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Petrology of Some Volcanic Rock Series of the Aeolian Arc, Southern Tyrrhenian Sea: Calc-Alkaline and Shoshonitic Associations

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Abstract. In the Aeolian island arc two different magmatological associations, calc-alkaline andesite series and shoshonites, occur in close vicinity. Although both associations erupted simultaneously during the last glaciation, there is a general tendency for the calc-alkaline rocks to be older. Shoshonitic activity is still going on.

Calc-alkaline lavas include high-Al basalts, andesites and dacites, with the general characteristics of the island-arc type andesite series. Large cation trace elements (Rb, Ba, Sr) however are distinctly enriched.

Shoshonite series include trachybasalts and latites, with which potassium-rich rhyolites can be associated. Leucite tephrites and potassic trachytes form a different evolution trend of the shoshonitic association.

Petrology relates both associations of the Aeolian Islands to the island arc dynamics which is presently characterized by deep-focus earthquakes in the depth range of 200–350 km. The present-day gap in seismic activity from 50–200 km coincides with the present-day lack of calc-alkaline volcanic activity and is explained by the model of a detached slab which continues to sink into the mantle.

Introduction

The seven Aeolian Islands—Lipari, Salina, Vulcano, Stromboli, Panarea, Filicudi and Alicudi—form a volcanic archipelago in the southern Tyrrhenian Sea near the north Sicilian continental slope (Fig. 1). For the floor of the Tyrrhenian abyssal plain, oceanic crust is postulated (Ryan *et al.*, 1970). Underneath the Aeolian Islands, sialic crust is evidenced by xenolites in the volcanic rocks (Honnorez and Keller, 1968). Equally in the central Tyrrhenian Sea, sialic crustal rocks were dredged from some faulted blocks (Heezen *et al.*, 1971). These are interpreted as remnants of the Tyrrhenian landmass which existed until upper Tertiary times. Ritsema (1969) discusses the oceanization of a formerly continental domain for the Tyrrhenian region. Recently, the Tyrrhenian abyssal plain has been considered a marginal sea in the sense of plate tectonics (Menard, 1967; Boccaletti and Guazzone, 1972; Barberi *et al.*, 1973). Basalt characteristics of Marsili seamount (Keller and Leiber, 1974) so far cannot serve as a support for this model.

The Aeolian Islands have to be considered an island arc structure (Caputo *et al.*, 1972; Ninkovich and Hays, 1971). Seismic and tectonic interpretations thus support the magmatological results, which indicated that on the islands, very clearly on Salina (Keller, 1966, 1967) and Filicudi (Villari, 1972), typical andesites of the calc-alkaline clan as in circumpacific island arcs were erupted.

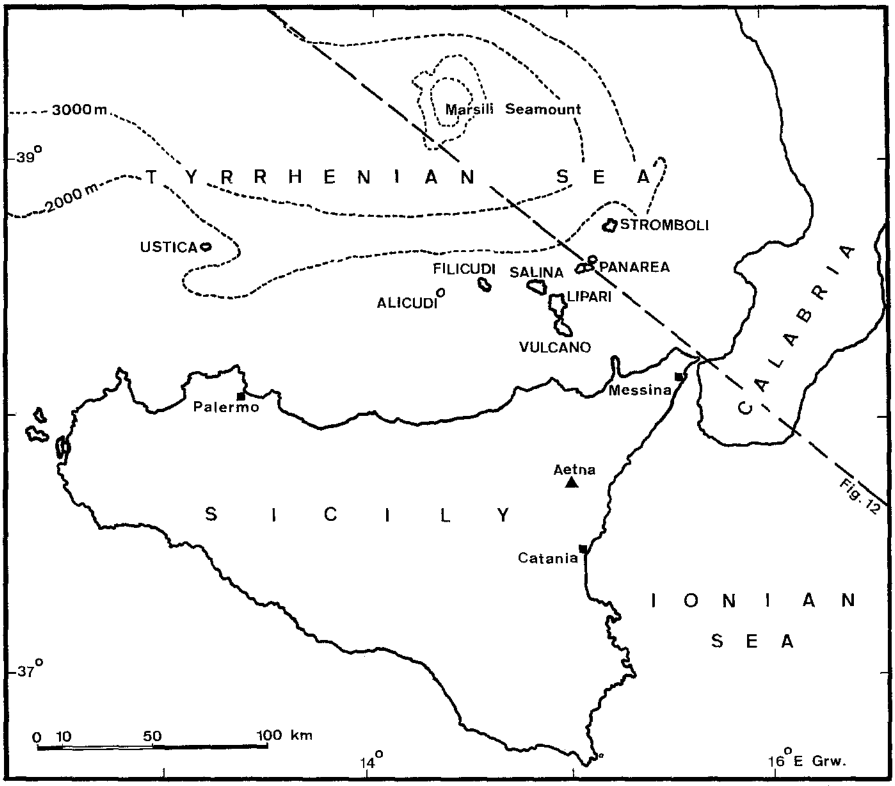

Fig. 1. Location of the Aeolian Islands in the southern Tyrrhenian Sea.

Island arcs are characterized by the dipping seismic Benioff-plain, which is explained as a subduction zone in terms of plate tectonics. Below the Aeolian region deep-focus earthquakes have centers with depths of up to 350 km (Peterschmitt, 1956; Caputo, *et al.* 1972).

Aside from the calc-alkaline volcanism of the Aeolian Islands, potash-rich lavas were erupted on some islands. Most prominent are leucite-bearing tephrites of Vulcanello. Thus, two quite different magmatological associations have been defined (Keller, 1966, 1967; Pichler, 1967):

a) Calc-alkaline association: high-alumina basalts, andesites, dacites. Typical evolution on Salina and Filicudi.

b) K-rich magmas, shoshonitic association: trachybasalts, tephrites, trachytes. Typically on Vulcano/Vulcanello, also Stromboli.

The petrological evolution of the two neighboring islands of Salina and Vulcano is discussed in this paper as they are the most typical representatives of both trends. Some lavas of Lipari are high-K andesites and intermediate between the two extremes (Barberi *et al.*, 1974).

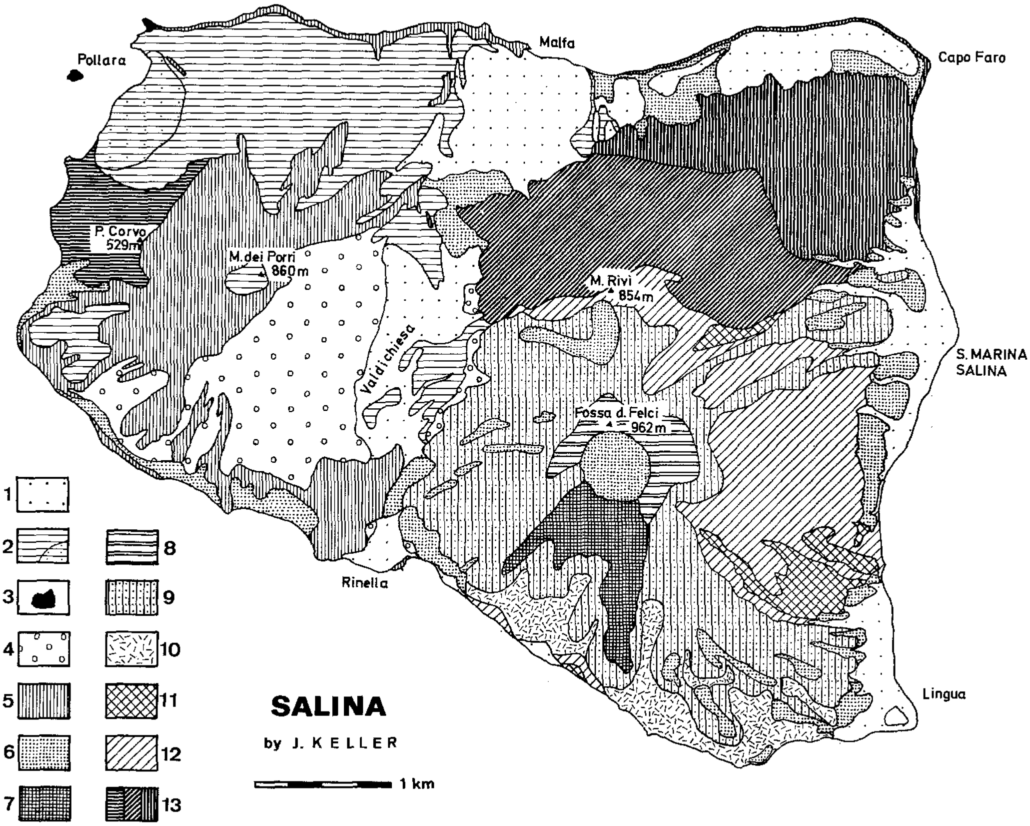

Fig. 2. Geological map of the Island of Salina. *1* Alluvium; *2* Pumice deposits and *3* Hornblende-dacitic lava flows of Pollara crater; *4* Red cinders and *5* Two-pyroxene andesitic lavas of Monte dei Porri; *6* Grey Porri-tuffs, initial explosion phase; *7* Two-pyroxene andesitic lavas of the latest Fossa activity and *8* Scoriaceous crater rim; *9* Andesitic lava flows and pyroclastites and *10* Hypersthene dacites of Fossa delle Felci; *11* Lava flows of the high-Al basaltic phase of Fossa, with *12* scoriaceous pyroclastic deposits; *13* Ruins of Corvo, Rivi and Capo volcanoes (high-Al basalts). *1–6* Upper Pleistocene; *7–13* Middle Pleistocene

Geological Evolution

A first phase of Aeolian volcanism started in early Pleistocene and had its maximum in the middle Pleistocene. After a long period of inactivity with marine destruction and formation of terraces of Quaternary raised beaches the volcanic activity started again during the upper Pleistocene and persists into recent times. The main evolution is within the last 1 m.y.

The Island of *Salina* has a surface of 26 km^2 and is composed of 6 independent volcanic edifices. They emerge from a >1000 m deep sea and reach an actual altitude of 962 m (Fig. 2).

Four stratocones, Capo, Rivi, Corvo, Fossa delle Felci, form the middle Pleistocene part of the island, which is dated <0.5 m.y. A high explosivity index is given by the clear predominance of scoriaceous pyroclastites over lava effusions.

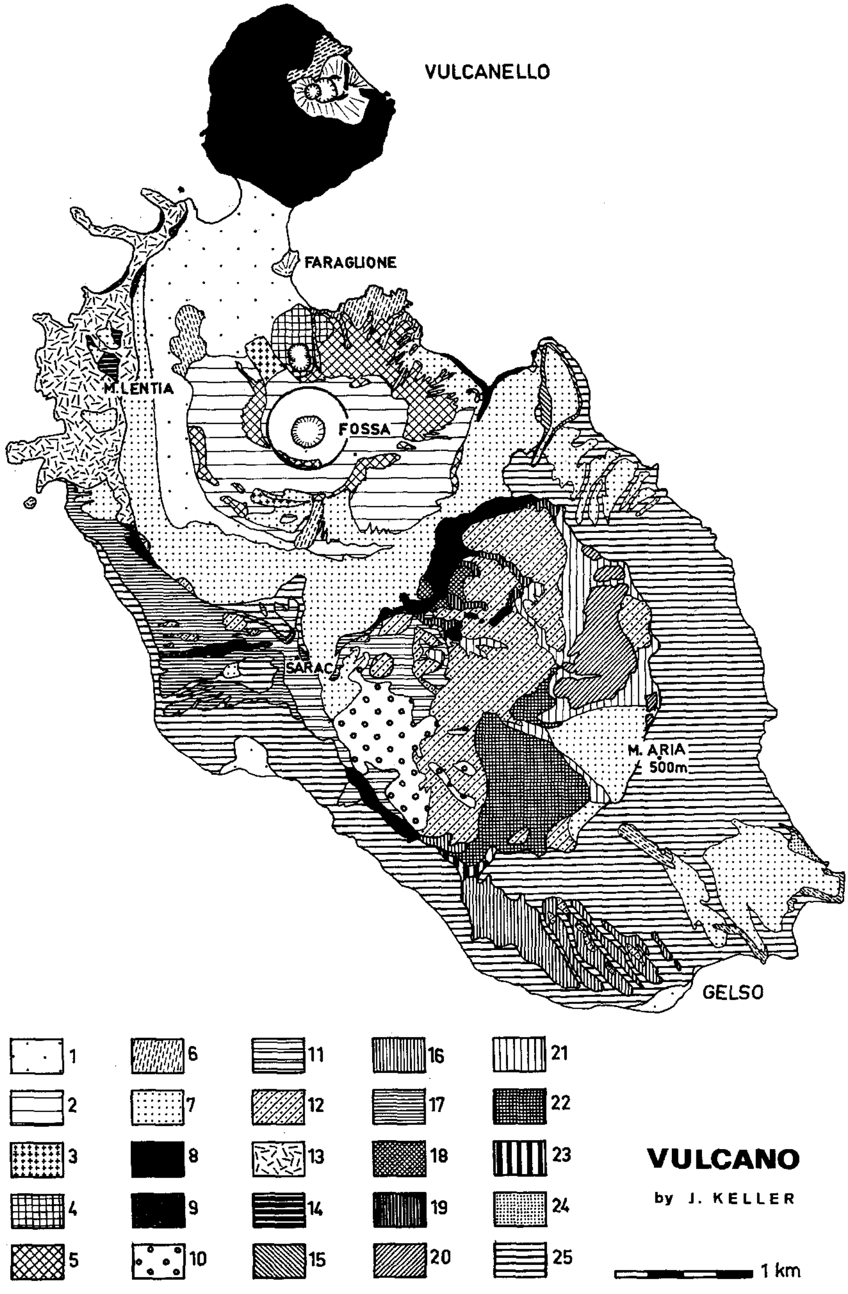

Fig. 3. Geological map of the Island of Vulcano. *1* Alluvium; *2* Explosion products of recent Fossa eruptions; *3* Alkalirhyolitic obsidian flows of Fossa volcano; *4* Ash tuffs of the eccentric craters of "Forgia Vecchia"; *5* Reddish ash tuffs of "Fossa Rossa" period, 6th cent. A. D. ff; *6* Trachytic lava flows of Fossa and Vulcanello; *7* Pyroclastic series of early Fossa ("Fossa I"); *8* Tephritic lava flows of Vulcano-Piano, Fossa, Vulcanello; *9* Tephritic lava flows on the flancs of M. Saraceno; *10 + 11* Hyaloclastitic facies and subaerial scoriae of the Alighieri formation;

The rocks are high-alumina basalts and only the youngest volcano of this cycle, the Fossa, produced in its final stages hypersthene dacites and two-pyroxene andesites (Fig. 2). An estimation indicates that more than 80% of Salina is made up of high-Al basalts and closely related basic rock types.

After a hiatus from middle to upper Pleistocene on Salina, the cone of Monte dei Porri (850 m) was built up during the last glaciation (Würm age). Its lavas are two-pyroxene low-silica andesites. On the northwestern edge of the island, tremendous pumice eruptions created the large crater of Pollara (Fig. 2) 13000 years ago. Hornblende dacites and biotite-hornblende rhyodacites were emitted.

The formation of Pollara crater represents for the whole archipelago the most recent activity with calc-alkaline petrological characteristics.

The volcanic activity of the island of *Vulcano* started during the upper Pleistocene. Probably restricted to the last glaciation (Würm) was the formation of the large stratovolcano of South-Vulcano (Fig. 3). The lavas are trachybasalts of the shoshonite association. This volcano collapsed with the formation of Caldera del Piano which was completely filled later on by pyroclastic rocks and lava flows (Fig. 3). In the filling of the caldera, trachybasalts and leucite tephrites alternate.

In the upper Würm, alkali-rhyolitic lavas formed the Lentia mountain group. These rhyolites were formerly considered as a foreign evolution within Vulcano, but they could be connected with the shoshonitic trachybasalts through latitic and trachytic transitional terms (Keller, 1972).

A second collapse produced the caldera in which the recently active cone of Fossa di Vulcano grew up. The magmatological evolution of the Fossa volcano proceeded from leucite tephrites to potash-trachytes. Hereupon followed alkali-rhyolitic obsidians in historical times.

Also in historical times (2nd cent. BC-16th cent. AD) the peninsula of Vulcanello was built up (Keller, 1970). The evolution from leucite tephrites to K-trachytes is petrologically identical with the early Fossa volcano.

Comparing Salina with Vulcano, an important stratigraphical difference between the calc-alkline and the shoshonitic association was established. This is explained in Fig. 4.

Petrography

The rock types within the andesite family were most effectively distinguished on the base of potassium-silica relationship (Taylor, 1969; Mackenzie and Chappell, 1972). In Fig. 5 Taylor's limits are adopted. Salina figures as straight association from high-Al basalt to dacite. Vulcano is distinctly richer in potassium and plots in the field, where Mackenzie and Chappell define the shoshonitic association.

12 Brown, earthy "Grotte dei Rossi"-tuffs; *13* Rhyolites and *14* Latites and trachytes of the Lentia group ; *15–17* Sheets of trachyandesitic welded scoriae, pyroclastic flow deposits connected with caldera collapses; *18* Monte Rosso cinder cone; *19* Varicolored ash tuffs of the tephritic cycle within Caldera del Piano; *20* Sheet of welded scoriae at Piano Luccia; *21* Grey sandtuffs of the filling of Caldero del Piano; *22* "La Sommata" intracalderical trachybasaltic cinder cone; *23* Trachybasaltic lavas at Monte Corvo; *24* Secondary eruptive center of Gelso-Petrulla; *25* Prime stratocone of South-Vulcano. *2–9* Holocene and historical; *10–25* Upper Pleistocene

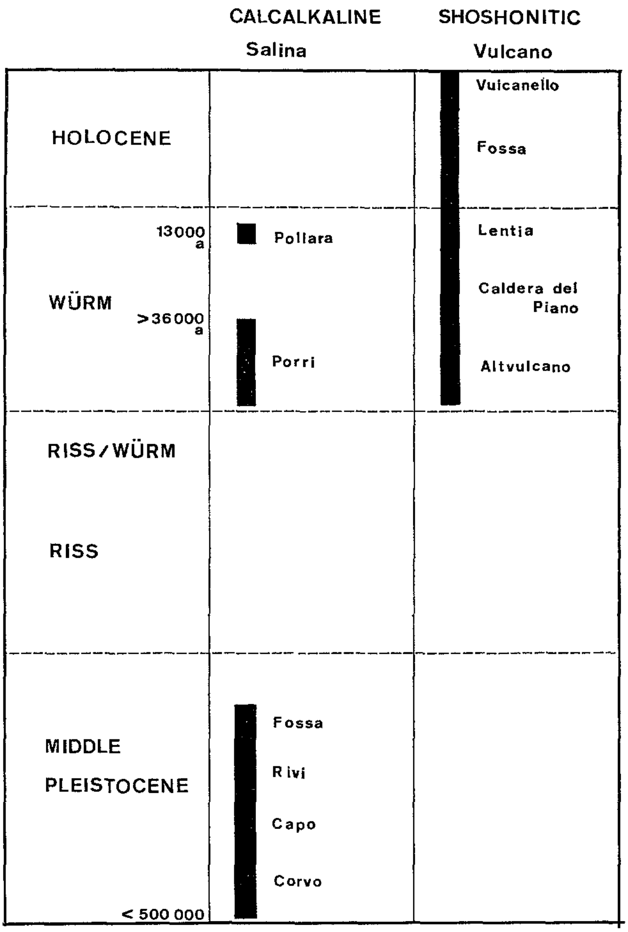

Fig. 4. Stratigraphical relationship between calc-alkaline and shoshonitic associations of Salina and Vulcano

The regionally familiar system of nomenclature with the aid of quartz-feldspar-feldspathoids double-triangle is represented in Fig. 6. Starting from chemical composition Rittmann's norm (Rittmann, 1973) is used. Again the two islands form very distinct groups.

In the calc-alkaline series (Salina) high-Al basalts make up the bulk of the lavas. They always contain modal olivine (Fo 88-77) despite the normative saturation. Olivine shows a reaction relation with Ca-poor clinopyroxene (pigeonite). Parallel to both, a diospidic augite is present. Towards the more acid andesites and the dacites there is again a reaction relation between pigeonite and orthopyroxene. Plagioclase is characteristically calcic in the basic rocks with cores of An 85–90 and rimmed by more sodic outer zones (An 50–60). Hydroxyl-bearing minerals, hornblende and biotite, are atypical for the rocks of Salina. They systematically only occur in the products of the Pollara crater.

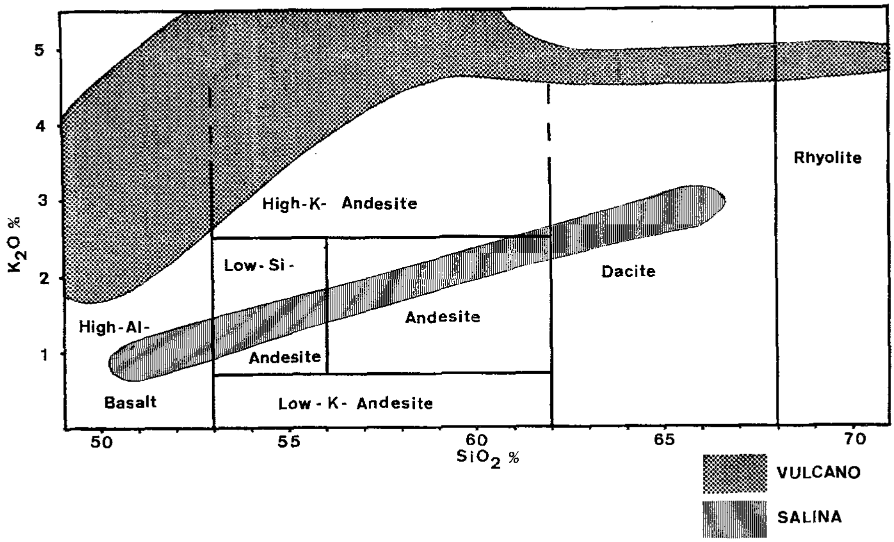

Fig. 5. Nomenclature based on potassium-silica relationship (limits after Taylor, 1969)

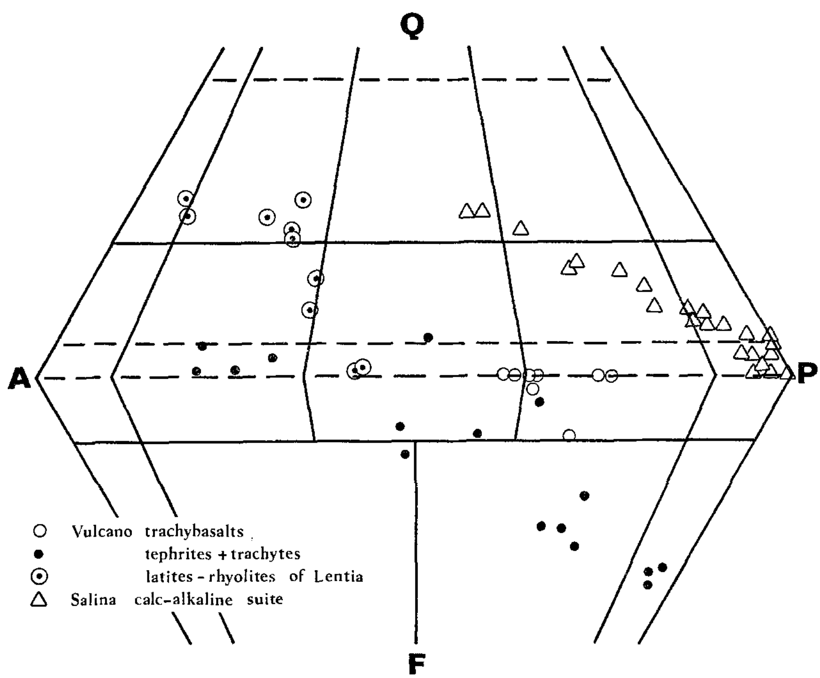

Fig. 6. Double triangle (quartz-alkali feldspar-plagioclase-feldspathoid) representation for Streckeisen's classification, employing Rittmann's norm calculation. Diagrams include all new analyses which will be published in the monographs of both islands in "Rivista Mineraria Siciliana".

Coarse-grained aggregates of calcic plagioclase with olivine, clinopyroxene and ores (Honnorez and Keller, 1968) suggest that crystal fractionation played a role in the evolution of the association.

Xenoliths of pyroxenite, spinel-phlogopite pyroxenite and garnet pyroxenite were brought up and ejected by the tremendous initial Porri eruption (Keller, 1966). These xenoliths may represent important information about mineral composition and mineral stability in the magma source region. Analytical data on mineral chemistry are not yet accomplished. Remarkably enough, peridotitic xenoliths have never been encountered.

The shoshonitic trachybasalts of Vulcano are composed of olivine and augite as phenocrysts. Plagioclase may or may not be present as phenocryst.

Characteristic is the coexistence of K-feldspar and plagioclase in the groundmass of the trachybasaltic rocks. This defines the shoshonite association mineralogically (Nicholls and Carmichael, 1969)

On Vulcano, plagioclase with An 65-50 is distinctly less calcic than in the calc-alkaline suite of Salina. Ca-poor clinopyroxene and hypersthene are completely absent and biotite and hornblende are restricted to minor pumice formations. Leucite tephrites of Vulcano and Vulcanello are composed of the same mineral species and of additional leucite in the groundmass. It forms round grains of up to 0.4 mm in diameter.

The leucite tephrites are best explained as low-pressure fractionation products of a shoshonitic trachybasalt (Barberi *et al.*, 1974).

Rhyolites and alkali-rhyolites of the Lentia group are qualitatively composed of the same minerals as the trachybasalts. Even olivine is still present as small resorbed grains. Quartz makes out the bulk of the microgranophyric groundmass.

Major Element Chemistry

The major element chemistry of the two associations differs, as already stated in Fig. 5, regarding the K_2O contents and is also clearly separated by K_2O/Na_2O ratios (Fig. 7, Table 1). Other differences are rather gradual (see the averages in Table 2). Both types are high in Al_2O_3 with the higher values (Al_2O_3 19%) in some calc-alkaline rocks. In contrast to average tholeiitic basalts both associations are low in total iron, MgO, CaO and TiO_2. Low TiO_2 is indicative for circum-oceanic suites according to Chayes and Velde (1965). TiO_2 increases from calc-alkaline series to shoshonites, confirming a trend already suggested by Boettcher (1973).

The iron enrichment is only slight in the basic members of Salina and almost lacking for the shoshonites as indicated in the AFM-diagram (Fig. 8). This pattern is typical of representative series from other island-arc regions (Jakeš and White, 1972; Mackenzie and Chappell, 1972). None of the high-Al basalts is undersaturated in the norm whereas from the trachybasalts of Vulcano only very few—highly oxidized—exceptions contain some normative quartz and several show Ne in the norm.

Differences between an "island-arc type" of calc-alkaline rocks and a "continental margin type" or "Andean type" were pointed out by Jakeš and White (1972). They found that in major element chemistry the island-arc type is character-

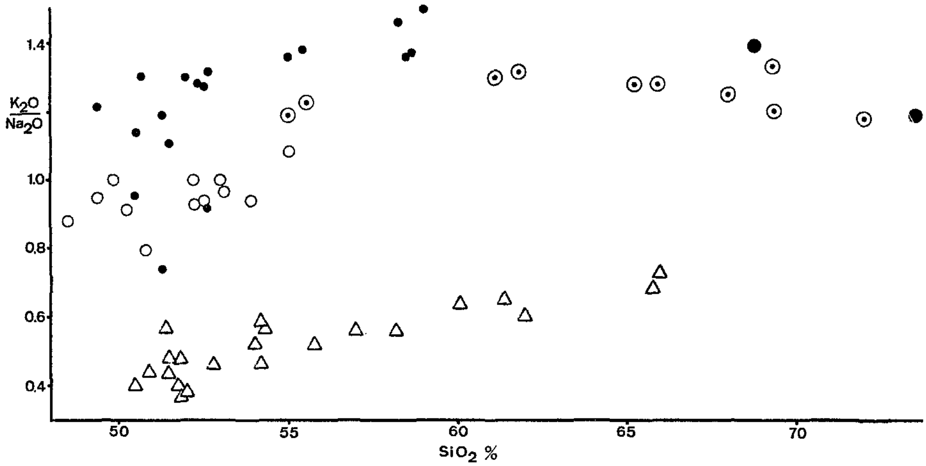

Fig. 7. K_2O/Na_2O ratio versus silica. Ratio is low and shows only slight increase with increasing silica for the calc-alkaline suite. The shoshonitic suite shows an early rapid increase of the ratio and a constancy or even decline towards the acid members. Symbols are as for Fig. 6

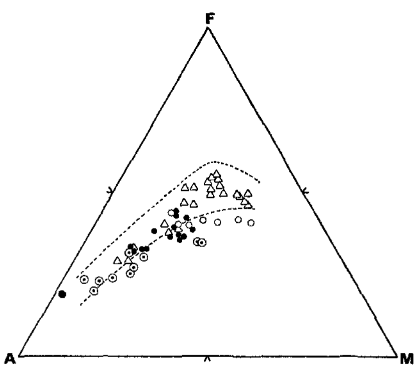

Fig. 8. AFM (alkalis-total iron-magnesium) diagram. Very slight iron enrichment in the early stages of Salina, no enrichment in the shoshonitic suite. Symbols as for Fig. 6. Broken lines delimit Kuno's hypersthenic rock series

ized by SiO_2 in the range of 50–66% against 56–75 in the Andean type. $FeO + Fe_2O_3/MgO$ is lower than 2.0 and K_2O/Na_2O is less than 0.8. In these terms, the calc-alkaline rocks of Salina are of the island-arc type. Jakeš and White (1972, Table 3) advocated further differences in phenocryst mineralogy which agree with the classification of Salina as "island-arc type".

The salient difference in K_2O between the shoshonitic and the calc-alkaline association cannot have originated from low-pressure fractionation processes involving the present phenocryst phases. Dickinson and Hatherton (1969) related the K_2O content in island arc volcanoes directly to the depth of the underlying Benioff-zone, claiming that island arc magmas originate at different depth near the subduction zone and K_2O differences reflect the different conditions under which partial melting occurs.

Table 1. Major element chemistry and trace elements of representative samples from

	Vulcano: shoshonitic association							
	Trachyandesites and Trachybasalts			Leucite tephrites			Trachyte	Rhyolite
	South-Vulcano V 46[a]	V 147[a]	V 62[a]	Piano V 85[b]	Fossa V 154[a]	Vulcanello VO 24[b]	Fossa V 40[a]	Lentia VL 39[b]
SiO_2 %	49.8	48.5	53.0	49.4	55.4	52.35	58.6	69.3
TiO_2	0.8	0.8	0.85	0.73	0.7	0.68	0.6	0.19
Al_2O_3	15.9	13.0	18.5	16.0	18.3	15.8	16.3	13.85
Fe_2O_3	3.85	3.8	3.1	5.05	3.85	3.7	3.75	2.15
FeO	5.0	6.4	5.25	3.65	2.75	4.6	2.45	0.95
MnO	0.16	0.2	0.15	0.15	0.13	0.15	0.12	0.06
MgO	6.6	8.7	3.4	5.55	2.5	4.75	2.6	0.82
CaO	9.9	12.6	7.6	9.6	4.9	8.1	4.9	1.9
Na_2O	2.8	2.5	3.6	3.2	4.2	3.8	4.1	4.15
K_2O	2.8	2.2	3.6	3.9	5.8	4.85	5.6	4.95
P_2O_5	0.3	0.32	0.42	0.4	0.52	0.39	0.34	0.09
H_2O^+	1.8	0.6	0.5	2.25	0.9	0.5	0.4	0.4
	99.71	99.62	99.97	99.88	99.95	99.67	99.76	98.81
Rb ppm	70	50	100	102	230	170	235	350
Ba	791	695	1011	977	1318	1181	971	167
Sr	1030	1090	1295	1400	1400	1330	930	227
K/Rb	333	366	300	312	212	236	200	117
Rb/Sr	0.07	0.05	0.08	0.07	0.16	0.13	0.25	1.54
La	27	27	40	45	51	51	58	56
Ce	57	53	94	78	129	94	143	132
Y	11	15	20	14	14	14	25	41
Zr	80	46	109	76	177	134	277	205
Cu	137	133	154	122	159	156	93	81
Zn	71	73	98	71	68	77	55	51
Co	29	10	20	15	16	20	12	4
Ni	22	38	11	21	13	18	12	8
Cr	57	149	24	52	23	40	23	34
V	200	—	200	—	150	190	120	35

[a] Anal. M. Weibel, Zürich (wet methods).
[b] Anal. Raschka & Lodziak (BfB Hannover, RFA methods).

Trace Elements and Sr-Isotopic Relations

Abundances of a set of trace elements were given in Table 1. The potassium-type elements (Rb, Sr, Ba) are high in the shoshonites and their concentrations are comparable with averages by Mackenzie and Chappell (1972) and Jakeš and White (1972). These elements reach extreme values in the leucite tephrites.

Salina calc-alkaline series show distinctly higher concentrations in the potassium type elements than given by Taylor (1969) for pacific island arcs. In this respect, Salina, which resembles the island-arc type according to the major elements, approximates the continental margin type of andesite series. But typical series shoshonitic association of Vulcano and calc-alkaline association of Salina

Salina: calc-alkaline association

High-Alumina Basalts			Low-Silica Andesite	Andesite	Dacite
Capo Sa 113[c]	Corvo Sa 124[c]	Rivi Sa 178[c]	Porri Sa 181[c]	Fossa Felci Sa 76[c]	Fossa Felci Sa 197[c]
50.5	51.5	51.8	54.2	61.4	65.8
0.52	0.5	0.55	0.56	0.45	0.36
16.7	17.6	19.6	19.3	17.1	16.2
3.2	3.6	4.7	2.7	3.0	2.8
6.5	5.7	4.8	5.5	3.1	1.6
0.2	0.18	0.18	0.17	0.15	0.12
7.0	6.4	4.5	3.1	2.0	1.7
11.5	10.7	10.0	9.2	5.6	4.2
2.0	2.3	2.5	2.7	3.7	3.95
0.8	1.0	0.9	1.6	2.4	2.7
0.16	0.21	0.16	0.22	0.21	0.17
0.65	0.4	0.25	0.4	0.3	0.45
99.73	100.09	99.94	99.65	100.01	100.05
30	34	22	38	65	88
324	357	348	492	609	690
690	683	738	740	667	600
223	308	340	350	308	254
0.04	0.05	0.03	0.05	0.1	0.15
21	18	11	26	21	19
26	35	40	46	68	71
17	17	16	<3	23	29
19	29	22	47	100	129
130	144	134	116	56	38
71	76	73	67	59	55
36	28	17	17	8	9
28	24	10	4	5	3
65	42	20	14	11	15
300	250	—	220	180	90

[c] Anal. J. Keller (wet methods).
Trace elements as [b]; Vanadium by W. Stern, Basel, with optical spectrometry.

of the continental margin type are yet distinctly higher in these elements (Siegers *et al.*, Jakeš and White, Keller *et al.*). The same explanation holds for Zr, La and Ce (Table 1).

K/Rb ratios are similarily low in all considered series. In detail, distinct groups can be seen (Fig. 9). The pattern found by Jakeš and White (1970) of decreasing K/Rb from calc-alkaline to shoshonitic rocks is not clearly developed on the Aeolian Islands. The rhyolitic rocks of the Lentia mountains, with their geologically

Table 2. Average composition of basic rock types from Vulcano and Salina compared with Pacific island arcs

	1	2	3	4	5	6	7
	Trachybasalts and Trachyandesites South-Vulcano	Leucite tephrites Vulcanello	High-Al Basalts Salina	High-Al Basalts New Zealand (Taylor, 1969	Low-Silica Andesite (Taylor, 1969)	Shoshonite Papua, New Guinea (Mackenzie Chappell, 1972)	Shoshonite Papua, New Guinea (Jakeš and White, 1972)
SiO_2	51.66	52.38	51.46	51.7	54.9	52.4	53.74
TiO_2	0.83	0.68	0.52	—	0.82	1.04	1.05
Al_2O_3	16.45	15.52	18.0	16.9	17.5	16.3	15.84
Fe_2O_3	4.03	3.58	3.76	—	—	3.64	3.85
FeO	4.7	4.8	5.6	10.4	8.18	4.62	4.85
MgO	5.48	4.9	5.8	6.5	4.71	6.4	6.36
CaO	9.04	8.03	10.55	11.0	8.49	8.5	7.9
Na_2O	2.98	3.65	2.3	3.1	3.43	3.05	2.38
K_2O	2.94	4.73	0.99	0.4	1.10	2.53	2.57
P_2O_5	0.32	0.46	0.17	—	—	0.60	0.54
K_2O/Na_2O	0.99	1.3	0.48	0.13	0.32	0.83	1.08
Rb	73	170	29	9.6	14	62	75
Ba	832	1181	343	115	200	561	1000
Sr	1140	1330	703	328	430	973	700
K/Rb	333	236	290	344	650	352	200
La	31	51	17	9.6	10.3	—	14
Ce	68	94	33	19	19	—	28
Y	15	14	17	26	22	18	—
Zr	78	134	23	100	92	122	50
Co	20	20	27	40	28	—	—
Ni	24	18	21	25	28	54	20
Cr	77	40	42	40	85	147	30
V	200	190	275	155	200	214	200

1 = average of 8 analyses.
2 = average of 4 analyses.
3 = average of 8 analyses.
Trace element averages from Table 1.

associated latitic and trachytic lavas, form a group with lowest K/Rb. With other trace element data (extreme Rb, low Ba), this gives the highly fractionated pattern of this unit.

During the obvious fractionation line of Salina from high-Al basalt to dacite, Rb and Ba (as well as Ce, Y, Zr) increase, whereas Sr shows a slight decrease. Ba/K and Ba/Rb correlations are positive and uniform for Salina and Vulcano (Fig. 10), but Sr behaves differently (Fig. 11). For Rb/Sr the fractionation trend of Salina is completely outside from the distribution of both elements in the shoshonitic rocks of Vulcano. This suggests, that the primary difference in Sr in the

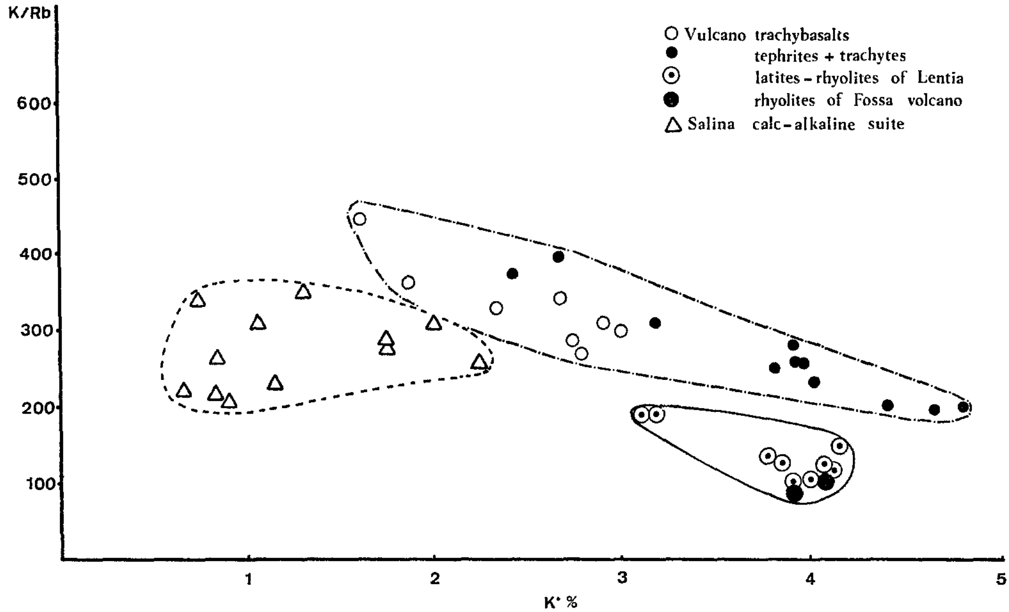

Fig. 9. K/Rb variation of Aeolian Island series

two magma series is governed by other mineral phases than plagioclase, which is responsible for the fractionation trend in the calc-alkaline suite of Salina.

Sr^{87}/Sr^{86} isotopic ratios (Barberi *et al.*, 1974, Table 3) range from 0.703 to 0.7064 and lie mainly in the range given by Puskar (1968) for andesites of Pacific island arcs. Both associations on the Aeolian Islands have similar low isotopic ratios. The leucite tephrites of Vulcanello and the Lentia rhyolites fit into this homogeneous isotopic group. Contamination with appreciable amounts of material, having higher contents of radiogenic Sr is ruled out. But to a minor extend wall rock reaction during ascent may account for elevated isotopic ratios as well as for high Th and U (Barberi *et al.*, 1974; Civetta and Gasparini).

The ferromagnesian elements (Ni, Cr, Co, V) behave generally similar in the associations of Salina and Vulcano (Table 1). Ni, Co, and Cr are low, Vanadium is in the range given by Taylor (1969) for island arc suites. Taylor's restrictions as to the possible magma genesis by fractionation of a basalt or by a one stage anatexis of peridotitic mantle are valid for the ferromagnesian trace element patterns of the Aeolian Islands. A common Ni/Mg- and Ni/Cr-correlation for Salina and Vulcano unifies the calc-alkaline and shoshonite series (Keller, 1972).

Potassium Content and Island Arc Structure

The fact is empirically well established that K_2O at given SiO_2 (K_{SiO_2}) in andesitic lavas rises with increasing vertical distance (h) to the underlying seismic plain in subduction zones. This was evidenced by Dickinson and Hatherton (1967)

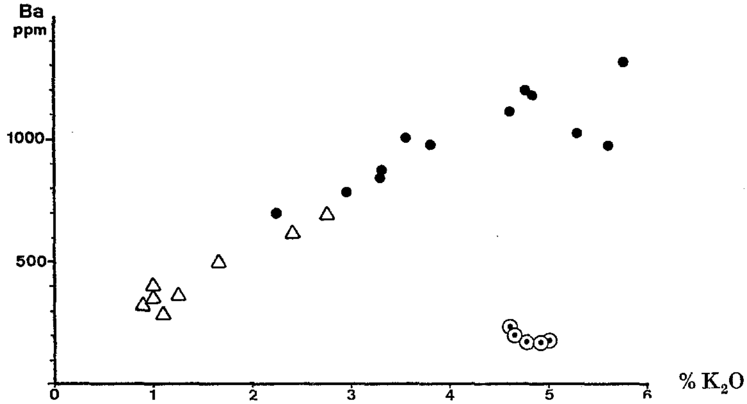

Fig. 10. K/Ba variation, showing a general positive correlation which includes calc-alkaline and shoshonitic series. Rhyolites form a group with lowest Ba. Triangles: calcalkaline suite of Salina; small circles: shoshonitic trachybasalts, tephrites, trachytes; circle + dot: latites, rhyolites of Lentia group and Fossa-rhyolites

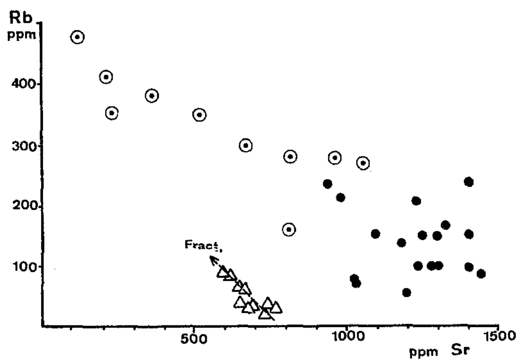

Fig. 11. Rb/Sr variation showing two independent evolutionary lines for Salina and Vulcano. Symbols as for Fig. 10

after statements of previous workers. Although regional variation of the K_2O level do not allow a numerical relation of a given potash value to a distinct depth (Nielson and Stoiber, 1973), the general trend works within a given arc.

The application of this K-h correlation for the Aeolian arc leads immediately to the conclusion of an almost vertical part of the subduction zone beneath the volcanic islands. Calc-alkaline andesites with $K_{55} = 1.5$ occured close to the shoshonitic series with $K_{55} > 3.5$. In a formalistic approach it should even be stated that the high-K volcanoes lie on the Calabrian side of the calc-alkaline islands, opposite to the generally accepted deepening direction of the Benioff-zone. But a dipping plain from the southern Tyrrhenian towards Calabria would not be supported by geophysical data.

The published interpretations of seismic data in the southern Tyrrhenian Sea draw a regularily NW to WNW dipping active seismic plain (Caputo *et al.*; Nin-

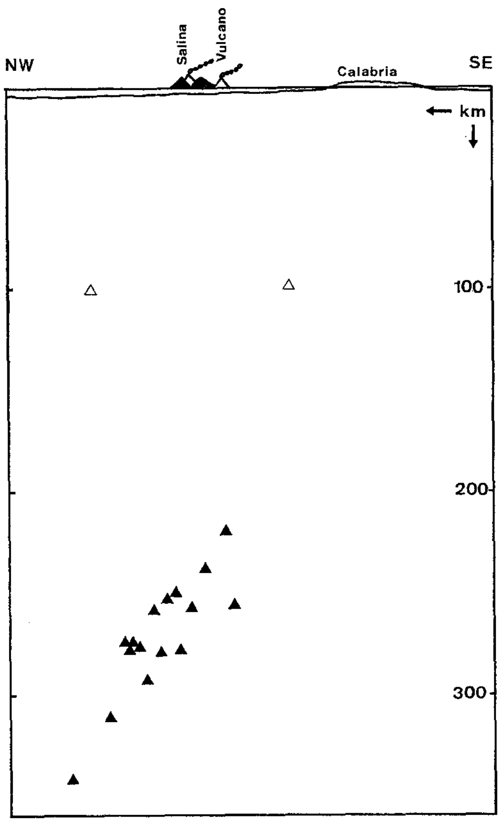

Fig. 12. SE-NW section through the Aeolian arc with deep-focus earthquake centers. Seismic data in a 100 km wide strip are projected along SE-NW line in Fig. 1. Data from Caputo *et al.* (1972), open triangles are two 100 km deep centers reported in the data collections, but omitted after recalculation by Schick (1972, Fig. 1)

kovich and Hays). It is stressed that, in fact, two concentrations of earthquake foci are below 50 km and >200 km, respectively (Fig. 12). In between is a complete gap. Schick (1972, p. 898) states after the recalculation of all present data that no proved center in this region is in the depth range of 35–200 km.

This gap in seismic activity covers the whole depth range above which andesitic volcanoes with the calc-alkaline characteristics of Salina generally stand. It has been stated that this type of volcanicity had its maximum in the middle Pleistocene and is nowadays inactive (Fig. 4). Presentday active seismicity in the depth of 200–350 km is in accord with an active volcanism of shoshonitic composition and extreme potash values.

It is known from several island arcs that the appearance of shoshonitic lavas indicates an advanced stage of arc evolution (Jakeš and White) and a beginning tectonic stabilisation after orogeny (Mackenzie and Chappell). In the Aeolian arc oceanic crust is no more available for subduction on the Calabrian side and the driving mechanism therefore stopped. The arc is in a senile stage (Barberi *et al.*, 1974).

In conclusion, lacking seismic and volcanic arc activity over a broad depth range, steep arrangement of the subduction zone and magmatological indications of a very mature evolution stage seem best explained by the picture of a detached piece of a formerly continuous slab, which continues to sink into the mantle. This

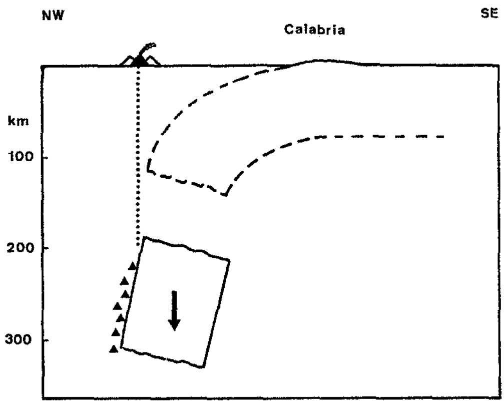

Fig. 13. Schematical model of a detached slab in the Aeolian arc

is very schematically explained in Fig. 13. Detached slabs, some with very steep inclination are not uncommon in island arcs and continental margins as stated by Oliver *et al.* (1973) and Barazangi *et al.* (1973).

The island-arc dynamics of the Aeolian region is therefore accomplished in the geologically very short time of less 1 m.y. This very special feature finds its counterpart in the limited geographical extension of the arc structure.

Discussion

Aeolian calc-alkaline series and shoshonites are involved in a single island arc evolution. Regarding major elements, ferromagnesian trace elements and Sr isotopic relations, both associations may be derived from similar source material. Strong differences in K_2O and potassium type trace elements suggest a source which is inhomogeneous in this respect or differing distribution mechanisms for these elements at the source and during the ascent. No simple low-pressure fractionation of one common parent magma can yield the two associations.

Among the various models to explain the characteristics of calc-alkaline and related magmas much attention has received the connection with plate tectonics, especially with subduction of the lithosphere in island arcs and continental margins and with the consumption of this downgoing slab within the mantle. Recent discussion concentrates on two different mechanisms:

Magma origin may occur in the eclogitic oceanic crust of the downgoing slab near the seismic plain in depth where garnet and clinopyroxene are the residual phases of the partial melting process. This "two stage model" is based on experimental work by Green and Ringwood (1968) and supported by the geochemical consideration of Taylor (1969).

Alternatively, calc-alkaline magmas may originate in the mantle above the seismic plain. Partial melting of peridotite may there be facilitated by upward migrating H_2O which escapes from the downgoing oceanic crust. Recent experiments support this possibility of generating quartz-normative liquids within the mantle (Kushiro *et al.*, 1972; Nicholls and Ringwood, 1973; Boettcher, 1973). A geochemical balance is not yet established and it must be questioned if the low Ni and Cr contents (Table 1) can be derived from partial melting of a peridotite parent. Evidences up to now speak not unambiguously in favour of one of the proposed mechanisms for magma genesis in the Aeolian arc.

Critical for both alternative models is the explanation of potassium variation. The increasing K_2O with increasing depth of the Benioff-plain could speak in favour of a magma generation in or near the subduction zone. For the Aeolian arc, the K-h-correlation holds in a complex way.

An explanation for this relationship is proposed by Dickinson and Hatherton and Jakeš and White (1972). The increase of potassium and related elements results from successive involvement of amphiboles and micas in the partial melting process and from the smaller degree of partial melting with increasing depth. The generally higher TiO_2 in the shoshonitic series may be derived from the high TiO_2 in the micas (Boettcher, 1973) and would fit into this picture.

Alternatively, if the magmas originate in the mantle above the seismic zone, enrichment of K, Rb, Sr, Ba etc. occurs when the magmas or the magma generating H_2O-rich solutions pass through a greater thickness of mantle containing interstitial melt rich in the critical elements.

Present knowledge on stability of hydrous minerals indicates that amphibole is almost out beyond the arc-trench gap, which is without volcanism (Boettcher, 1973; Lambert and Wyllie, 1972). This is a major argument against a magma generation in the subduction zone. But if, by breakdown of amphibole at 25–30kb, the oceanic lithosphere is already dehydrated when the volcanic front is reached, it is also difficult to account for the water for a wet anatexis of mantle peridotite.

Presence or absence of the micas, biotite and phlogopite, depend widely on the estimated thermal regime, as reviewed by Wyllie (1973). The findings of phlogopite-bearing spinel-pyroxenite xenoliths however prevents from ruling out definitively the involvement of mica phases from processes which determine the potassium content of the Aeolian arc magmas.

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