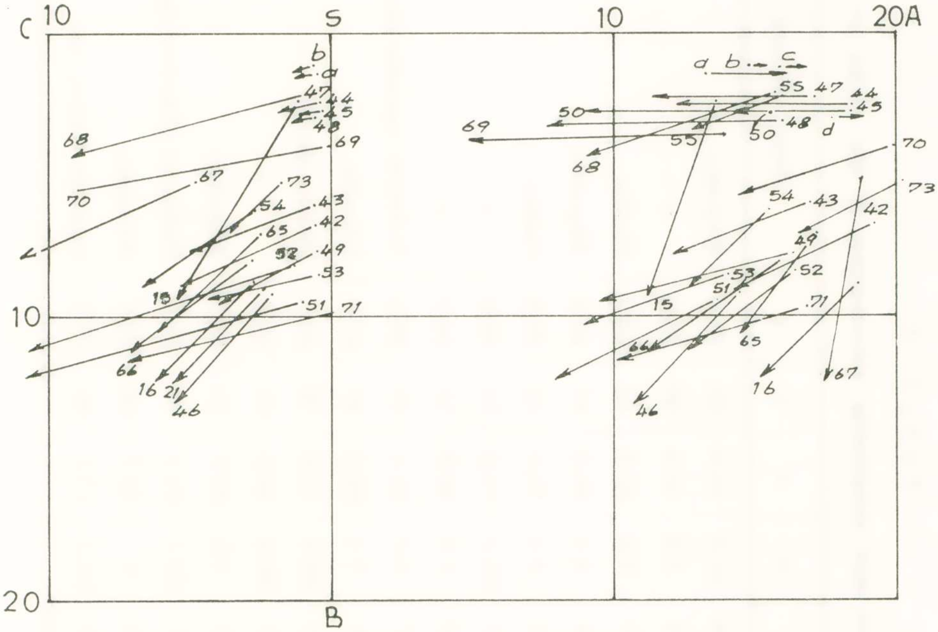

Fig. 2. Petrochemical diagramme of the eruptive rocks of the island Patmos.

According to the values listed in table C, rhyolitic peraluminous rocks show a lower average value of the sum of the principal magmatic features "a" and "c" than the dacitic rocks of the same area. This may be attributed

TABLE B.

Principal numeral features and magmatig parameters of the rocks of the table A.

	a	c	b	s	f′	m′	a′	n	q	Name of rock	Author
1	14.10	1.37	2 09	82.5	71.6	11.8	16.6	62	35.4	Rhyolite	Anastopoulos
2	14.73	0.27	2.35	82.7	49.0	9 8	41.2	60	35.6	»	»
3	11.43	0.84	4.84	82.8	46.6	9.6	47.8	42	42.0	Perlite	»
4	12.48	0.77	3.11	83.6	39.4	4.4	56.2	67	41.6	Rhyolite	Ktenas
5	13.18	1.76	1.43	83.7	16.1	9.4	74.5	62	39 2	Perlite	Bourlos
6	13.15	9.36	4.86	79.6	29.7	55.1	15.2	50	30.6	»	»
7	13.22	0.45	5.44	80.9	11.8	1.9	86.3	52	34.9	»	»
8	12.75	1.71	2.31	83.2	49.7	5.6	44.6	62	39.2	Dellenite (quartz latite)	Ktenas
9	11.62	1.98	2.68	83.6	56.6	7.4	36.0	60	42.0	Liparite	Sonder
10	11.47	3.37	5.26	76.9	44.2	18.0	37.8	78	24.5	Biotite-dacite	Papastamatiou
11	11.09	3.74	5.80	79.3	40.5	36.2	23.3	63	32.7	»	»
12	12.39	0.26	3.23	84.2	52.7	7.5	39.7	70	43.3	Rhyolite	Karageorgiou
13	13.55	1.33	4.30	80.9	42.7	23.2	34.1	60	33.1	Dellenite (Dacite-Liparite)	Ktenas
14	15.66	1.04	3.59	79.8	25.6	0	76.7	68	27 1	Rhyolite	»
15	13.80	1.02	2.38	82.8	28 0	54.3	17.7	60	37 0	Liparite Conci, see	Paraskevopoulos

Table B (continued)

	a	c	b	s	f′	m′	a′	n	q	Name of rock	Author
16	18.63	2.80	8.79	69.8	46.3	26.2	27.6	47	—0.5	Trachyte Conci, see	Paraskevopoulos
17	9.83	0.50	2.14	87.8	65.2	30.8	4.1	61	55.2	Liparite	Bianchi
18	12.63	0.38	4.09	82.9	25.5	34.6	40.0	68	40.2	»	»
19	13.81	1.73	2.29	82.1	59.8	32.8	7.2	54	14.9	»	»
20	14.27	1.12	2.32	88.1	69.9	14.8	15.4	46	34.8	»	»
21	15.29	2.24	9.02	73.45	43.5	26.4	30.1	47	14.1	Quartz Latite	Robert
22	12.13	4.22	6.97	76.68	62.5	20.3	17.2	65	24.9	Dacite, see	Paraskevopoulos
23	10.75	8.21	7.91	73.1	49.6	32.0	18.4	77	25.4	mica Andecite	Bianchi
24	13.62	1.14	1.38	83.9	68.6	24.7	6.7	67	39.5	Liparite	Liatsikas
25	15.2	0.24	7.56	77.0	45.0	4.4	50.6	26	23.3	»	»
26	13.29	1.80	2.19	82.8	32.6	31.9	35.5	39	37.1	Rhyolite	Rentzeperis
27	10.89	0.83	3.35	84.9	17.7	14.1	68.2	52	42.9	»	»
28	13.28	4.24	7.17	75.31	77.1	21.4	1.5	79	19.8	Dacite	Ktenas
29	14.72	2.89	7.97	74.42	54.7	23.5	21.8	70	16.5	Dacitoide Washington, see	»
30	13.52	3.55	8.75	74.18	51.1	18.1	30.8	87	17.8	Andecite »	»
31	13.79	3.47	8.89	73.85	58.4	26.7	14.9	80	16.7	Dacite »	»

Table B (continued)

	a	c	b	s	f′	m′	a′	n	q	Name of rock	Author
32	8.80	7.04	10.62	73.45	51.6	26.4	21.9	75	22.4	Dacite	Davis
33	10.81	2.57	9.97	76.62	34.8	13.3	50.8	42	29.1	Rhyolite	Georgalas
34	13.00	3.50	8.26	75.5	28.9	32.0	39.8	48	21.9	»	»
35	10.44	6.03	13.66	69.8	40.5	38.4	21.1	76	12.8	Dacitoide	»
36	12.36	5.38	11.07	71.10	46.4	43.3	10.3	64	12.1	Dacite	»
37	11.05	7.84	14.13	67.00	41.5	56.5	2.0	50	40.4	Andesite	Georgiades
38	12.07	4.04	11.39	72.50	27.7	44.7	27.6	54	16.8	Dacite	Rentzeperis
39	9.50	6.18	13.74	70.50	39.9	52.6	7.5	54	15.9	»	»
40	7.25	8.48	13.62	70.6	26.5	68.7	4.8	70	18.3	Andesite	Liatsikas
41	6.37	6.74	24.05	62.8	28.8	49.2	22.0	82	6.2	»	»
42	19.35	0.48	6.86	73.3	45.5	17.2	38.3	28	7.4	Trachyte	Panagos
43	17.05	0.48	5.91	76.56	47.4	14.2	38.4	24	18.5	»	»
44	18.52	0.36	2.42	78.69	49.7	0	50.3	18	20.0	Rhyolite	»
45	18.45	0.48	2.76	78.29	67.6	0	32.4	35	19.2	»	»
46	14.46	1.70	2.15	74.69	39.2	31.4	29.4	47	18.8	Trachyte	»
47	17.21	0.60	2.29	79.90	52.6	0	47.4	48	24.9	Rhyolite	»

Table B (continued)

	a	c	b	s	f′	m′	a′	n	q	Name of rock	Author
48	15.98	0.59	2.91	80.51	34.5	0	65.9	34	28.5	Rhyolite	Panagos
49	16.37	0.36	7.78	75.94	31.0	12.9	56.1	28	17.9	Trachyte	»
50	15.69	0.66	2.81	81.03	42.8	0	57.2	19	29.8	Rhyolite	»
51	13.89	0.84	1.46	75.80	33.1	21.3	45.6	27	23.8	Trachyte-dacite	»
52	16.64	1.10	8.29	73.96	47.2	22.5	30.2	13	13.6	Trachyte	»
53	13.98	0.61	8.55	76.86	46.5	13.9	39.7	14	25.2	Trachyte-dacite	»
54	15.48	2.60	6.20	75.72	55.9	22.2	21.9	45	17.9	»	»
55	16.04	0.48	2.16	81.33	64.7	7.8	27.5	55	30.1	Rhyolite	
56	12.19	0.12	3.49	84.20	59.0	5.9	35.1	71	42.9	Rhyolite	Karageorgiou
57	13.71	0.09	2.89	83.39	69.6	6.0	23.5	71	39.2	»	»
58	11.90	1.38	3.34	83.38	31.3	12.7	56.0	65	41.6	Obsidian	Shelford
59	11.87	1.38	3.35	83.40	31.1	12.6	56.3	61	41.7	»	»
60	8.72	1.36	6.68	83.24	15.6	6.6	77.8	48	47.7	»	»
61	11.89	1.35	3.52	83.24	29.4	12.5	58.1	60	41.4	»	»
62	12.10	1.34	3.00	83.53	33.8	14.5	51.6	63	41.6	»	»
63	11.75	1.40	3.39	83.45	30.2	12.6	57.3	62	42.0	»	»

Table B (continued)

	a	c	b	s	f′	m′	a′	n	q	Name of rock	Author
64	13.00	1.60	2.40	83.00	55.4	22.8	21.7	68	38.4	Obsidian	Shelford
65	17.21	2.47	7.03	73.28	49.5	28.0	22.5	46	9.7	Quartz Latite	Robert
66	15.83	2.57	8.12	73.48	37.7	23.7	38.5	49	12.7	»	»
67	18.86	4.74	5.10	71.29	32.3	57.1	10.6	24	0.1	Latite (Trachyte potassic)	»
68	16.0	0.11	2.19	81.71	26.7	18.2	55.1	20	31.3	Rhyolitoide	»
69	14.73	0	3.62	81.65	36.8	0.9	62.3	25	33.8	»	»
70	20.05	0.18	3.89	75.88	43.9	13.5	43.2	20	11.5	Trachyte	»
71	16.86	0.05	9.72	73.38	29.8	13.6	56.6	26	13.0	»	»
72	13.57	0.82	1.36	84.25	57.5	39.6	2.9	54	40.5	Rhyolitoide	»
73	20.21	1.73	5.16	72.89	58.8	13.1	28.1	55	3.6	Trachyte sodapotassic	»
74	10.52	1.64	10.65	77.19	11.9	12.2	75.9	36	31.7	Ignimbrite - Perlite	Vgenopoulos
75	11.01	1.88	8.62	78.49	17.4	15.2	67.4	50	33.1	» »	»
76	9.40	1.95	7.94	80.71	20.3	6.0	73.7	15	40.7	Perlite	»
77	8.98	2.14	8.27	80.61	23.4	17.6	59.0	24	41.1	»	»
78	12.94	1.41	5.18	80.46	24.1	12.4	63.5	30	33.6	»	»
79	12.44	1.15	6.22	80.19	18.9	12.9	68.2	32	34.4	»	»

Table B (continued)

	a	c	b	s	f′	m′	a′	n	q	Name of rock	Author
80	13.33	3.12	4.08	79.47	55.0	39.3	5.7	58	29.2	Liparite	Soldatos
81	13.17	2.76	4.81	79.26	54.8	32.4	12.8	56	24.4	»	»
82	13.94	0.96	1.42	83.68	55.2	16.5	28.3	54	38.5	Biotite-Liparite Burri	Soptrajan.
83	12.69	1.41	3.10	82.78	33.2	42.1	24.7	67	38.8	Plagioliparite »	»
84	13.65	3.05	2.72	80.58	65.5	24.9	9.6	68	30.8	» »	»
85	14.68	2.08	7.28	75.96	35.2	42.1	22.7	48	21.5	Rhyodacite »	»
86	9.97	6.94	8.90	74.19	49.5	34.1	16.3	82	21.5	Amphibole dacite »	»
87	11.42	3.90	4.86	79.82	50.4	32.2	17.4	58	32.9	Dacite	Nicholls
88	12.94	3.55	5.10	78.41	51.0	43.3	5.6	72	27.4	»	»
89	13.24	3.47	5.12	78.17	51.2	39.1	9.7	75	26.4	»	»
90	12.01	1.85	4.31	81.82	33.1	6.9	60.0	51	37.8	»	»
91	13.58	1.65	5.54	79.23	75.4	9.2	15.4	72	22.6	hyalodacite	»
92	9.61	1.10	9.92	79.37	33.5	5.3	61.2	65	38.4	»	»
93	11.68	1.56	2.55	84.21	54.5	6.6	38.9	34	43.5	Rhyolite	Georgalas
94	16.69	1.09	3.54	78.68	48.6	16.6	34.8	51	22.9	Phanerotrachyte	Prager
95	11.06	2.57	5.6	75.77	45.2	43.5	11.3	52	16.8	Ignimbrite	»

to the fact that by differentiation of magma the feldspathic-alkalis increase does not counterbalance the simultaneous feldspathic-lime decrease, resulting in a decrease of the feldspar content of the residual magma. Thus, the average "a+c" value of the Evros peraluminous rocks is reduced from 15.89 in dacites to 12.37 in rhyolites, due to the decrease of the "c" average value from 5.11 to 1.65, which corresponds to a decrease of 68%, whereas the "a" average value increases from 10.78 to 11.18, which means an increase only of 3.7%. This view is supported by the data included in papers of other authors concerning the normative constitution of Greek volcanic rocks. Thus, in the case of Evros rocks the An-value 17.84 in dacites is reduced to 6.34 in rhyolites, i.e. a decrease of 64.5%, whereas the Or + Ab value increases from 41.41% to 43.76%, i.e. only of 5.7%.

On the other hand the values listed in table C indicate that the average feldspar content in peraluminous rocks usually is less than the corresponding content in non peraluminous rocks. Though, it should be noted that the average feldspar content for the 10 Patmos peraluminous rocks is higher than that of the 8 non peraluminous rocks. This conclusion is questionable, given that the "a+c" average value of the 10 peraluminous rocks is 18.35, whereas the average "a+c" value of the 8 non peraluminous rocks is 20.21. This means that according to the Savarizki system the peraluminous rocks of Patmos contain less feldspar that the non peraluminous.

As both, peraluminous and non peraluminous, rocks of the same district derive from the same magma, it is expected that any difference in the trace elements will be in quantity and not in composition. Thus, as is known potassium content increases with silica, the SiO_2—rich rocks, peraluminous and non peraluminous, are rich also in K_2O. Therefore, it is expected (Kiskyras 1967, p. 306) that the alkali rhyolites to be rich in cesium (Cs) and rubidium (Rb) with high ionic radius $r = 1,65$ and $r = 1.49$, and with low ionic potential $I = 0,61$ and $I = 0,67$, respectively. New trace element analyses (Puchelts - Hoefs, 1970) have proved that acid calc-alkaline rocks from Santorini are richer in Rb than andesitic rocks. Generally speaking the peraluminous rocks, which are on the average richer in SiO_2 and poorer in CaO than the non peraluminous, are also expected to be richer in Rb and poorer in Sr than the non peraluminous rocks.

TABLE C.

Feldspar content of calc-alkalic peraluminous and non-peraluminous rocks in Greece. The listed values of Or+Ab+An are based on the known normative analyses, excluding tuffs and bentonites.

Locality	Rock types	Peraluminous rocks						Non-peraluminous			
		a+c	c	Or+Ab +An	An	K_2O	Average of	Or+Ab +An	An	K_2O	Average of
Antiparos	Rhyolite	13.99	0.81	56.85	2.57	3.97	4 Analyses	62.84	2.88	4.83	12 Analyses
Chios	»	15.79	1.19	62.56	6.12	4.01	2 »	64.26	9.24	2.3	3 »
Samos	Rhyolitoide	12.92	0.16	53.22	0.37	2.76	3 »	58.03	23.02	1.63	7 »
Evros area	Rhyolite	12.78	1.60	50.1	6.34	4.57	8 »				
»	Dacite	15.89	5.21	59.25	17.84	3.34	2 »				
»	average	13.96	3.1	51.90	8.64	4.33	10 »	59.66	20.89	2.29	4 »
Mytilene	Rhyolite	14.74	2.48	56.39	9.36	4.77	3 »				
»	Dacitoide	16.47	6.03	56.30	10.96	1.7	1 »				
»	average	14.90	3.73	56.37	10.78	4.00	4 »	64.94	18.48	3.23	20 »

Table C (continued)

Locality	Rock types	Peraluminous rocks						Non-peraluminous			
		a + c	c	Or+Ab +An	An	K_2O	Average of	Or+Ab +An	An	K_2O	Average of
Patmos	Rhyolitoide	15.1	0.31	62.29	1.3	7.88	3 Analyses				
»	Quartz lat.	18.54	2.43	69.90	8.33	5.77	3 »				
»	Latite	20.67	1.68	80.06	6.05	8.7	4 »				
»	average	18.35	3.73	71.84	5.32	7.34	10 »	69.36	14.45	4.75	8 Analyses
Milos		14.05	1.85	57.33	7.93	3.42	2 »	60.54	15.85	2.51	9 »
Rhodope	Liparite	16.19	2.94	66.85	11.45	3.93	2 »	69.84	23.52	2.95	9 »
Sousaki	Dacite	14.84	3.55	58.84	14.58	2.26	2 »	62.43	19.28	3.16	4 »
Porphyrion (Thessaly)	Andesite	18.89	7.84	69.99	27.66	3.64	1 »	72.12	20.13	3.36	8 »
Nisyros	Andesite	18.96	8.21	71.53	31.69	1.63	1 »	68.57	19.20	2.14	19 »
Santorini	Dacite-Andes.	15.57	2.97	63.29	11.71	2.42	10 »	65.1	19.74	1.77	40 »
Methana	Dacite	15.84	7.04	64.5	28.5	1.48	1 »	67.46	27.94	1.79	10 »

TABLE D.

Geographical distribution of the peraluminous calc-alkalic speciments in Greece.

Locality	Number of samples			Locality	Number of samples		
Patmos	26	out of	51	Mytilene	26*	out of	99
Kos	4	»	17	Lemnos	0	»	14
Kalymnos	1	»	3	Ag. Eustratios	0	»	7
Nisyros	1	»	20	Imbros	1	»	10
Yali-Tilos				Chios	2	»	5
Pserimos etc.	0	»	10	Samos	3	»	8
Antiparos	4	»	16	Euboea	0	»	10
Milos	17	»	50	Lichades	0	»	26
Antimilos	0	»	8	Thessaly	1	»	20
Santorini	10	»	96	N. Sporades	0	»	2
Methana	1	»	12	Evros	4	»	8
Poros - Aegina	0	»	9	Dhadhia Thrace	6	»	6
Sousaki/Kromm.	2	»	6	Feres Thrace	4	»	8
Psara - Kaloyeri	0	»	2	Almopia	0	»	8
				Rhodope	2	»	9
	66		300		49		240

* 20 chemical analyses of peraluminous rocks taken from the paper of Pe-Piper (1979) have been not listed in the table A and their magmatic features are not included (table B) in onder to ltmit the lenght of the paper.

DISCUSSION AND INTERPRETATION

According to the formula $Al_2O_3 > Na_2O + K_2O + CaO$, the formation of peraluminous calc-alkalic rocks will be related either to the increase of the first term of the inequility or to the decrease of the second term. As peraluminous rocks are usually rich in alkali the question here concerns especially the CaO. Decrease of the CaO content of the volcanic rocks takes place under normal conditions of magma differentiation, i.e. by fractional crystallization, associated with increase of their SiO_2 content. Besides, as Fig. 3 shows, the SiO_2 increase in the Greek peraluminous rocks is associated with a decrease of their Al_2O_3 content. Thereafter, the formation of peraluminous volcanic rocks will be favoured only in the case, where CaO decreases more rapidly than Al_2O_3.

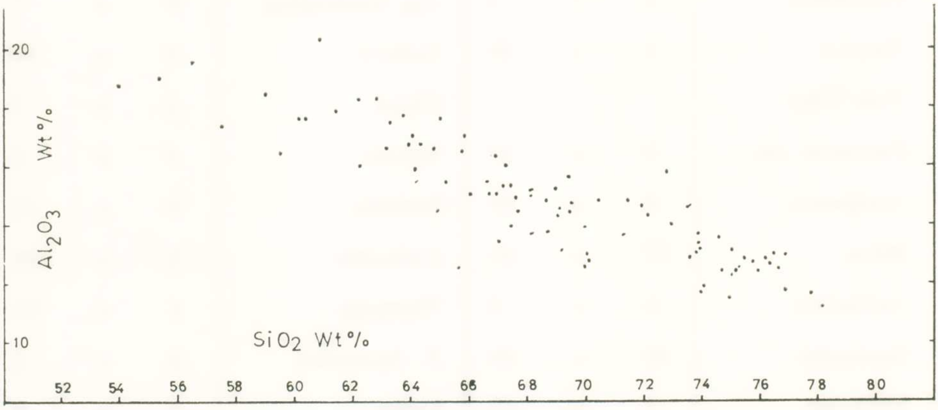

Fig. 3. Diagramme showing that the SiO_2 increase of the Greek peraluminous rocks is associated with ad Al_2O_3 decrease

Congruent with the table A, the alumina content of the peraluminous rocks varies from 8,51% (sample No 17) to 20.3% (s. No 23). It is known (Akella 1974) that weight percentage of Al_2O_3 in orthopyroxene coexisting with clinopyroxene decreases as the pressure increases. Such a decrease of the Al_2O_3 content with increasing pressure is also found in the case of orthopyroxene coexisting with olivine and spinell (MacGregor's results, cited by Fujii 1975). On the other hand CaO content in peraluminous rocks varies from 0.13% (s. No 56) to 6.41% (s. No 23). The molar ratio Al_2O_3/CaO

varies from 38.3 (s. No 56) to 1.74 (s. No 23) which indicates that the ratio Al_2O_3/CaO depends on still more factors e.g. on the presence of MgO, as Fig. 4 shows, which contributes in the chemical composition of the aluminiferous minerals, biotite and amphibole. It is of interest to notice that peraluminous rocks with $Al_2O_3/CaO < 1.62$* have not been found in this area. However many samples of Nisyros, Santorini etc. with a ratio $Al_2O_3/CaO =$

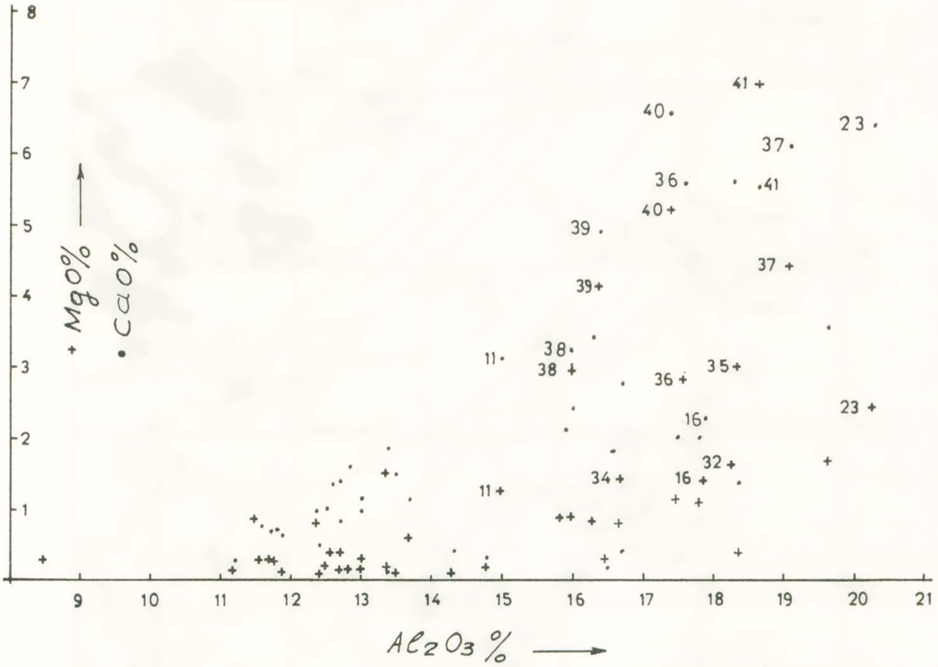

Fig. 4. Diagramme of the MgO and CaO change versus the Al_2O_3 content of the Greek peraluminous rocks.

$= 2.64$ to 8.9 are non peraluminous. In this way may be explained the pausity of peraluminous rocks with a SiO_2 content from 54 to 62 % and from 70 to 72.

Taking into consideration that the Greek peraluminous rocks (1) are connected with strongly differenciated magma (2) contain hydrous minerals (3) have a smaller feldspar content than non peraluminous rocks and

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* Basalt from Lesbos island.

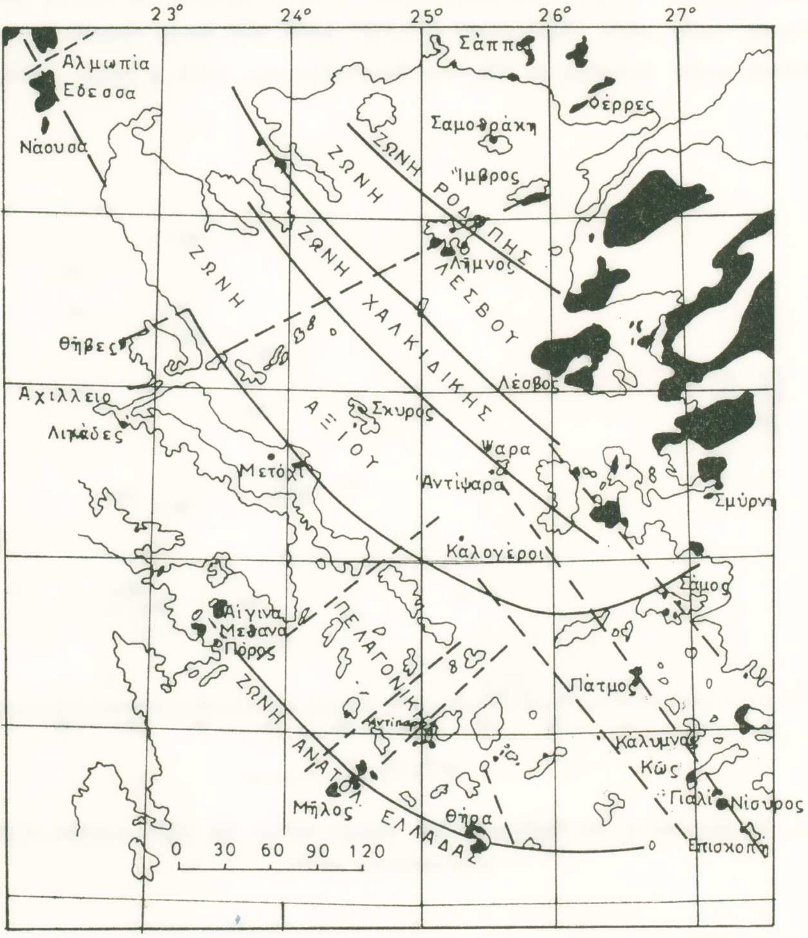

Fig. 5. Map showing the andesitic volcanoes in the Aegean area (black blots).

(4) that the feldspar content of magma can increase under elevated water pressures (Yoder 1969) we suggest that the peraluminous rocks in Greece are formed in small magma chambers close to the earthsurface and isolated from the asthenosphere (Kiskyras 1982, 304). In these places was possible the magma to be strongly differenciated under lower pressures and further to assimilate water and probably other materials of the geosyncline, essential for the building of hydrous minerals, as the potassium bearing biotite and the amphibole (Kiskyras 1964 and 1968, Kiskyras and Papayannopoulou - Economou 1982 and Kiskyras 1982). The above is supported by Kuno's view (cited by Kushiro and Yoder) that the origin of the peraluminous calk-alkalic andesites and dacites in Japan may be attributed to assimilation of argilaceous sediments or gaseous tranfer of alkali elements.

CONCLUSIONS

According to the above, peraluminous alkali rhyolites of Antiparos, Patmos, Kos and Mytilene with $MgO < FeO$, (all Fe as FeO) and $K_2O > Na_2O$ may be considered as characteristics of the last stage of magma differentiation. The same can be said for the rhyolites of Chios and Samos, where the residual magma, even close to the earthsurface, is supposed (Kiskyras 1974) to be unable to undergo new eruptions.

Consequently, it is suggested that the appearance of paraluminous alkali rhyolites from a volcano signifies the end of its volcanic activity. Thereafter, from this volcano only a postvolvanic activity may be expected in forme of fumaroles. On the contrary, andesitic volcanoes, as those of Methana, Santorini and Nisyros, are associated with a magma, able to undergo a further differentiation, resulting in new eruptions. However, the occurrence of some peraluminous dacites with tendency to rhyolite in this area led us to suppose that the magma below these volcanoes already has started to loose its activity, due to high differentiation, which means that the volcanic activity also of Santorini will be very limited in the future.

ΠΕΡΙΛΗΨΗ

Κατὰ τὴν πετροχημικὴ ἐξέταση μὲ τὸ σύστημα Sawarizki 540 περίπου χημικῶν ἀναλύσεων ἡφαιστειακῶν πετρωμάτων τοῦ Πλειο - Τεταρτογενοῦς διαπιστώθηκε ὅτι τὰ 115 εἶναι ὑπεραργιλικά, δηλαδὴ σὲ μοριακὲς ἀναλογίες $Al_2O_3 > Na_2O + K_2O + CaO$. Αὐτὰ προέρχονται ἀπὸ τὸ Σουσάκι - Κρομμυωνίας, Μέθανα, Μῆλο, Ἀντίπαρο, Σαντορίνη, Νίσυρο, Κῶ, Κάλυμνο, Πάτμο, Σάμο, Χίο, Μυτιλήνη, Δυτ. Θράκη (Φέρρες) καὶ Ροδόπη. Στὶς περιπτώσεις αὐτὲς πρόκειται γιὰ ὄξινα πετρώματα, ὅπως ρυολίθους (λιπαρῖτες, περλῖτες, ὀψιδιανοὺς) δακῖτες, ὄξινους ἀνδεσῖτες, τραχεῖτες καὶ τραχειανδεσῖτες. Τοῦτο σημαίνει ὅτι τὰ ὑπεραργιλικὰ πετρώματα σχηματίσθηκαν, ὅταν τὸ μάγμα εἶχε ἤδη ὑποστεῖ ἔντονη διαφοροποίηση (κλασματικὴ κρυστάλλωση) καὶ μάλιστα μὲ αὔξηση μέχρι ὑπερκορεσμὸ τοῦ SiO_2 καὶ σημαντικὴ μείωση τῶν Ca, Mg καὶ Fe, ἔτσι ὅμως ὥστε $MgO < FeO$, ὅπου τὸ FeO ἐκφράζει τὸν ὁλικὸ σίδηρο καὶ ἐπὶ πλέον μείωση τοῦ ποσοστοῦ ἀστρίων (Or+Ab+An) ἀπ' ὅ,τι στὰ ἀντίστοιχα μὴ ὑπεραργιλικὰ πετρώματα. Στὸ σχηματισμὸ τῶν πετρωμάτων αὐτῶν συνέτεινε καὶ ἡ ἀπορρόφηση ἀπὸ τὰ γύρω ἰζήματα H_2O, ἀπαραιτήτου γιὰ τὴ δομὴ τῶν ἐνύδρων ὀρυκτῶν, βιοτίτη καὶ κεροστίλβης, ποὺ συνοδεύουν τὰ ὑπεραργιλικὰ πετρώματα. Κατάλληλες συνθῆκες γιὰ τὸ σχηματισμὸ τῶν πετρωμάτων αὐτῶν παρουσιάζονται σὲ μικροὺς μαγματικοὺς θαλάμους, ποὺ βρίσκονται σὲ μικρὸ βάθος κάτω ἀπὸ τὴ γήινη ἐπιφάνεια.

Ὁ σχηματισμὸς ὑπεραργιλικῶν πετρωμάτων, πλουσίων σὲ ἀλκάλια καὶ μάλιστα σὲ σχέση mol $K_2O > Na_2O$ πρέπει νὰ θεωρηθεῖ, ὅτι ἀντιπροσωπεύει τὸ τελευταῖο στάδιο διαφοροποίησης μάγματος, ὁπότε τὸ μάγμα, ποὺ ἔχει παραμείνει στὸ θάλαμο, δὲν μπορεῖ νὰ ὑποστεῖ ἄλλη διαφοροποίηση, ποὺ σημαίνει ἀπώλεια τῆς ἐκρηκτικῆς ἱκανότητας. Συνεπῶς ἡ παρουσία ὑπεραργιλικῶν ἀλκαλικῶν ρυολίθων σὲ περιοχὴ ἡφαιστείων π.χ. Ἀντιπάρου, Πάτμου, Κῶ, Σάμου, Χίου καὶ Μυτιλήνης, πρέπει νὰ θεωρηθεῖ ὡς ἡ τελευταία ἡφαιστειακὴ ἐκδήλωση, τὴν ὁποία ἀκολουθεῖ μεταηφαιστειακὴ δράση (ἀτμῖδες). Ἀντίθετα, οἱ μαγματικοὶ θάλαμοι, ποὺ τροφοδότησαν τὰ ἡφαιστειακὰ κέντρα τοῦ ἡφαιστειογενοῦς τόξου τοῦ Ν. Αἰγαίου, περιέχουν ἀνδεσιτικὸ μάγμα, ποὺ μπορεῖ νὰ ὑποστεῖ καὶ ἄλλη διαφοροποίηση καὶ νὰ δώσει νέες ἐκρήξεις. Ἡ ἐμφάνιση ὅμως στὴν περιοχὴ τοῦ τόξου αὐτοῦ ὑπεραργιλικῶν δακιτικῶν πετρωμάτων μὲ τάση πρὸς ρυόλιθο σημαίνει ὅτι καὶ ἐκεῖ ἔχει ἀρκετὰ προχωρήσει ἡ διαφοροποίηση. Συνεπῶς, τὸ μάγμα τῆς περιοχῆς αὐτῆς, ἀκόμα καὶ αὐτό, ποὺ βρίσκεται κάτω ἀπὸ τὰ ἐνεργὰ ἡφαίστεια Μεθάνων, Σαντορίνης καὶ Νισύρου, ἔχει ἀπὸ καιρὸ ἀρχίσει νὰ χάνει τὴν ἐκρηκτική του ἱκανότητα. Ἔτσι, οἱ ἐκρήξεις τῆς Σαντορίνης θὰ εἶναι πολὺ περιορισμένες στὸ μέλλον, ἀφοῦ τὸ τέλος τοῦ ἡφαιστείου της ἔχει ἤδη σημάνει.

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