

JÖRG KELLER *

THE ISLAND OF VULCANO

ABSTRACT. — Together with Stromboli Vulcano is the only active island of the Aeolian island arc. The volcanic activity of the island of Vulcano started during the Upper Pleistocene with the formation of the large stratovolcano of Southvulcano. The lavas, traditionally called trachybasalts and trachyandesites, belong to the shoshonitic association. This volcano collapsed with the formation of Caldera del Piano which was then completely filled with pyroclastic rocks and lava flows of intracaldera activity in which shoshonitic-basalts and leucite-bearing tephrites alternate.

During the uppermost Pleistocene rhyolitic and alkali-rhyolitic lavas formed the Lentia mountain group. These rhyolites, formerly considered exotic within Vulcano, are connected with the shoshonitic basalts through latitic and trachytic transitional varieties forming a fractionation series under elevated pressure conditions. During the early Holocene further collapse produced the caldera in which the recently active cone of Fossa di Vulcano is nested. The magmatic evolution of the Fossa volcano proceeded from leucite tephrites to highly potassic trachytes, followed by alkali-rhyolitic obsidian in historical times. Also in historical times (2nd century B.C. - 16th century A.D.) the peninsula of Vulcanello was built up. The evolution from leucite tephrites to K-trachytes is very similar to that of the early Fossa volcano.

The most conspicuous petrological feature of Vulcano is the potassic character expressed by high K_2O/Na_2O at a moderate to high alkali level. These characteristics are already present in the most unfractionated magmas and are maintained over a wide range. High to very high large-ion lithophile trace elements (LIL-elements = Rb, Sr, Ba, Zr, U, Ti and LREE) accompany the high K, but ferromagnesian trace elements (Ni, Cr, Co) show the low concentration of the circum-oceanic environment. Sr isotopic ratios are typically around 0.7040-0.7045 and preclude substantial contamination by sialic material. The magma source is conceived in the mantle, overlying and influenced by a subducted slab.

Vulcano represents a late-stage evolution of the Aeolian island arc and contrasts with the earlier calc-alkaline series of neighbouring islands. The present-day seismicity with foci 200-350 km beneath the islands favorably correlates with the high-K character of the active volcanoes.

RIASSUNTO. — Vulcano è l'unica isola dell'arco Eoliano che, assieme all'isola di Stromboli, presenta attività vulcanica attuale. Il vulcanismo sull'isola ha avuto inizio durante il Pleistocene Superiore, dando luogo alla formazione dello strato-vulcano centrale di « Vulcano Primordiale ». I prodotti vulcanici di questo ciclo presentano una composizione variabile da trachibasalti a trachiandesiti ed appartengono ad un'associazione magmatica a carattere shoshonitico. Il primo ciclo di attività si concludeva con il collasso della parte sommitale dell'edificio e con la conseguente formazione della Caldera del Piano, parzialmente colmata dai prodotti di un'intensa attività infracalderica. Questa fase di parziale colmamento della caldera è caratterizzata dall'alternanza di prodotti piroclastici e lavici con composizione variabile da basalti shoshonitici a tefriti a leucite.

La formazione degli ammassi lavici riolitici ed alcali-riolitici che costituiscono i M.ti Lentia aveva luogo successivamente, verso la fine del Pleistocene. I termini riolitici della Lentia si inseriscono nella successione evolutiva di Vulcano per la presenza di prodotti latitici e trachitici.

* Mineralogisches Institut der Universität Freiburg, D7800 Freiburg, W-Germany.

È stato infatti riconosciuto un trend di frazionamento (a pressione elevata) che lega i basalti shoshonitici alle rioliti.

La formazione della caldera che ospita il cono attivo della Fossa di Vulcano, è da attribuirsi all'inizio dell'Olocene. L'evoluzione magmatologica della Fossa è caratterizzata dalla successione tefriti a leucite-trachiti potassiche; termini riolitici si rinvencono tra i prodotti di età storica.

Ad un'attività vulcanica di età storica (183 a.C. - 1550 d.C.) è peraltro da attribuire la formazione della penisola di Vulcanello, costituita da tefriti a leucite e trachiti potassiche, in una sequenza evolutiva simile a quella della Fossa.

I caratteri più salienti dei magmi di Vulcano sono rappresentati da un elevato tenore in K_2O e da valori ugualmente elevati del rapporto K_2O/Na_2O . La natura spiccatamente potassica dei prodotti è già decisamente marcata nei termini meno evoluti della successione vulcanica (basalti shoshonitici) e permane con immutata evidenza fino ai termini riolitici.

L'alto contenuto in K_2O è accompagnato da concentrazioni parimenti elevate di elementi a largo raggio ionico. Gli elementi di transizione (Ti, Ni, Cr e Co) presentano le basse concentrazioni tipiche di ambiente circum-oceanico. Il rapporto $^{87}Sr/^{86}Sr$, compreso tra 0,7040-0,7045, esclude sostanziali contaminazioni crustali. Sulla base delle evidenze petrochimiche viene quindi suggerita un'origine profonda dei magmi primari di Vulcano, che si sarebbero prodotti per fusione parziale del Mantello, al di sopra della zona di subduzione, con probabili apporti da parte dello « slab » subdotto.

L'attività eruttiva di Vulcano rappresenta uno stadio tardivo nella dinamica dell'arco Eoliano e come tale differisce chiaramente da quella che ha prodotto la serie calco-alkaline delle isole più antiche. La sismicità attuale, con profondità focali comprese tra 200 e 350 km nell'area dell'arco, presenta una significativa correlazione con il carattere potassico dei vulcani attivi di quest'area.

1. Introduction

Vulcano is the southernmost of the seven islands of the Aeolian island arc and, with an area of 22 km² it is the third largest island, following Lipari and Salina. As are all the others of the Aeolian islands, Vulcano is composed exclusively of volcanic and epivolcanic rocks. Fossa di Vulcano represents an active eruption center. The Vulcanello peninsula was formed also during historical times.

Within the frame of Aeolian volcanism Vulcano occupies a special position due to the highly potassic nature of its magmas. As early as 1896 BAECKSTROEM described leucite-bearing lavas from Vulcanello. JACOB (1958) showed that all volcanic rocks of Vulcano exhibit a high level in K_2O and later on leucite-bearing lavas were found in several different units of the island (KELLER, 1972).

A subdivision of Aeolian volcanism into two contrasting geochemical associations — (1) potassium-rich alkaline magmas of Vulcano and Stromboli and (2) calc-alkaline series of Salina, Filicudi, Alicudi, Lipari and Panarea — stemmed from these results (KELLER, 1967; PICHLER, 1967). Further subdivisions recognized four distinct series and incorporated these within one single island-arc evolution (BARBERI et al., 1974; KELLER, 1974, 1979):

- 1) calc-alkaline series: Salina, Filicudi, Panarea, Alicudi, Lipari, Stromboli;
 - 2) high-K calc-alkaline series: Lipari, Stromboli;
 - 3) shoshonitic series
 - 4) leucite-tephritic series
- } Vulcano, Stromboli.

Our knowledge of the geological structure of Vulcano resulted from the early studies of CORTESI & SABATINI (1892), BERGEAT (1899) and DE FIORE (1922, 1925-26). Morphologically, Vulcano can be divided into four main structural units:

- 1) Southern Vulcanic or Old Vulcano
- 2) Lentia mountains
- 3) Fossa di Vulcano
- 4) Vulcanello peninsula.

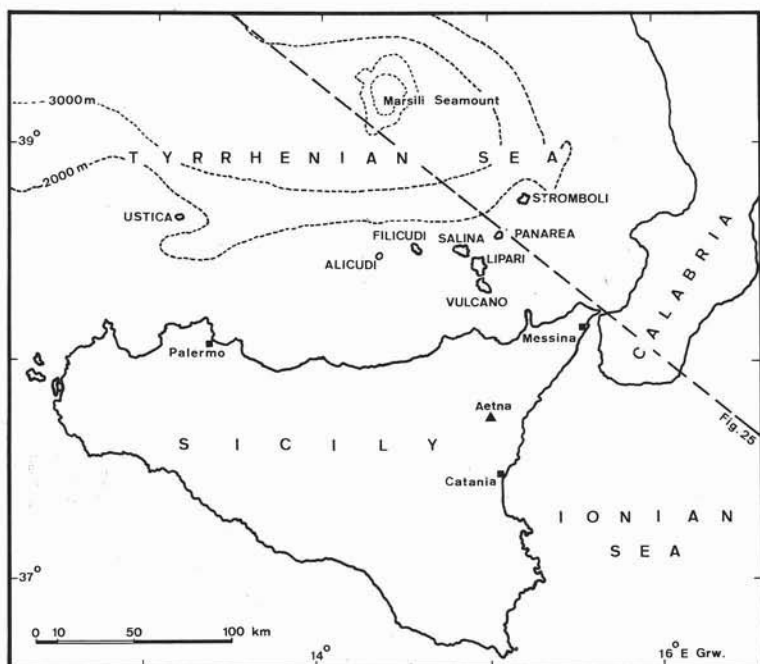


Fig. 1. — Map of the Aeolian Islands in the southern Tyrrhenian Sea. Indicated is the section of the seismic profile of fig. 25.

The map of Vulcano distinguishes all the major volcanic units, of which descriptions are given in the following chapters.

2. Southvulcano or Old Vulcano

Southvulcano is the oldest part of the island. Its morphology represents an almost circular truncated composite cone. On all sides the strata dip at angles up to 40° towards the sea. At 300-400 m above sea level the plain of Vulcano Piano truncates the cone almost horizontally. The morphology resulted from the collapse of the central part of the strato-cone and the formation of Caldera del Piano. The caldera was completely filled by intracaldera activity. Fig. 2 illustrates this structure schematically and fig. 3 shows the form and outline of the caldera in an air-photograph.

Views of a submarine origin of Southvulcano (BERGEAT, 1899; CORTESE & SABATINI, 1892) were recently repeated by BALDANZA et al. (1973) who compared the flat Piano with a guyot. This view clearly contrasts with the interpretation given in figs 2 and 5. The highest elevations of Southvulcano — e.g. Monte Aria and Monte Saraceno — are remnants of the caldera rim and belong to the primary cone. This fact is concealed in many places by a covering of younger pyroclastics (fig. 4),

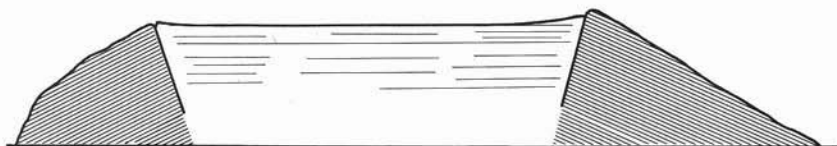


Fig. 2. — Schematic W-E section through Southvulcano explaining Vulcano Piano as a filled caldera. Caldera diameter approximately 2.5 km.

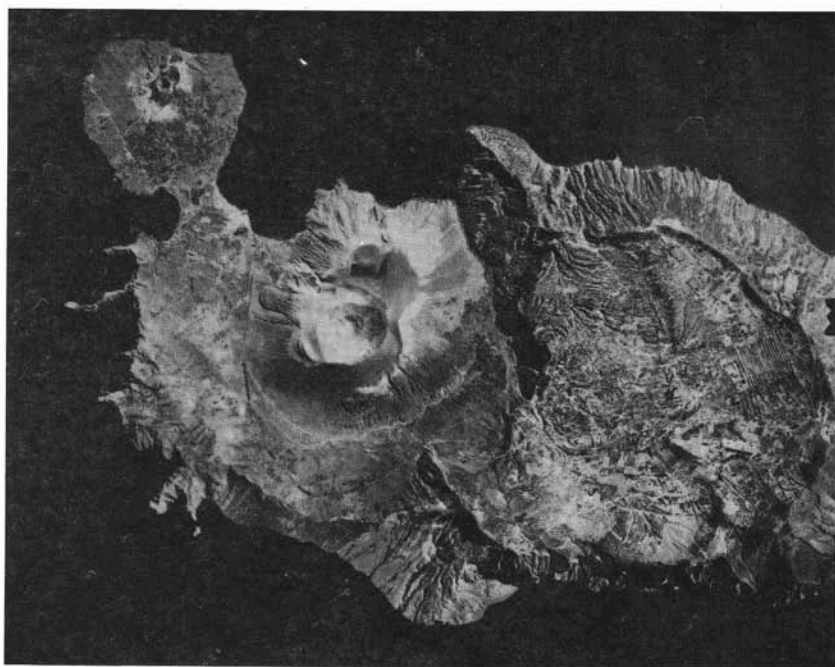


Fig. 3. — Aerial photograph of Vulcano. The circular Caldera del Piano is well distinguished.

which induced contradictory interpretations by earlier authors (BERGEAT, 1899; DE FIORE, 1922, 1925) who saw for instance in Monte Saraceno an independent volcanic center. According to form and structure the primary cone of Southvulcano represents a rather uniform and regular stratovolcano. However, in the course of its activity small displacements of the eruptive axis took place. In the final stage, before the collapse of the caldera, the eruptive center was situated somewhat eccentrically near Monte Aria.

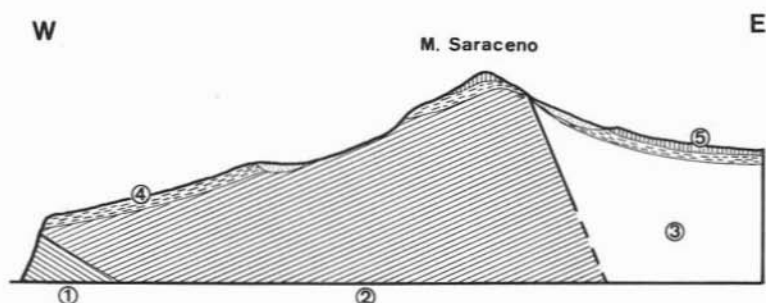


Fig. 4. — Geological section from Spiaggia Lunga through Monte Saraceno. 1 - Eastwards dipping lavas of Spiaggia Lunga-complex; 2 - Southvulcano stratocone; 3 - Caldera del Piano; 4 - Scoriae-blanket Saraceno-Spiaggia Lunga; 5 - Alighieri formation.

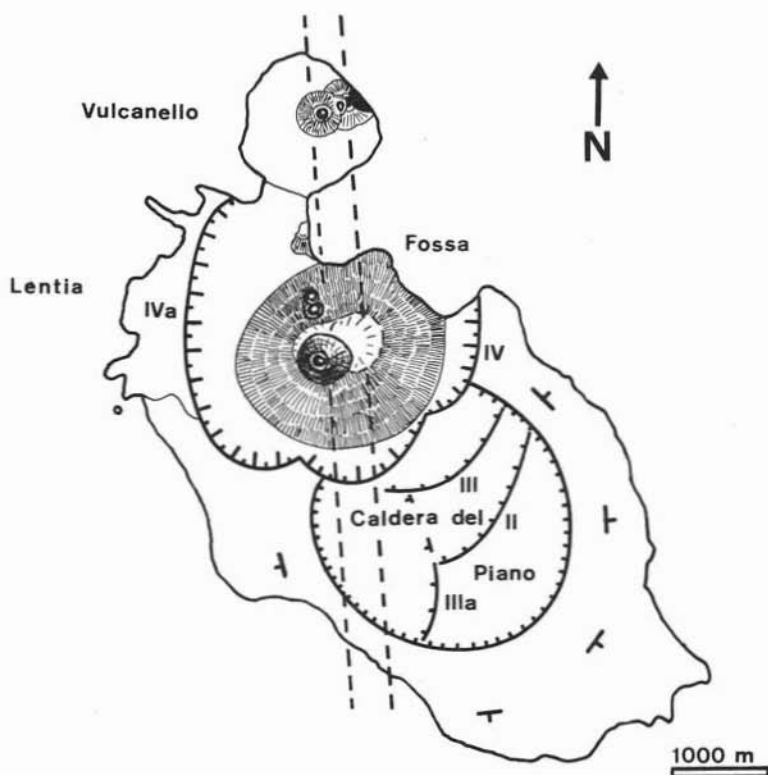


Fig. 5. — Volcano-tectonic structure of Vulcano. I-IV are ring faults of caldera segments.

In the composite cone, lavas clearly predominate over pyroclastics. Mostly the lavas are thin aa-flows with intercalated flow scoriae. According to the nomenclature of the previous authors and in accordance with the classification of STRECKEISEN (1967) these are trachybasalts and trachyandesites. The shoshonitic chemical composition is discussed in a later section.

The eroded outer slopes of the original cone expose a great number of dikes which can frequently be traced from sea level up to 200-300 m above the sea.

TABLE 1
*Shoshonites (trachybasalts and trachyandesites) belonging to the pre-caldera
 cone of Southvulcano*

	V 200	V 46	V 62	V 72	V 218
SiO ₂	52.2	49.8	53.0	50.5	52.3
TiO ₂	0.7	0.8	0.85	0.95	0.75
Al ₂ O ₃	18.1	15.9	18.5	16.6	15.5
Fe ₂ O ₃	2.85	3.85	3.1	4.05	5.1
FeO	5.00	5.0	5.25	4.8	3.75
MnO	0.15	0.16	0.15	0.16	0.12
MgO	4.7	6.6	3.4	5.7	6.4
CaO	8.4	9.9	7.6	8.4	9.7
Na ₂ O	3.3	2.8	3.6	2.9	2.8
K ₂ O	3.3	2.8	3.6	3.3	2.6
P ₂ O ₅	0.4	0.3	0.42	0.38	0.35
H ₂ O	0.8	1.8	0.5	2.1	1.2
	99.90	99.71	99.97	99.84	100.57
Mg/Mg+Fe ²⁺ (Mol)	.56	.61	.46	.58	.61
CIPW-NORM					
Q	-	-	-	-	1.10
or	19.50	16.54	21.27	19.50	15.28
ab	27.91	21.62	30.45	24.53	23.56
an	24.83	22.55	23.69	22.54	21.92
ne	-	1.11	-	-	-
di	11.52	19.66	9.21	13.30	18.61
hy	0.75	-	1.97	2.44	8.76
ol	8.21	8.62	5.80	6.88	-
qt	4.13	5.58	4.49	5.87	7.35
il	1.33	1.52	1.61	1.80	1.42
ap	0.95	0.71	0.99	0.90	0.82
C.I.	27.0	36.0	24.0	31.0	37.5

V 200: Trachyandesite, lava flow Spiaggia Lunga-unit, Capo Secco (Anal. WEIBEL).

V 46: Trachybasalt, dike of Chiappe Liscie near Monte Aria (Anal. WEIBEL).

V 62: Trachyandesite, lava flow, southern slope of Felicicche at 360 m NN (Anal. WEIBEL).

V 72: Trachybasalt, lava flow near P. 249 between M. Molineddo and M. Luccia (Anal. WEIBEL).

V 218: Trachyandesite, lava flow of the Gelso-Petrulla secondary center.

TABLE 1: *continued*

	V 51	V 143	V 192	V 193
SiO ₂	53.1	53.9	55.0	50.6
TiO ₂	0.8	0.8	0.7	0.79
Al ₂ O ₃	18.0	17.8	18.2	18.1
Fe ₂ O ₃	4.7	4.3	3.4	4.3
FeO	3.4	3.55	4.35	4.8
MnO	0.14	0.19	0.1	0.12
MgO	4.2	4.0	3.3	4.8
CaO	7.7	7.3	7.6	9.3
Na ₂ O	3.3	3.5	3.3	3.1
K ₂ O	3.2	3.3	3.6	2.5
P ₂ O ₅	0.36	0.37	0.5	0.36
H ₂ O	0.5	0.7	0.95	0.8
	99.4	99.71	100.91	99.57
Mg/Mg+Fe ²⁺ (Mol)	.53	.52	.47	.53
CIPW-NORM				
Q	1.64	1.77	2.79	-
or	18.89	19.50	21.25	14.76
ab	27.90	29.60	27.90	26.21
an	24.83	23.12	24.20	28.07
ne	-	-	-	-
di	8.85	8.47	9.50	13.06
hy	7.60	7.95	7.82	3.78
ol	-	-	-	4.38
mt	6.83	6.23	4.94	6.25
il	1.52	1.52	1.32	1.51
ap	0.86	0.88	1.17	0.86
C.I.	26.0	25.0	24.5	29.5

V 51: Trachyandesite, lava flow from Pisani to Gelso, Punta Bandiera.

V 143: Trachyandesite, lava flow from Pisani to Gelso, south of Portella della Trovatina (Anal. WEIBEL).

V 192: Trachyandesite, dike west of Faro Vecchio Gelso (No. XIV of DE FIORE, 1922, pp. 40-41).

V 193: Trachybasalt, dike west of Faro Vecchio Gelso (No. XIII of DE FIORE).

DE FIORE has made an attempt to number the most prominent of these dikes; this numbering has been retained here (cf. DE FIORE, 1922, p. 40, fig. 3). A dike concentration exists in the area of Monte Aria with frequent transitions into sill intrusions. Some dikes are here clearly eruptive, with small effusions and explosive eruptions originating from them. In general the dikes are arranged in a radial

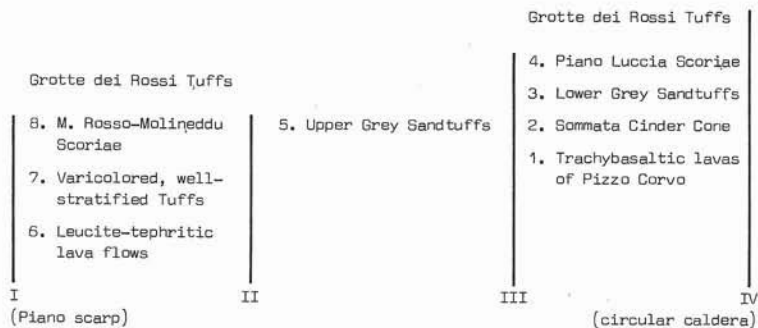
direction to the stratocone. In petrography they are identical to the lavas of Southvulcano. The only exceptions are dikes at Punta del Mortaro and below Scoglio Conigliara on the West coast (Nos. IV, V, XII of DE FIORE). According to their petrography and chemical composition (Table 2) they belong to the feeding system of units within the Caldera del Piano.

To the west of Monte Saraceno, at Spiaggia Lunga, westward dipping lavas of Southvulcano cover an eastward dipping unit (Fig. 4). This must be an individual cone and the oldest part of Southvulcano. The lavas of the Spiaggia-Lunga complex are identical in petrography to the other lavas of Southvulcano (Tab. 1).

Near Gelso-Petrulla the coastal section exposes a small parasitic cone, composed of lava-formation deposits and subordinate lava flows. DE FIORE's fig. 5 (1922, p. 43) illustrates this volcanic structure. Products of the Gelso-Petrulla center alternate with the youngest deposits of the main stratovulcano of Southvulcano. Both have the same petrography. The high amount of quartzitic xenoliths in this parasitic cone is worth mentioning (DE FIORE, 1922). The chemical analyses of Table 1 show the whole range in composition for lavas and dikes of Southvulcano.

3. Caldera del Piano

Volcano-tectonic structure - The central part of the stratocone of Southvulcano subsided due to caldera collapse forming the circular Caldera del Piano with a diameter of 2-2.5 km. Its boundaries coincide with the present morphological rim of Vulcano-Piano. Monte Aria (500 m), Monte Saraceno (480 m) and Sassari dei Pisani (466 m) are the highest elevations of the caldera rim.



I to IV are unconformities and fault-scarps of multiple caldera collapse

Tuffs, scoriae and lava flows from centers within the caldera completely filled the caldera-depression with nearly horizontal strata. The regular form of the Caldera del Piano contrasts with its complicated internal-structure. The profiles of the caldera filling differ in the various areas (figs 4, 5) and show sequential subsidence and filling. The structural synthesis is presented below; units are numbered with decreasing age.

Unconformity II is visible as a morphological escarpment, within Vulcano

Piano. It separates Piano Luccia (380 m) from Cugno di Molinello and Piano Grotte dei Rossi (330 m).

A geological section through this escarpment is given in fig. 6. Unconformity III is mostly hidden by the cover of Grotte dei Rossi tuffs, as shown in fig. 6. It follows from the structural analysis that isolated segments continued to subside and were filled continuously after the main collapse of the circular Caldera del Piano. Caldera del Piano may therefore be described as a multiple collapse caldera. The axis of collapse migrated continuously from SE to NW. The circular depression in which the actual Fossa volcano is nested represents the latest stage of this evolution.

The caldera phenomena of Vulcano do not fit easily the genetic classifications of WILLIAMS (1942) nor MCBIRNEY & WILLIAMS (1969). Vulcano is an intermediate type, mainly because its basic highly explosive magmas caused phenomena commonly related to acid volcanic rocks. Ignimbrite-like deposits connected with the caldera formation are described in a later section.

Intracaldera lava flows - The oldest visible rocks of the filling of Caldera del Piano are lava flows at Timpone del Corvo. These are plagioclase-augite-olivine phenocrystic trachybasalts (Anal. V 130 of Tab. 2). Chemically and petrographically these rocks still show strong analogies to the lavas of the pre-caldera stratocone. Later trachybasalts in the caldera have few or no plagioclase phenocrysts and remarkably higher color index (V 90, V 194, V 147).

Grey Sand tuffs - Well stratified, grey sandy tuffs, with subordinate lapilli sized ones and some coarser layers, fill the northeastern part of the caldera. The exposed thickness exceeds 80 meters. Unconformity II subdivides the lithologically identical Lower and Upper Grey Sandtuffs (fig. 6). The eruption center is localized within the Caldera del Piano itself. Several faults in these tuffs with dislocations on the meter scale indicate postdepositional dislocations related to continuing subsidence in the caldera. Gearsutite ($\text{Ca}[\text{Al}(\text{F},\text{OH})_5\text{H}_2\text{O}]$) impregnations and concretions derive from fumarolic alteration of the deposit.

Intracaldera cinder cone of La Sommata - The hill named La Sommata in the Caldera del Piano is composed of scoriae with spindle-shaped and twisted bombs which led BERGEAT (1899) to the conclusion that La Sommata is a cinder cone. The former cinder cone extended to the topographical height P. 398, with its center between these two hills. As indicated in the profiles of the colored map and in fig. 6, the Sommata scoriae are intercalated within the Lower Grey Sandtuffs. The scoriae contain abundant phenocrysts of olivine and augite in an aphanitic matrix. A trachybasaltic composition is shown by analysis V 147 (Tab. 2).

Welded-scoriae sheet of Piano Luccia - On Piano Luccia, red agglutinated scoriae cover the Lower Sandtuffs as a sheet-like deposit (fig. 6). Strong welding-

TABLE 2
Chemical characterization of the volcanic rocks filling Caldera del Piano

	V 130	V 147	V 90	V 194	V 85	V 178
SiO ₂	52.5	48.5	49.1	50.2	49.4	50.8
TiO ₂	0.9	0.8	0.8	0.7	0.73	0.8
Al ₂ O ₃	16.4	13.0	13.7	12.8	16.0	16.5
Fe ₂ O ₃	4.4	3.8	4.85	3.7	5.05	5.55
FeO	4.75	6.4	4.2	5.1	3.65	3.5
MnO	0.12	0.2	0.13	0.13	0.15	0.14
MgO	4.5	8.7	8.5	8.8	5.55	5.0
CaO *	9.1	12.6	12.3	13.0	9.6	8.25
Na ₂ O	3.0	2.5	1.9	1.9	3.2	3.45
K ₂ O	2.8	2.2	1.8	1.75	3.9	3.2
Cr ₂ O ₃	0.33	0.32	0.21	0.3	0.4	0.52
H ₂ O	1.1	0.6	2.3	1.4	2.25	2.65
	99.90	99.44	99.79	99.78	99.88	100.36
Mg/Mg+Fe ²⁺ (Mol)	.51	.64	.67	.68	.58	.54
CIPW-NORM						
Q	1.54	-	-	-	-	-
or	16.53	13.00	10.63	10.34	23.04	18.89
ab	25.36	12.07	16.07	16.07	15.89	28.98
an	23.00	17.76	23.54	21.23	17.78	20.07
ne	-	4.91	-	-	6.05	0.10
di	16.33	34.22	28.45	32.88	21.44	14.49
hy	7.20	-	8.18	7.49	-	-
ol	-	9.28	1.58	2.98	3.79	4.56
mt	6.39	5.51	7.03	5.36	7.32	8.06
il	1.71	1.52	1.52	1.33	1.39	1.52
ap	0.78	0.76	0.50	0.71	0.95	1.23
C.I.	32.5	51.5	47.5	51.0	35.0	30.0

V 130: Trachybasaltic lava, Timpone del Corvo.

V 147: Trachybasaltic bomb of La Sømmata, NW of the church of Vulcano Piano (Anal. WEIBEL, Zurich).

V 90: Trachybasaltic lava, road Porto to Piano P. 250.

V 194: Trachybasaltic dike, West coast at P. del Mortaro.

V 85: Lava flow, leucite tephrite series, caldera-wall below M. Rosso (Anal. RASCHKA & LODZIAK, BfB (Hannover)).

V 178: Lava flow, leucite tephrite series, Caldera del Piano, P. 333 near Sc. Conigliara.

TABLE 2: *continued*

	V 102	V 104	V 76	V 198	V 75	V 129
SiO ₂	50.5	51.2	50.7	51.3	55.0	51.5
TiO ₂	0.75	0.9	0.85	0.7	0.75	0.9
Al ₂ O ₃	17.7	17.0	16.3	16.1	17.4	16.4
Fe ₂ O ₃	3.55	2.95	4.35	4.75	2.7	3.3
FeO	4.9	5.7	6.1	3.05	4.8	6.2
MnO	0.16	0.17	0.18	0.14	0.16	0.17
MgO	5.5	4.7	4.4	3.0	3.3	4.4
CaO	8.6	8.1	7.7	8.1	6.0	7.8
Na ₂ O	3.7	4.0	3.6	3.6	3.6	3.7
K ₂ O	3.5	2.9	4.7	4.3	4.9	4.1
P ₂ O ₅	0.42	0.50	0.54	0.5	0.45	0.53
H ₂ O	0.5	1.6	0.6	4.2	0.8	0.6
	99.78	99.72	100.02	99.74	99.86	99.6
Mg/Mg+Fe ²⁺ (Mol)	.58	.53	.47	.45	.48	.49
<u>CIPW-NORM</u>						
Q	-	-	-	-	-	-
or	20.68	17.13	27.77	25.38	28.95	24.22
ab	20.61	28.79	17.87	25.63	30.45	22.96
an	21.36	19.87	14.44	15.06	16.85	16.04
ne	5.79	2.73	6.81	2.61	-	4.52
di	14.91	13.86	16.42	17.45	6.36	15.68
hy	-	-	-	-	-	-
ol	8.39	8.59	6.89	0.05	4.30	7.86
mt	5.15	4.28	6.31	6.9	3.91	4.78
il	1.42	1.71	1.61	1.32	1.42	1.71
ap	1.00	1.19	1.28	1.19	1.07	1.26
C.I.	31.0	30.0	32.5	27.0	17.0	31.5

V 102: Lava flow, leucite tephrite series, Caldera del Piano, West of P. 383, Conigliara-Corvo (Anal. WEIBEL).

V 104: Lava flow, leucite tephrite series, Caldera del Piano, West of P. 383, Conigliara-Corvo.

V 76: Eruptive dike of Alighieri-formation, tephritic, Passo del Piano (Anal. WEIBEL).

V 198: Dike, tephritic, Alighieri-formation, West coast, South of Conigliara (No. V of DE FIORE, 1922. pp. 40-41).

V 75: Recent lava flow, western flank of Monte Saraceno (Anal. WEIBEL).

V 129: Eruptive dike, leucite tephritic, North of Scoglio di Capo Secco, southern Lentia (Anal. WEIBEL).

together of these clots resulted in a lava-like appearance. BERGEAT (1899, p. 155) therefore considered this formation as a lava flow and reached erroneous conclusions

as to flow direction and following tectonic movements. The scoriae sheet has an average thickness of 10-20 m. It was formed as one single eruption unit and was not accumulated by lasting Strombolian activity. A pyroclastic scoriae-flow is presumed to be the eruption mechanism.

Leucite tephrites of Caldera del Piano - The northwestern rampart of Caldera del Piano is destroyed and the horizontal superposition of thick tephritic lava flows can be seen in a 300-m section through the filling of Caldera del Piano. Related ash tuffs which cover the flow sequence are finegrained, varicolored and very well bedded. Also the southwestern rim of the caldera is opened by erosion on a stretch near Scoglio Conigliara and leucite tephritic lavas are exposed with their horizontal layering.

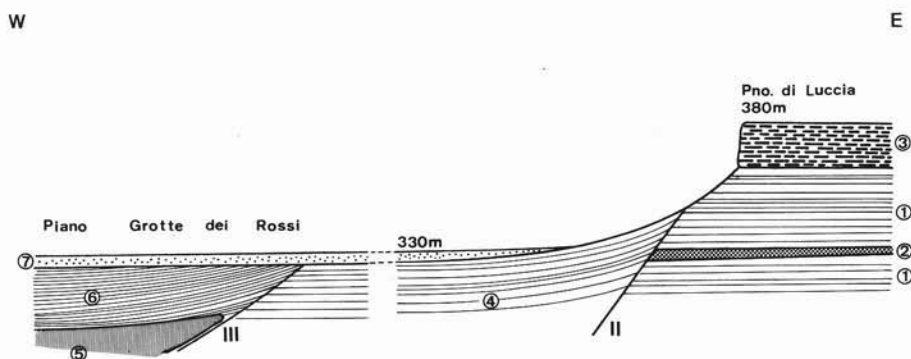


Fig. 6. — Geological section, approximately W-E through Piano Grotte dei Rossi and Piano Luccia. 1 - Lower Grey Sandtuffs; 2 - Lapilli of La Sommata cinder cone; 3 - Piano Luccia scoriae-blanket; 4 - Upper Grey Sandtuffs; 5 - Leucite-tephritic lavas of Caldera del Piano; 6 - Varicolored, well-stratified tuffs; 7 - Grotte dei Rossi Tuffs.

The chemical composition of the lavas is reported in Table 2 (V 85, V 102, V 104, V 178). In the rocks of Vulcano Piano leucite is megascopically visible as round grains or xenomorphic patches. However, leucite is for the most part converted to analcite.

Scoriae of Monte Rosso, Molineddu and trachybasaltic lava at P. 250 - Monte Rosso is a cinder cone situated immediately on the cliff from Vulcano Piano to Caldera della Fossa. Its position in the sequence (fig. 7) shows that a depression of Caldera della Fossa already existed in this place at the time when Monte Rosso was formed. Monte Rosso is covered by the similar but sheet-like scoriae deposit of Molineddu.

The scoriae are easily weathered and disintegrated. This results in surface accumulation of isolated crystals of augite, plagioclase and minor olivine, all with perfect crystal faces. Gearksutite forms as concretion by alteration of the scoriae. A thick basaltic lava flow is exposed in a limited outcrop at P. 250 m along the

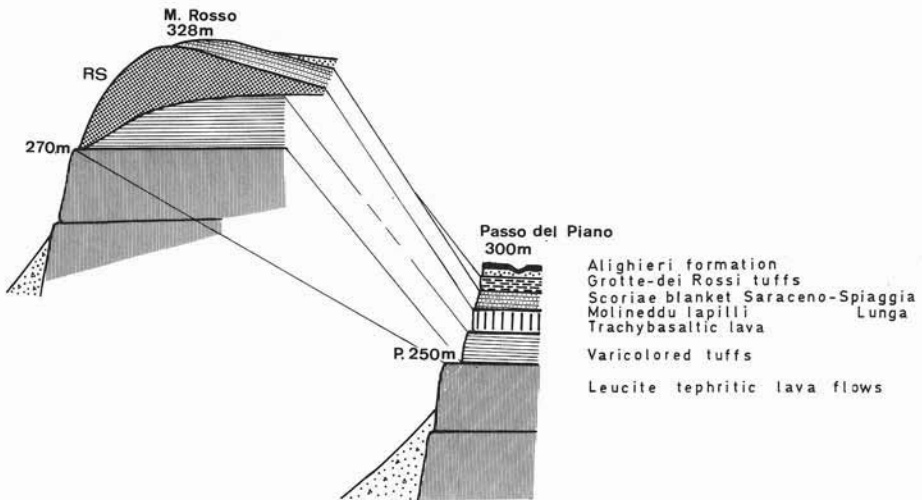


Fig. 7. — Geological profiles of the fault scarp from Piano to Caldera della Fossa at Monte Rosso and Passo del Piano. RS = Monte Rosso-Scoriae.

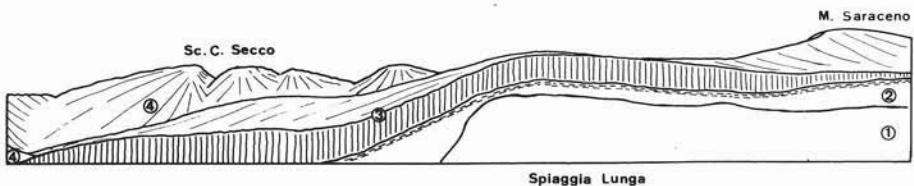


Fig. 8. — Coastal section and panorama along Spiaggia Lunga, showing the sheet-like blanket of strongly agglutinated scoriae and the columnar jointing in the lava-like pyroclastic unit. Profile length ca. 2 km. 1 - Eastwards dipping Spiaggia Lunga lavas; 2 - Stratocone of Southvulcano; 3 - Saraceno-Spiaggia Lunga scoriae sheet; 4 - Lentia rhyolites.

road to Piano. The occurrence is 500 m SW of Monte Rosso and the flow has the same profile position as the Monte Rosso pyroclastics (fig. 7). This lava has a trachybasaltic composition (Tab. 2, V 90) and represents the latest lava effusion in the area of Piano. It is the most primitive trachybasalt of Vulcano. The rock is augite-olivine porphyric and the absence of plagioclase phenocrysts distinguishes this trachybasalt from trachybasalts and trachyandesites of the pre-caldera stratocone. In chemical and petrographical composition a dike rock at Punta del Mortaro (dike No. XII of DE FIORE (Anal. V 194 in Table 2) can best be compared to this trachybasalt.

Blankets of welded scoriae - In three places on the island very similar pyroclastic rocks were deposited in the same stratigraphical position. Their mechanism of eruption and mode of deposition require special consideration.

The three sheet-like deposits cover the following areas:

- 1) the Quadrara region near Gelso;
- 2) the area between Spiaggia Lunga and Monte Saraceno;
- 3) the Monte Luccia.

TABLE 3

Chemical analyses of the pyroclastic sheets of strongly agglutinated scoriae around Caldera del Piano. These pyroclastite analyses serve as chemical information about these rocks, but were not used in petrochemical diagrams
V 158: Luccia blanket, Punta Luccia; V 223: Spiaggia Lunga-Saraceno blanket, opposite Pietra Quaglietta. V 222: Quadrara sheet, loc. Quadrara. V 230: Pumice layer at the base of Quadrara welded scoriae, Faro Vecchio.

	V 158	V 223	V 222	V 230
SiO ₂	52.8	51.0	54.0	59.5
TiO ₂	.69	.84	.78	.46
Al ₂ O ₃	15.3	16.00	17.50	17.75
Fe ₂ O ₃ total	9.30	10.3	8.95	4.60
MnO	0.13	0.15	0.12	0.13
MgO	1.75	4.3	3.0	1.25
CaO	8.9	9.9	7.2	3.55
Na ₂ O	2.9	2.9	3.4	4.25
K ₂ O	3.6	2.7	3.8	5.3
H ₂ O ⁺	1.2	0.85	1.1	4.1
	99.57	100.94	99.85	100.89

The deposits are lava-like banks which cover a pre-existing morphology. Earlier authors described these rocks as lava flow because of their compact appearance. However, marginally and towards the top of each sheet a change occurs towards coarse eutaxitic «fiamme»-structures and then towards less agglutinated accumulations with twisted and spindle-shaped bombs and scoriae. The blankets attain thicknesses of 50 meters. Each is very clearly the product of one single eruption, and not of a continuing activity over a longer period. There is no indication of bedding or sorting in the vertical sequence (fig. 8).

The description given implies close analogies to the ignimbritic products of acid magmas. However, the composition is trachybasaltic. The gas-rich magmas were erupted as hot pyroclastic suspension flows during the collapse of caldera segments.

The eruption of these scoriae sheets must have occurred towards the end of the Pleistocene. The Quadrara scoriae near Gelso cover the tephrochronological layer

TABLE 4
*Chemical analyses and norms of latites, trachites and rhyolites
 from Monte Lentia complex*
 For classification see fig. 18

	VL 11	VL 23	VL 30	VL 5	VL 15	VL 35	VL 25	VL 39	VL 49	VL 6
SiO ₂	55.0	55.5	61.8	61.1	65.2	65.9	68.0	69.3	69.3	72.0
TiO ₂	0.6	0.55	0.4	0.55	0.31	0.32	0.3	0.19	0.2	0.15
Al ₂ O ₃	13.5	13.6	14.5	16.1	13.9	13.9	14.2	13.85	14.2	13.2
Fe ₂ O ₃	4.0	4.5	2.25	2.35	1.7	2.3	2.95	2.15	2.55	1.10
FeO	3.55	2.75	2.7	3.15	2.3	1.6	0.70	0.95	0.6	1.45
MnO	0.14	0.09	0.07	0.16	0.06	0.05	0.08	0.06	0.04	0.07
MgO	6.1	6.2	2.8	2.2	2.4	2.4	1.8	0.82	1.25	1.2
CaO	8.7	8.9	4.9	3.8	3.9	3.9	2.5	1.9	2.4	1.3
Na ₂ O	3.1	3.0	3.4	3.9	3.4	3.4	3.9	4.15	3.6	4.0
K ₂ O	3.7	3.7	4.5	5.0	4.6	4.6	4.9	4.95	4.8	4.7
P ₂ O ₅	0.31	0.34	0.28	0.31	0.17	0.36	0.15	0.09	0.1	0.07
H ₂ O	0.8	0.7	1.95	0.9	1.4	1.0	0.5	0.4	0.60	0.7
	99.50	99.83	99.55	99.52	99.34	99.73	99.98	98.81	99.64	99.94
CIPW-NORM										
Q	1.13	2.54	12.27	8.40	17.26	19.03	19.97	22.12	23.90	25.96
or	21.86	21.86	26.59	29.54	27.18	27.18	28.95	29.25	28.36	27.74
ab	26.22	25.37	28.76	32.94	26.76	26.76	32.98	35.10	30.45	33.82
an	12.00	12.72	11.02	11.66	9.09	9.09	6.78	4.55	8.42	4.18
di	23.04	23.03	9.1	4.20	7.36	6.24	3.62	3.34	2.21	1.51
hy	6.79	5.30	5.17	6.67	4.85	3.67	2.81	0.50	2.09	3.89
mt	5.80	6.52	3.26	3.41	2.46	3.33	1.65	2.71	1.48	1.60
il	1.14	1.04	0.76	1.04	0.59	0.61	0.57	0.36	0.38	0.30
ap	0.74	0.81	0.67	0.74	0.40	0.86	0.36	0.21	0.24	0.17
hm	-	-	-	-	-	-	1.81	0.28	1.53	-

VL 11: Latite, Cala di Mastro Minico (Anal. WEIBEL, Zürich).

VL 23: Latite, Mastro Minico, Fossa-wards flank.

VL 30: Trachyte, Cala del Formaggio, Fossa-wards flank.

VL 5: Trachyte, summit of Monte Lentia (Anal. WEIBEL).

VL 15: Rhyolite, saddle towards Cala di Mastro Minico.

VL 35: Rhyolite, SE-side of Scoglio di Mastro Minico.

VL 25: Rhyolite, lava ridge of Capo Grosso (Anal. WEIBEL).

VL 39: Rhyolite, main mass of Monte Lentia, Eastern slope (Anal. RASCHKA & LODZIAK, BfB, Hannover).

VL 49: Rhyolite, Capo Testa Grossa.

VL 6: Alkalirhyolite, vitrophyritic obsidian, South of P. 140 (Anal. WEIBEL).

of « Lower pumices of South Lipari », which has an age of > 10,000 but < 25,000 years B.P..

At the base of the Quadrara sheet, a pumice layer several meters thick represents an immediate forerunner of the Quadrara scoriae. This is the only pumice in southern Vulcano and with SiO₂ = 58 % it is the most acidic volcanic rock there (Table 3).

The phenocryst content of biotite, clinopyroxene, plagioclase and K-feldspar deviates from the more monotonous mineralogy in rocks of Southvulcano.

4. The Lentia group

The rocky hills which form the western edge of Caldera della Fossa are called Lentia-group after the highest peak. While all older volcanic rocks are of more basic nature, rhyolitic lavas form the Lentia Mountains. Therefore, the Lentia has repeatedly been interpreted as an exotic unit on Vulcano. A relationship with the similar «liparites» of the Guardia group of neighboring Lipari has been suggested.

The stratigraphic position of the Lentia rocks has induced controversies: MERCALLI (1879) and BALDANZA (1961) regard the Lentia as the oldest part of the island. BERGEAT (1899) explained the group as younger than his «Saraceno volcano». DE FIORE (1925) considered the Lentia to be coeval with Southvulcano. BALDANZA et al. (1973) interpreted the Fossa tuffs, which cover the Lentia mountains, as submarine deposits. This interpretation requires that high sea-levels and complicated up-and-down tectonics have to be postulated for the very recent past.

Best evidence for the stratigraphic position of the Lentia rocks is given by the coastal section at Pietra Quaglietta-Punta di Capo Secco. There the rhyolites cover the scoriae blanket of the Saraceno-Spiaggia Lunga unit (fig. 8). Consequently, the Lentia is much younger than Southvulcano. Its formation is related to the multiple-stage caldera formation. Lentia follows in time the welded scoriae sheets but is in turn cut by the ring faults of Caldera delle Fossa.

HELMQUIST (1956) explained the Lentia rhyolites as ignimbrites and PICHLER (1967) described the Lentia Mountains as mainly extrusive domes. Here, the Lentia is interpreted as part of an ancient lava volcano, formed by the superposition of several thick, highly viscous flows. Their flow direction is to the East. Formation of extrusive domes is subordinate in the Lentia. Examples are the hills near Scoglio di Capo Secco and Punta della Sciarra del Monte.

Basic and intermediate lavas are concordant members of the west-dipping lava sequence at Cala di Mastro Minico, Cala del Formaggio and on top of Monte Lentia. The analyses of Table 4 show a wide range in SiO_2 for the Lentia rocks. This demonstrates that the Lentia rhyolites are linked to the rest of Vulcano by transitional rock types. However, in volume rhyolites predominate by far over latitic and trachytic rocks. Glassy to almost obsidian-like, pumiceous and lithoidal rock types occur among the rhyolites.

5. Caldera della Fossa

The depression in which the cone of Fossa di Vulcano grew is a caldera of similar size to the older Caldera del Piano. Again, caldera formation occurred as a multiple collapse with earlier subsidence in the southeastern part, migrating towards the North and Northwest.

Within the caldera the recent Fossa products hide the older structures, but

several volcanic series which cover the rims of that caldera and the adjoining Piano erupted within Caldera della Fossa or cover it already in its present morphology and contribute to the reconstruction of the caldera forming phenomena.

Grotte dei Rossi Tuffs - Large parts of Vulcano Piano are covered by finegrained, brown, earthy tuffs, which are almost unstratified and reach a thickness of more than 10 m. The appearance is that of a dark loess. Former underground dwellings in these tuffs led to the name «Grotte dei Rossi» for the region of their main occurrence. This name was applied to the unit here. The main characteristic of the deposit is the fine grain-size in all occurrences (fig. 10). The mineral content (augite, plagioclase and some olivine) shows the usual phenocrysts found in the rocks of Southvulcano. The tuffs cover a morphology which is already very similar to the present-day morphology. The eruption center is presumed to be situated in the southern area of the Caldera della Fossa. In several places the Grotte dei Rossi tuffs are covered by the 11,000-8,500 years old Lower Pumice tephra from Monte Pelato/Lipari.

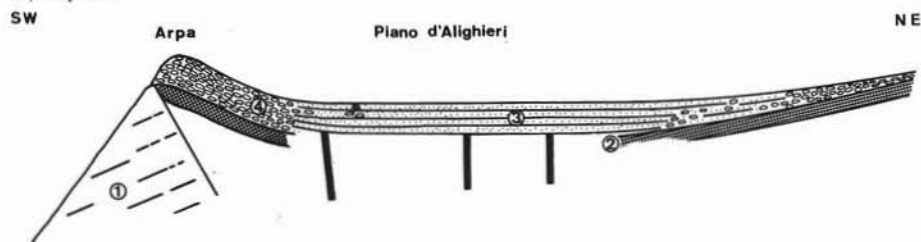


Fig. 9. — Geological section through Piano d'Alighieri showing facies change of Alighieri deposits. 1 - Primary cone of Southvulcano; 2 - Grotte dei Rossi Tuffs; 3 - Hyalotuffs of Alighieri formation; 4 - Scoriae of Alighieri formation; 5 - Schematic representation of N-S running feeding dikes.

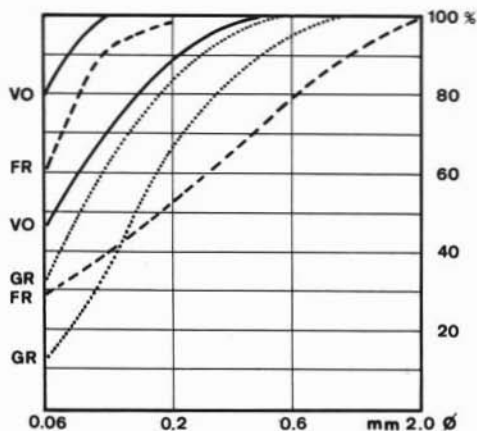


Fig. 10. — Grain-size characteristics of different fine-grained ash-tuff units. Generally an average and a coarse grained ash-tuff were chosen. - VO = Vulcanello III; FR = Fossa Rossa; GR = Grotte-dei-Rossi Tuffs.

The Alighieri formation - The Piano d'Alighieri is a remarkably flat part of Vulcano-Piano, Southeast of Monte Saraceno. The Alighieri formation includes deposits in and around Piano d'Alighieri which are different depositional facies of the same volcanic event (fig. 9).

Well stratified, lapilli-sized tuffs form the flat Piano. Characteristic are the predominance of the grain-size 0.5-2 cm Ø and the small amount of ash-sized matrix. The lapilli are glassy, roundish and not very vesicular. Fresh material is dark and has a vitreous lustre, while altered parts assume the conspicuous yellow-orange-brown colors of

palagonitized basaltic glass. In thin section the lapilli consist of translucent glass with small microlites. This is the typical sideromelane of hyaloclastites and is never found in other pyroclastic rocks of Vulcano. Palagonitization causes the yellow hydration rims of the lapilli. The material is still X-ray amorphous, and does not yet show the presence of montmorillonite — as shown by HAY & IJIMA (1968) for Hawaiian palagonite tuffs. Opal-coating and -cementation mark a stage of beginning hydration (HAY & IJIMA, 1968). These characteristics indicate a hyaloclastic origin of the pyroclastic rocks. This suggests the former existence of a local lake, at 300 meters above sea-level. Morphology supports this postulate. Where the erupting magma came into contact with the lake water hyalotuffs were produced by a similar mechanism as TAZIEFF (1968) described for marine conditions.

Abundant fossil plant imprints (mainly leaves of *Quercus ilex*) are encountered in the basal parts of the hyalotuffs.

Proceeding from the flat Alighieri plain towards the surrounding slopes the hyalotuffs suddenly change their facies into red scoriae. In places these are loosely agglutinated agglomerates of twisted bombs and in others they are intensely welded together assuming a lava-like appearance. At Passo Piano a black 0.5-1 m thick lava-like layer covers all the irregularities of a dissected morphology with almost constant thickness.

Scoriae, lava-like sheets and hyalotuffs occupy an identical stratigraphic position immediately above the Grotte dei Rossi tuffs. They are all products of one single eruptive cycle, with facies changing according to the conditions of eruption and deposition. The Alighieri formation is the most recent eruption within the Caldera del Piano. This volcanic event is not directly connected with the volcano-tectonics of caldera formation, but is related to a N-S lineament (fig. 5) to which all Holocene eruption centers of Vulcano and Lipari belong (KELLER, 1970, fig. 2).

Several dikes, which belong to the Alighieri formation, are exposed North (Passo Piano) and South (descending from Scoglio Conigliara to the shore) of the Alighieri plain, crossing it in a N-S direction.

Even in some thicker dikes, the rocks of the Alighieri series are aphanitic without phenocryst. The chemical composition with high alkalis and high K_2O/Na_2O (V76, V198 in Table 2) places these rocks among the tephrites although leucite has not been detected. Weathering produces white patches, which can reach diameters of up to 1 cm. X-ray diffractometry reveals analcite in these patches: such weathering is known as « Sonnenbrenner » alteration.

Subrecent lava flows West of Monte Saraceno - Two lava flows on the western flank of Monte Saraceno cover the Alighieri formation and the Grotte-dei-Rossi Tuffs. The subrecent age is suggested by the stratigraphic position and also by the observation that the flows fill gullies of the recent drainage system. Analyses are given in Table 2 (V75, V129). Alkali content and K_2O/SiO_2 ratio relate these rocks with the leucite tephrites. V129 is almost identical in petrographic appearance and chemical composition with the lavas of the Alighieri formation.

6. Fossa di Vulcano

The active crater of the island of Vulcano is *Fossa di Vulcano*, which rises from sea level up to 391 m and forms a steep cone with a broad crater platform. Countless reports of the island's activity since Greek and Roman times refer to this volcano. The last eruption took place in 1888-90. Presently it is in a fumarolic stage. The fumaroles commonly have temperatures of 100-200° with deposition of sulfur, ammoniumchloride and sassolite. Increase in temperature has occurred several times since that last eruption. It reached 550° C in 1921 and > 300° C in 1978-79. A great variety of fumarole minerals have been described by DE FIORE, 1922 (pp. 317-380).

From tephrochronological results the start of Fossa activity within the existing Caldera della Fossa goes back about 11,000-8,500 years, using fission-track ages for the Gabelotto obsidian of Lipari (WAGNER et al., 1976; BIGAZZI & BONADONNA, 1973) as the age of the Lower Pelato Pumice layer. The morphology of the cone and of its crater platform indicate a vent displacement of about 500 meters in WSW direction (Fossa I → Fossa II of DE FIORE).

On the geological map, the volcanological and structural units of the Fossa-volcano have been summarized as follows:

Pyroclastic deposits of the recent eruptions (sands, blocks, breccias) mainly of the period 1888-1890.

Alkali-rhyolitic obsidian flow of Pietre Cotte (1739 A.D.).

Ash tuffs of the eccentric craters of Forgia Vecchia (1727 A.D.).

« Fossa Rossa », reddish, well-bedded ash tuffs.

Upper Pelato tephra 6th century A.D.

Trachytic lava flows (Punte Nere, Palizzi, Piano del Porto).

Pyroclastics of the earlier Fossa, with Palizzi obsidian.

Leucite-tephritic lava flow of the coast from P. Roia to P. Luccia.

Lower Pelato tephra, 11,000-8,500 years B.P.

Tephritic lavas of the Roia coast - Lavas of the Roia coast form the oldest unit of the Fossa. Critical for the geological interpretation are the coastal sections at Punta Luccia where the lava flowed against the steep cliffs bordering the Caldera della Fossa (fig. 11). The leucite tephrites are very similar to the lavas of the Vulcanello-platform. The alkaline character (anal. V 154, Table 5) is still more pronounced and this results in a marked higher content of K-feldspar in the groundmass. Leucite is mostly converted to analcite. Phenocrysts are plagioclase, olivine and augite.

Pyroclastic series of Fossa I - The cone of Fossa I is almost completely covered by later Fossa tuffs and is defined mainly as a morphological unit. The elliptical plain NE of the present crater indicates the position of the Fossa I center. Good sections of Fossa I tuffs exist in the deep valley of Rio Grande (Vallone della Roia)

TABLE 5
Chemical composition and norms, Fossa di Vulcano

	V 154	V 227	V 40	V 185	V 205	V 228
SiO ₂	55.4	58.3	58.5	59.0	73.0	68.6
TiO ₂	0.7	0.7	0.6	0.5	0.1	0.1
Al ₂ O ₃	16.3	17.5	16.3	16.1	13.6	13.8
Fe ₂ O ₃	3.85	2.3	3.75	3.65	1.15	1.75
FeO	2.75	2.7	2.45	3.2	1.05	1.4
MnO	0.13	0.07	0.12	0.13	0.08	0.09
MgO	2.5	1.3	2.6	2.65	0.15	0.6
CaO	4.9	2.7	4.9	4.75	1.0	1.7
Na ₂ O	4.2	4.1	4.1	3.7	4.5	3.5
K ₂ O	5.8	6.8	5.6	5.55	5.15	4.9
P ₂ O ₅	0.52	0.3	0.34	0.15	0.05	0.08
H ₂ O	0.9	2.4	0.4	0.6	0.6	4.1
	99.95	99.17	99.76	99.38	100.43	100.82
<u>CIPW-NORM</u>						
Q	-	1.10	2.27	4.87	25.00	24.93
or	34.23	40.18	33.05	32.76	30.30	28.92
ab	31.80	34.68	34.66	31.28	38.25	29.59
an	13.94	9.27	19.53	11.20	1.49	7.47
ne	2.01	-	-	-	-	-
di	5.77	1.78	10.05	8.96	2.49	0.31
hy	-	4.44	2.40	2.62	0.18	2.47
ol	3.17	-	-	-	-	-
mt	5.59	3.34	5.45	5.74	1.67	2.54
il	1.33	1.34	1.14	0.96	0.20	0.20
ap	1.23	0.72	0.81	0.35	0.12	0.19

V 154: Tephritic lava flows of early Fossa, Punta Luccia (West); V 227: Trachytic pumice, Palizzi. V 40: Trachyte, Palizzi-flow (Anal. WEIBEL); V 185: Trachyte, Punte Nere; V 205: Obsidian, Pietre Cotte; V 228: Rhyolitic pumice, pre-1888 eruption, southern crater rim.

and the whole island is covered by stratified tuffs and loose sands, which can be correlated essentially with Fossa I activity. In different places, at the base of these tuffs the rhyolitic Lower Pelato tephra was found.

Within the Fossa I - series a 2-m-thick pumice deposit was formerly exploited in the Palizzi area («Cava di pumice» on the map). The composition of Palizzi pumice is trachytic (V 227) with extreme potassium contents compared with other rocks on Vulcano. This has produced a distinctive phenocrysts assemblage of predominant biotite and sanidine, together with plagioclase and augite.

Trachytic lava flows of the Fossa - Terminal lava flows descended over the northern, western and southern slopes of the cone in identical stratigraphic positions.

They are covered by the 6th century tephra and are therefore older than this date. In all occurrences the petrographic appearance is very similar and is also remarkably similar to the Roveto flow of Vulcanello. The analyses V 40 and V 85 show the trachytic chemical composition. It will be shown in the petrological discussion that these trachytes are late-stage fractionation products of the leucite-tephritic magma.

The «Fossa Rossa» - The name «Fossa Rossa» has been given to the cone of mostly reddish, characteristically fine-grained ash tuffs which dominate the actual appearance of the cone. The beginning of Fossa Rossa activity is placed in the 5th-6th century A.D. (KELLER, 1970). The ashes of Fossa Rossa are mostly magmatic-juvenile and compare in chemical bulk composition with the trachytic lava flows of the preceding lava activity.

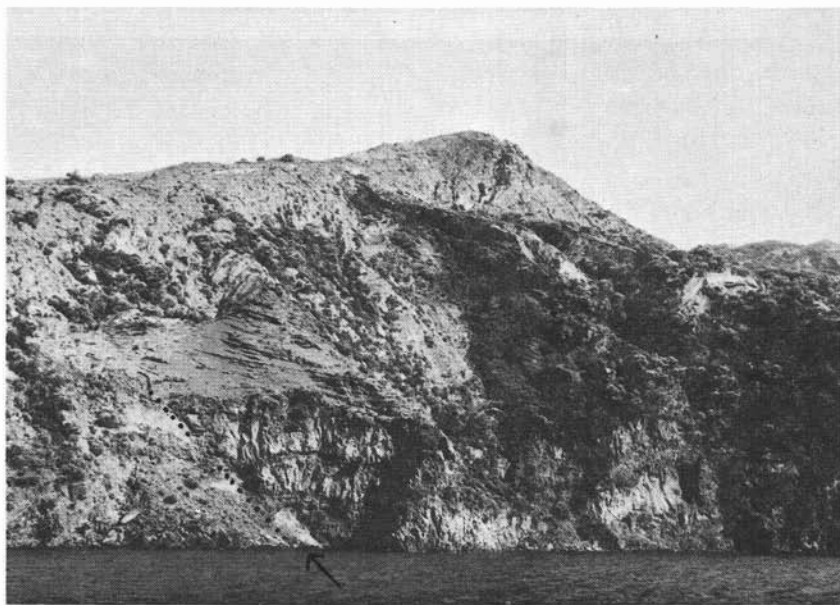


Fig. 11. — Punta Luccia-West with tephritic lava flows of early Fossa against the steep wall of Caldera della Fossa (dotted line). Key outcrop for early Fossa-Caldera della Fossa-relationship.

Grain-size characteristics are given in fig. 10. The extremely fine grain size even at the immediate crater rim, requires a special explanation. The regular bedding of the fine-grained ash tuffs in thin strata shows no interbedding of coarser material. Rhythmic stratification is due more to color differences than to change in grain size. The vent seems to have remained open during the whole eruptive cycle. This gives the picture of a continuous pulsating gas-stream, which was capable of keeping the fine particles in constant motion within the chimney, as in an expanded bed in the technical fluidization process (REYNOLDS, 1954). If the gas stream increased, the material was ejected over the crater rim and the deposits show a sorting-degree and grain-size which ashes exhibit only after a longer transportation. Chemical

reactivity in the fluidized system accounts for the rapid change of red and grey-green colours, due to different degrees of oxidation of iron. Some layers are composed almost exclusively of accretionary lapilli, with hardly any matrix between the round ash aggregates. This means that the fluidization gas stream kept the whole ash fraction in turbulence until almost all particles were accreted. The facies and eruptive mechanism of Fossa Rossa tuffs appear again in the pyroclastic deposits of Forgia Vecchia and of Vulcanello III.

«*Forgia Vecchia*» and «*Pietre Cotte*» - Forgia Vecchia is the name of two adventive craters on the northern slope of the Fossa. The most probable interpretation of historical accounts is that Forgia Vecchia was active in 1727 and that the obsidian flow of Pietre Cotte originated in 1739 (KELLER, 1970). Comagmatic ashes of Forgia Vecchia are trachytic, comparable to the Fossa Rossa. The chemical composition of the Pietre Cotte obsidian is alkali-rhyolitic (Table 5, V 205). Remarkable is the complete chemical analogy to some Lentic rocks, which is recognizable even in the highly fractionated trace-element concentrations.

The recent Fossa activity - During the 18th and 19th centuries numerous reports collected by DE FIORE (1922) indicate a continuous more or less intense fumarolic activity, which increased episodically to the point that flames were visible and detonations ejected loose material. The last eruption, 1888-90, represents a climax in this development and since then, the fumarolic activity is at a stage comparable to that described prior to the climax of the last century.

The depositional record referring to the period before 1888 is very limited. On the southern crater a ca 40-m-high profile is exposed, which shows about 10 meters of layered pyroclastic material between the Fossa Rossa and the products of the 1888-90 period. Sandtuffs and breccias show intercalations of ashes, some with accretionary lapilli, although subordinate, authigenic-juvenile material was erupted in the form of thin pumice layers and some larger scoriae bombs in the form of «*bouse de vache*». The scoriae are trachytic, the pumices immediately below 1888 have a rhyolitic composition.

The eruption period 1888-90 led MERCALLI (1907) to establish the type «*vulcanian activity*». The following characteristics are important for the definition:

- high explosivity without lava effusion;
- extremely violent acoustic detonations;
- irregular and abrupt changes between explosive paroxysms with intervals of calm fumarolic activity or complete calm;
- predominant ejection of resurgent volcanic material: the «*new magma*» is only represented by the characteristic, bread-crust bombs (BERNAUER, 1935; LACROIX, 1908).

MERCALLI further on defined an «*ultravulcanian activity*» as characterized by complete lack of «*new magma*».

TABLE 6
*Chemical composition of bread-crust bombs of Fossa eruption 1888-90
 showing strong chemical variability*

	VF 3	VF 16	VF 22	VF 23	VF 27	JAKOB Tab. 8/16	LACROIX 1908 Anal. a	LACROIX 1908 Anal. b
SiO ₂	63.6	58.8	66.0	67.2	69.9	64.45	66.2	66.51
TiO ₂	0.36	0.55	0.36	0.26	0.16	0.43	0.38	0.41
Al ₂ O ₃	15.1	15.7	15.1	14.3	13.3	15.22	16.18	16.18
Fe ₂ O ₃	2.70	2.5	2.2	2.2	1.5	2.33	0.1	0.36
FeO	2.45	3.4	1.85	1.7	1.3	1.93	3.75	3.75
MnO	0.07	0.1	0.09	0.06	0.05	0.08	—	—
MgO	1.9	2.8	1.25	1.2	0.5	1.65	1.28	1.62
CaO	3.45	4.4	2.6	2.4	1.5	3.69	2.12	1.97
Na ₂ O	3.8	3.8	3.85	3.9	3.7	4.41	3.74	4.15
K ₂ O	5.1	5.4	5.0	5.2	4.9	5.72	5.15	5.45
P ₂ O ₅	—	—	—	—	—	0.31	0.63	—
H ₂ O	1.35	1.5	1.4	1.8	2.4	0.28	0.12	0.12
	99.68	98.95	99.70	100.22	99.21	100.50	99.65	100.53

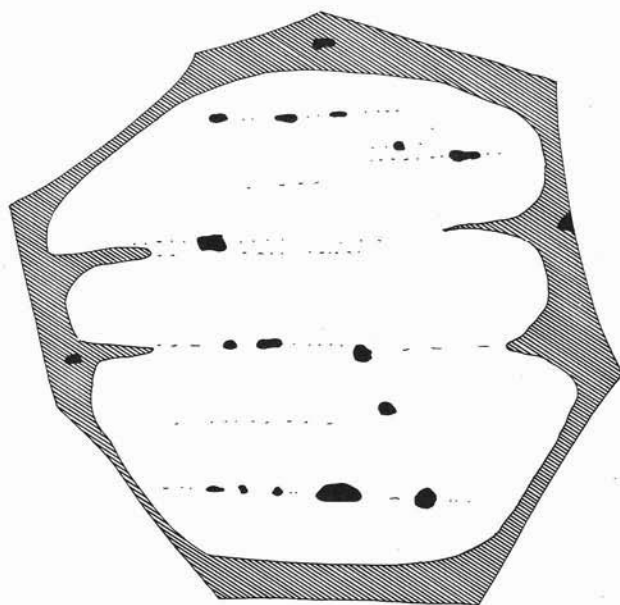


Fig. 12. — Drawing of a bread-crust bomb from Fossa 1888-90.

The juvenile-magmatic explanation of the bombs relies upon the reports of eye-witnesses who saw that the bombs were incandescent. But reports equally state that the blocks were ejected relatively dark and were heated to bright incandescence only during flight. This must have happened by gas reactions. The derivation from even a very viscous melt poses problems to explain the following observations:

- the angular form, which suggests an interpretation of the bombs as fragments of older rocks;
- bombs with relic textures of sintered pyroclastics (fig. 12) and of flow-banded rhyolites of the Lentia type;
- all transitions between bread-crust bombs and the angular non-pumiceous ejecta which were interpreted by all authors as fragments of older rocks;
- the pumice expansion of the inner parts of the bombs occurred mainly after landing. Large bombs show smooth bottom sides without expansion cracks, while the top side had burst open like a cabbage. WALKER (1969) set up the convincing argument that, the large bread-crust bombs, which attain several m³, are such fragile structures that they can have obtained this form only after their impact;
- chemical analyses show a considerable variation in composition as shown in Table 6;
- frequently the structure of the glassy crust cannot be explained by quenching but only by external fusion (fig. 12).

All observations on the bread-crust bombs of Vulcano suggest that they are blocks of older volcanic material, reheated to a viscous state. Only by gas reaction during the flight through the air did the outer zone reach fusion temperatures.

The reports of the 1888-90 activity convey the impression of an immense intensity of the explosive phenomena. This results probably from the tremendous detonations. The comparison of illustrations and maps of the crater area before the eruption (BALITZER, 1873; PISTOIA in DE FIORE, 1922, Tav. IV) with the present-day situation reveals no essential changes of the morphology. Photographs and descriptions of the eruption suggest phreatic effects during the eruption cycle.

Evolution of the Fossa - Up to now the Fossa was characterized as trachytic to rhyolitic by the composition of bread-crust bombs and Pietre Cotte obsidian (LACROIX, 1908; JAKOB, 1958) with a SiO₂ range of 60-73 %. According to the presented synthesis the Fossa evolved from leucite-tephrites to potassic trachytes. This same evolution is repeated on Vulcanello, but Fossa adds the phase of rhyolitic obsidians and vulcanian eruptions. Up to the present there exists no evolutionary link between the trachytes and the rhyolites.

The volcano-tectonic seismicity of Vulcano (BLÖT, 1971) is presently characterized by tremors at a depth of 2-2.5 km below the fumarolic area between Fossa and Vulcanello. The concentration of seismic foci suggests the presence of a possible common magma chamber for Fossa and Vulcanello.

7. Vulcanello

Vulcanello, the northerly peninsula of Vulcano is built up by a lava platform and three closely-spaced volcanic cones. Here, BÄCKSTRÖM (1896) identified leucite for the first time in the platform lavas. According to the most probable interpretation of historical accounts by PLINIUS and STRABO, which received new geological

support by KELLER (1970), Vulcanello appeared as a new island in 183 B.C.. Recent eruptions occurred in the 6th and 16 th centuries. Intense fumarolic activity persisted until 1878. About 1550 A.D. the former island of Vulcanello was connected with Vulcano by sand accumulation in the isthmus area.

The geological field evidence recognizes five main structural units on Vulcanello whose sequence is determined in the following manner:

recent	Vulcanello III (Western cone), 6th and 16th centuries
↑	Pelato-tephra, 6th century
↑	Trachytic Roveto flow
↑	Leucite tephrites of the platform
↑	Vulcanello II (Middle cone)
183 B.C.	Vulcanello I (Eastern cone)

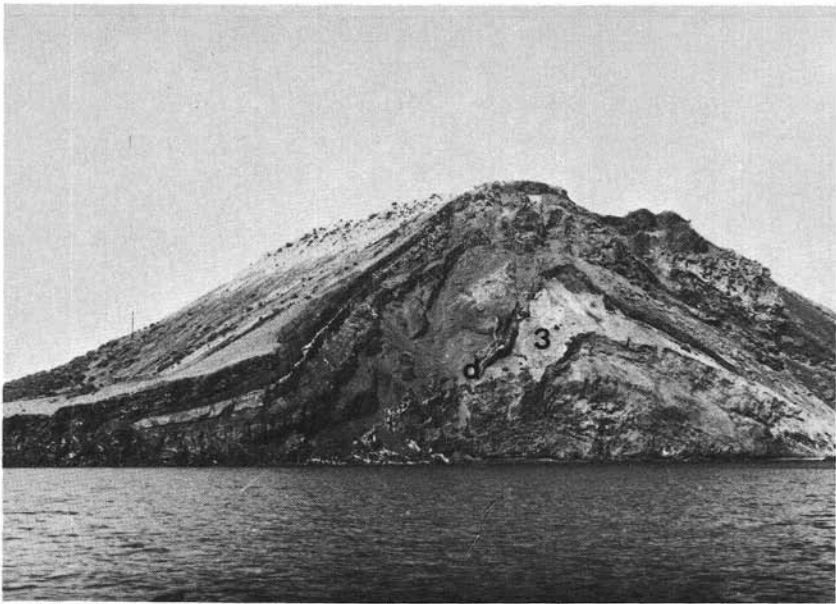


Fig. 13. — Cone of Vulcanello I. Numbers refer to DE FIORE's units as explained on p. 395. *d* = dikes.

The lava plateau - The lava platform of Vulcanello is the result of numerous successive effusions of fluid lava. The up-to-30-m-high sea cliffs of Vulcanello exhibit the superposition of up to 8 flows with only thin intercalations of flow scoria. On the surface ropy pahoehoe-lava forms are abundant. The effusion centers for the platform lavas are to be located West and South of the western cone and partly covered by its pyroclastic material. This zone is characterized by a high degree of fumarolic alteration of the material. Several hills which rise up to 10 meters above the plateau are not independent effusion centers, but rootless upwellings.

TABLE 7
New chemical analyses and norms of rocks from Vulcanello
 Other data in JAKOB, 1958 and BINI et al., 1973

	VO 18	VO 22	VO 24	VO 27	VO 42	VO 6	VO 37
SiO ₂	52.5	52.0	52.35	52.6	53.0	58.5	58.25
TiO ₂	0.7	0.68	0.68	0.68	0.7	0.6	0.53
Al ₂ O ₃	15.5	15.1	15.8	15.7	15.8	15.7	16.15
Fe ₂ O ₃	4.10	3.5	3.7	2.95	3.0	2.90	2.55
FeO	4.90	4.55	4.6	5.15	4.9	3.55	3.7
MnO	0.16	0.11	0.15	0.12	0.10	0.16	0.09
MgO	4.6	5.2	4.75	5.05	5.4	3.3	3.0
CaO	8.3	7.8	8.1	7.9	8.0	5.1	5.3
Na ₂ O	3.6	3.6	3.8	3.6	4.4	3.9	3.7
K ₂ O	4.6	4.7	4.85	4.75	3.4	5.3	5.4
P ₂ O ₅	0.47	0.52	0.39	0.45	0.47	0.37	0.39
H ₂ O	0.5	1.85	0.5	0.75	1.1	0.3	1.0
	99.93	99.61	99.67	99.70	100.27	99.68	100.06
<u>CIPW-NORM</u>							
Q	-	-	-	-	-	1.96	2.06
or	27.15	27.77	28.65	28.06	20.09	31.28	31.90
ab	20.94	20.73	18.34	20.06	28.12	32.97	31.29
an	12.54	11.17	11.74	12.66	13.33	9.67	11.52
ne	5.15	5.27	7.48	5.63	4.93	-	-
di	20.84	19.35	20.82	19.08	18.75	10.83	9.92
hy	-	-	-	-	-	6.43	6.63
ol	4.45	5.91	4.58	6.85	7.19	-	-
mt	5.96	5.07	5.36	4.28	4.35	4.21	3.70
il	1.33	1.29	1.29	1.29	1.33	1.14	1.00
ap	1.11	1.23	0.92	1.07	1.11	0.88	0.92

VO 18: Leucite tephrite, platform lava. South of P. 27 (Anal. WEIBEL); VO 22: Leucite tephrite, dike in center of Eastern cone; VO 24: Leucite tephrite, platform lava, P. 25 (Anal. RASCHKA & LODZIAK); VO 27: Leucite tephrite, platform lava, P. 28; VO 42: Analcitic tephrite, platform lava, Punta dello Scoglito; VO 6: Trachyte, Roveto flow, Punta del Roveto (Anal. WEIBEL); VO 37: Trachyte, vitrophyric bomb of Vulcanello III (Western cone).

The platform lavas are petrographically uniform. Analyses of Table 7 reveal the chemical composition varies much less than expected from the published analyses (JAKOB, 1958).

The pyroclastic cones of Vulcanello and il Faraglione - As the oldest unit of Vulcanello, the *cone I* rises about 100 m above sea-level. Its eastern flank is opened by marine erosion and exhibits a splendid section of the inner structure of a pyroclastic cone (fig. 13). Right in the center a feeding dike is exposed, indicating a fissure type vent. DE FIORE (1922, p. 97, 109) described the sequence of the section and numbered the units. This is given here with slight modifications.

11. Subterminal lavas of cone I (leucite tephrites)
10. Scoriae deposit of Strombolian activity
9. Terminal lava flows (leucite tephrites)
- 6-8. Ash- and lapilli-tuffs
5. Lava-like bank of strongly agglutinated scoriae (leucite tephrite)
- 2-4. Lapilli tuffs

TABLE 8
Mineral analyses from leucite tephrite of Vulcanello

	Phenocrysts				Groundmass		
	olivine	plagioclase	augite	opaque	leucite	augite	leucite
SiO ₂	37.3	54.8	50.2	0.24	56.2	51.1	56.9
TiO ₂	0.03	—	0.66	6.9	0.06	0.41	0.08
Al ₂ O ₃	—	28.0	3.4	5.9	21.7	3.0	21.5
FeO total	27.6	0.61	8.8	74.1	0.51	5.4	0.71
MnO	0.71	—	0.20	0.34	—	0.13	—
MgO	34.1	0.09	13.5	3.0	—	14.9	0.08
CaO	0.35	9.7	21.7	0.05	—	22.2	—
Na ₂ O	—	4.8	0.40	—	0.06	0.36	0.08
K ₂ O	—	1.6	—	—	20.3	0.05	20.1
Cr ₂ O ₃	0.05	—	0.06	0.21	—	0.17	—
NiO	—	—	—	0.09	—	0.07	—
BaO	—	0.17	0.14	—	—	—	—
	100.14	99.77	99.06	90.83	98.83	97.79	99.45

— = below detection limit. Electron microprobe analyses by A. CUNDARI.

DE FIORE's « basal lavas » as unit (1) are dropped, his lava-unit (5) is interpreted as scoriae deposit. This scoriae carries a large quantity of quartzitic and quartz-feldspatic xenoliths.

The middle cone, *Vulcanello II*, appears with Vulcanello I as one single cone. Almost no insight into its inner structure is exposed. Both cones are circumflown by the platform lavas whereas the western cone, *Vulcanello III*, is superimposed on the lava platform.

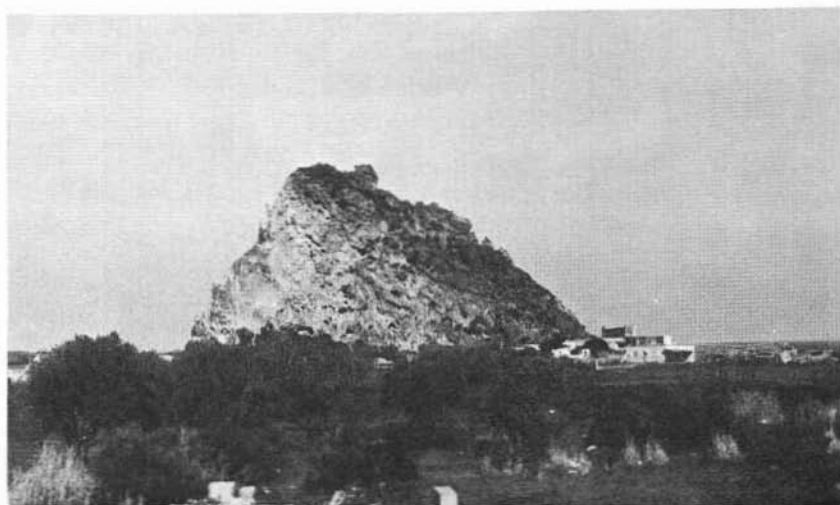


Fig. 14. — Il Faraglione seen from South. Remnant of a leucite-tephrite cone comparable to Vulcanello I and II.

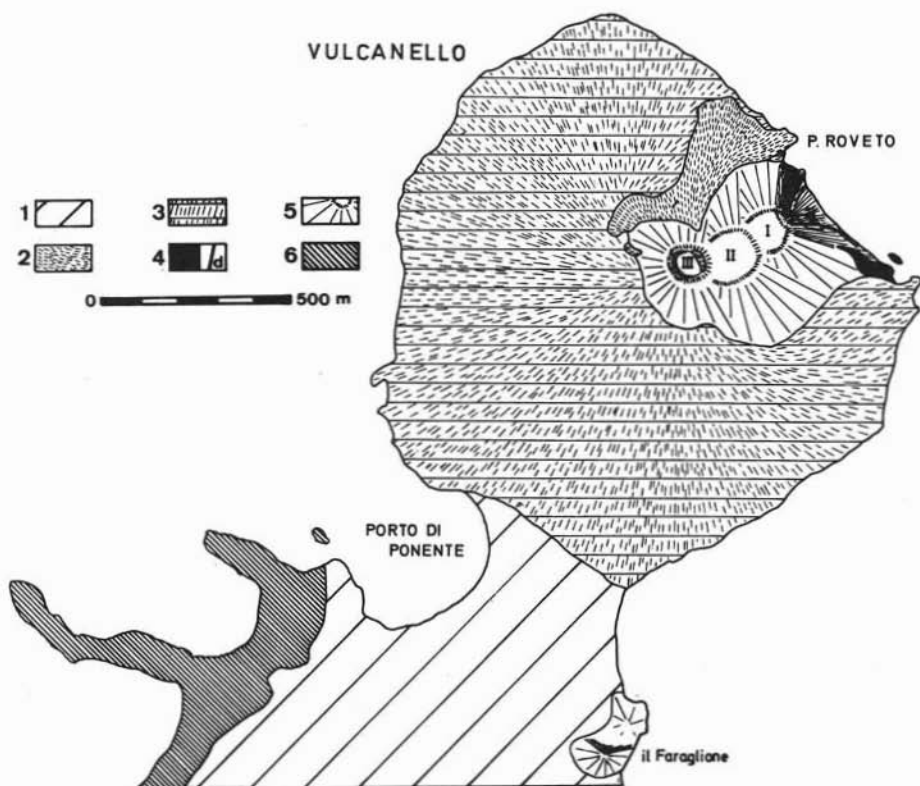


Fig. 15. — Geological map of Vulcanello. - 1 - Alluvium of the isthmus area and Piano del Porto; 2 - Trachytic Roveto flow; 3 - Leucite-tephritic platform-lavas; 4 - Leucite-tephritic lavas of Vulcanello I, *d* = dike; 5 - Lentia mountains.

Petrographically the material of Vulcanello I and II does not differ from the leucite-tephritic platform lavas. Analysis VO 22 represents the central dike of the eastern cone. JAKOB (1958) published analyses for DE FIORE's units 5 and 9.

The crater of Vulcanello III has a completely fresh morphology. Older rocks were already extremely altered by fumarolic activity when they were covered by the tuffs of crater III. By tephrochronological correlation with the aid of the Monte Pelato tephra from Lipari the formation of Vulcanello III has been attributed to the 6th century A.D. (KELLER, 1970). Within the tuff profile of Vulcanello III an erosion unconformity with plant relics proves a certain hiatus within the Vulcanello III activity. The organic matter was radiocarbon dated and gave an age of 325 ± 100 C-14-years B.P. This result, together with a hitherto not considered activity report for the year 1550 B.P. (1), speaks clearly for a Middle-Ages activity of Vulcanello III. Fumarolic activity ceased only in 1878.

Vulcanello III is a trachytic volcano. Scoriae and vitrophyric bombs were emitted towards the end of the activity. Their composition is given under VO 37 in Table 7. They are close in composition to Roveto flow and trachytic Fossa. Predominant among the pyroclastic products of this cone are fine-grained red and grey-green ash-tuffs with fine bedding of the type already described from the trachytic stages of Fossa Rossa and Forgia Vecchia (fig. 10).

At Porto di Levante the crag of il *Faraglione* rises up to a height of 65 m. In spite of extreme fumarolic alteration of the material, destruction by marine erosion and by former exploitation of sulphur and alunite complicated the interpretation of its volcanic structure. The Faraglione can be explained as a remnant of a pyroclastic cone comparable in size with Vulcanello I and II. Even in the altered material the originally leucite-tephritic composition can be shown (KELLER, 1972). Il Faraglione is therefore considered as part of the earlier Vulcanello evolution. Fig. 15 shows the main part as remnant of a cone with southwards dipping tuff strata.

The lava flow of Punta del Roveto - From the northern flank of cone II a trachytic lava flow was emitted which ends in Punta del Roveto. It is clearly younger than the platform lava, but covered by the tuffs of Vulcanello III. The flow is morphologically superimposed onto the platform and very individualized by its higher viscosity as compared with the leucite tephrites. In petrographical appearance and chemical composition (VO 6 in Table 7) this trachyte is almost indistinguishable from the trachytes of the Fossa.

At variance with the clear field relationship between platform leucite tephrites and the trachytic Roveto flow (fig. 15) are the misinterpretations and discussions about these relationships which have continued ever since 1896 (see BÄCKSTRÖM, 1896; BERGEAT, 1899; DE FIORE, 1922; JAKOB, 1958; BINI et al., 1973). Emphasis must be

(1) FAZELLUS (1955): «Tertia insula Vulcanellus... quae et ignem aliquando evomit» (citation from DE FIORE, 1922).

laid on the key outcrop, the cliff section near Punta del Roveto: the Roveto flow covers the preexisting leucite-tephritic platform. Consequently the leucite-bearing lavas appear at the base of the cliff followed higher up by the trachytic Roveto lava. (That's why people in almost regular alternation found either tephrite or trachyte at this locality).

8. Chronology of the volcanic phenomena on Vulcano

The relative sequence of the volcanic formations is given in the legend of the geological map and has been followed in the previous chapters. The major units and events are:

younger	Vulcanello
	Fossa di Vulcano
	Alighieri formation, Grotte dei Rossi tuffs
	Collapse of Caldera della Fossa
	Lentia group
	Sheets of agglutinated scoriae
	Intracaldera activity
	Multiple collapse of Caldera del Piano
older	Primary cone of Southvulcano

Very few direct arguments for the stratigraphical age determination are available on Vulcano. However, with comparisons to other islands and with the aid of tephrochronological correlations the frame of the stratigraphy was established (Tab. 9).

Marine terraces - It was shown by KELLER (1967) and PICHLER (1968) that an older group of Aeolian volcanoes is rimmed by terraces of Quaternary raised beaches and that a more recent group shows no traces of higher sea level. The pre-erosion volcanism is Middle Pleistocene and radiocarbon dating and tephrochronology demonstrated an Upper Quaternary age for the younger, post-erosional group of volcanoes i.e. their formation during the Last Glaciation or the Holocene.

Vulcano belongs to this younger group. No submarine volcanic rocks occur, no trace of higher sea levels are present.

Tuff-loess - A problem in the geology of the Aeolian Islands was always the origin of yellow-brown, very fine volcanic material, for which BERGEAT (1899) introduced the name tuff-loess. It covers most of the islands with a thickness of several meters and is prominently represented in all late Pleistocene (Würm) profiles of Salina, Lipari, Panarea and Filicudi. The Aeolian tuff-loess is indeed wind-transported volcanic ash and is now explained as shower soil, deriving directly from the continuing activity of Southvulcano. A suitable source volcanism of high explosivity developed mainly in the latest stages of the pre-caldera stratocone, and during the filling of Caldera del Piano. TAYLOR (1933) described such shower-soil

TABLE 9
Stratigraphical synopsis of the evolution of Vulcano

TIME COLUMN (not scaled)	VOLCANISM	PRODUCTS	PETROGRAPHIC TYPE	VOLCANOTECTONICS	IMPORTANT EVENTS ON NEIGHBOUR-ISLANDS
1800-1800	Last eruption of Fossa	blocks, sand, bread-crust bombs	resurgent		
1700	Pietre Cotte Forgia Vecchia craters	obsidian flow ash, blocks	rhyolitic trachytic		
1500	Vulcanello III	ash-tuffs, vitrophyric bombs	trachytic		
	Vulcanello III Fossa Rosse	ash-tuffs ash-tuffs	trachytic		
600	Upper Pelato Tephra				Lipari: Upper Pelato Pumice Obsidian flows
	Trachytic Fossa lavas	lava flows	trachytes		
183 B.C.	Platform lavas and Vulcanello cones I & II	lava flows pyroclastics	leucite- tephrites		
	Fossa I	breccias sand-tuffs			
	Raja Lavas of Fossa	flows	lc-tephrites		
8,600- 11,000 B.C.	Lower Pelato Tephra				Lipari: Gebelotto-Obsidian Lower Pelato Pumice
HOLOCENE LAST GLACIATION	"Recent lava flows" and Alghieri formation	flows hyalotuffs & scoriae	tephritic	N-S fracture and dikes	
	Grotte-dei-Rossi Tuffs	ash-tuffs		Lentia scarp of Caldera della Fossa (IVa)	
	Lentia group	flows, domes	rhyolites trachytes latites		
	Welded-scoriae blanket	scoriae	trachyandesitic		Lipari: Guardia group
	South-Lipari Tephra				
	Molineu - Monte Rosso pyroclastics	scoriae, lapilli-tuffs	+trachybasaltic	Caldera della Fossa/ Piano scarp (IV)	Salina: Pollara
	Tephritic lavas within Caldera del Piano	flows	tephrites	Subsidence at unconformity III	
	Upper Grey Sandtuffs	sandtuffs		Segmental subsidence within Caldera del Piano, unconformity II	
	Piano-Luccia-Scoriae Lower Grey Sandtuffs La Sommeta cone Corvo lavafloes	welded scoriae sandtuffs cinder cone flows	trachybasalts trachybasalts		Tuff-loess accumulation e.g. Lipari, Salina Filiuoli, Milazzo Iachiatephre in tuffloess
	Primary stratocone of Southvulcano Spiaggia Lunga	strato-volcano	trachybasalts trachyandesites	Collapse of circular Caldera del Piano (I)	Salina: Porri Lipari: S. Angelo

deposits from New Zealand. They « are not only fine throughout, but also weathered for their full depth » (COTTON, 1944, p. 195). Among classical deposits in volcanology of similar aspect and origin to the Aeolian tuff-loess I would quote the Pahala Ash on the Island of Hawaii.

Main arguments for the origin of the Aeolian tuff-loess in the explosive activity of southern Vulcano are the following (see also the description of Salina in this volume):

1. The distribution pattern shows maximum thicknesses on both sides of Vulcano, i.e. Milazzo peninsula (Sicily) and Lipari island.
2. Typical tuff-loess is only lacking on Vulcano, where it must be represented by normal pyroclastic series.
3. Petrographic similarities exist between tuff-loess and the trachybasalts/trachyandesites of Southvulcano. The potassic character is recognized in bulk samples of tuff-loess. A sample from Cala S. Antonio at Capo Milazzo yielded 2.3 % K_2O at $SiO_2 = 51$ %, tuff-loess from Serro Favarolo/Salina has 1.5 % K_2O at 48 % SiO_2 .

TABLE 10

Microprobe data of phenocrysts in pyroclastics of Vulcano (Scoriae of Molineddu series) compared with crystals from coarser layers in brown «tuff-loess» of Vallone Ponte, Lipari

	VULCANO:						LIPARI:		
	augite (centre)	augite (rim)	magnetite	plagioclase	olivine (core)	olivine (rim)	augite	plagioclase	olivine
SiO_2	51.01	49.53	.11	52.54	36.77	35.78	50.32	53.03	36.54
TiO_2	.49	.67	9.14	-	-	-	.59	-	-
Al_2O_3	2.57	3.87	5.43	29.42	-	-	3.51	29.25	-
FeO_{total}	9.2	10.15	81.03	.73	28.91	33.20	8.96	.68	29.11
MnO	-	.14	.40	-	.73	.61	-	-	.60
MgO	14.18	13.08	3.25	-	33.38	30.08	14.15	-	33.5
CaO	22.13	22.09	.28	12.13	.34	.33	21.8	11.7	.25
Na_2O	.21	.37	-	4.08	-	-	.4	4.4	-
K_2O	-	-	-	0.80	-	-	-	.9	-
Cr_2O_3	.11	.09	.37	-	-	-	.14	-	-
An	-	-	-	59.3	-	-	-	55.3	-
Mg-value	73.1	69.7	-	-	67.0	62.0	73.8	-	67.0

The mineral content of the tuff-loess is dominated by augite and plagioclase. Conspicuous are the euhedral augite and plagioclase crystals of up to 0.5 mm $\varnothing$ which have been found in coarse tuff-loess layers in Vallone Ponte/Lipari and which are typical for pyroclastic rocks of Southvulcano and Caldera del Piano.

Tuff-loess is predominantly represented in the sequences belonging stratigraphically to the Last Glaciation. A direct age indication is the intercalation of the $\sim 25,000$ year-old Ischia-tephra (KELLER, 1969, 1971, and this volume). Used as evidence of continuous volcanic activity in Southvulcano a Würmian age of the latter is indicated.

Tephrochronological correlations - Lipari had three violent eruptions of rhyolitic pumice during the Upper Quaternary. All three pumice eruptions have been identified in form of tephra-layers within profiles of Vulcano (KELLER, 1970).

The pumice deposit of the Guardia group in southern Lipari («*Unterer Bimshorizont*» of BERGEAT, 1899) is younger than the 25,000-year Ischia tephra (KELLER, 1969, 1971a). This Lipari-pumice is characterized by its heavy mineral association of hypersthene-hornblende-augite-zircon. It can serve as reference level for an Upper Würm age (PICHLER, 1979). On Vulcano this tephra was found between Portella and Gelso, covered by the Quadrara unit. Consequently, eruptions in and around Caldera del Piano were going on during the uppermost Würm and are contemporaneous and in part younger than the rhyolites of Southern Lipari.

Two other tephra layers are composed of phenocryst-free rhyolitic pumice tephra with obsidian splinters, such as are only known from Monte Pelato on Lipari («*Lower Pelato pumice*» and «*Upper Pelato Pumice*»). The Lower Pelato Pumice is connected with the Gabelotto obsidian flow. A fission-track age of about 11,000 years was given by BIGAZZI & BONADONNA (1973) and neolithic artefacts taken from that same flow range in age until 8,000 years B.P.. An age which was corrected for thermal annealing of the fission tracks is $8,600 \pm 1,500$ years B.P. (WAGNER et al., 1976); 11,000-8,500 years are used here as best value. The «*Lower Pelato Pumice*» appears, 10-20 cm thick and with maximum grain-size of 2 cm Ø, immediately above Grotte dei Rossi tuffs and at the base of the oldest Fossa tuffs which cover the Vulcano Piano, Vallonazzo and Punta Luccia regions. The Upper Pelato pumice is historical and well dated for the 6th century A.D. (KELLER, 1971b; BIGAZZI & BONADONNA, 1973). On Vulcano/Vulcanello its fine-grained tephra is 5-10 cm thick. It served as tephrochronological tracer for Fossa (below Fossa Rossa) and Vulcanello (covering the plateau, but covered by Vulcanello III). A summary of the geological evolution is given in Tab. 9.

9. Petrology

9.1. NOMENCLATURE

The dominant feature of all volcanic products of Vulcano/Vulcanello is the potassic character of this alkaline suite. This becomes evident through K_2O/SiO_2 - and K_2O/Na_2O -relationships in figs 16 and 17, based upon chemical analyses in Tables 1, 2, 4, 5, 7. The encountered SiO_2 range is 48.5-73.5 wt%; a pronounced volumetric maximum is around 50-53 % SiO_2 .

In petrochemistry and mineralogy the volcanic rocks of Vulcano have the characteristics of the shoshonite association as described and defined by NICHOLLS & CARMICHAEL (1969), JOPLIN et al. (1972), JAKES & WHITE (1972). Shoshonitic rocks are high- to very high-K volcanics of broadly circumoceanic context. They occur characteristically in late stages of island arc evolution. Examples are to be found among others in Kamchatka, Japan, Indonesia, New Guinea and Fiji: JAKES & WHITE (1972); GILL (1970); MACKENZIE (1976); JOHNSON et al. (1976); WHITFORD and NICHOLLS (1976).

For Vulcano the adjective «shoshonitic» is applied to characterize the association as a whole. To the single rocks the traditional denominations are given

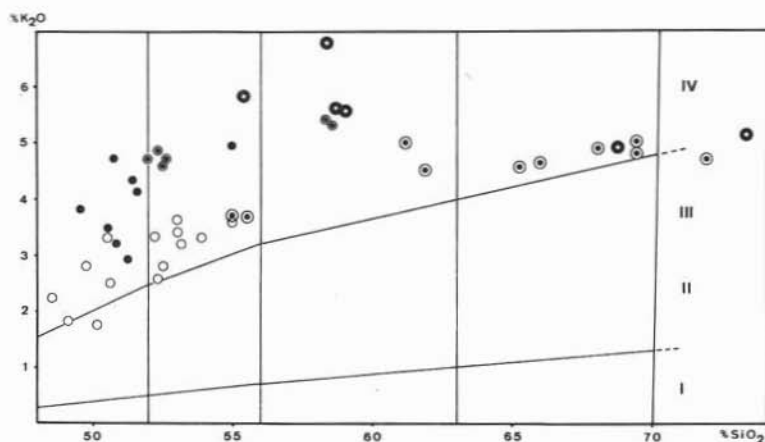


Fig. 16. — Potassium-silica relationship for Vulcano. Symbols as in fig. 18. Field boundaries from PECCERILLO and TAYLOR (1976). I = island arc tholeiitic series; II = calc-alkaline series; III = high-K calc-alkaline series; IV = shoshonitic series.

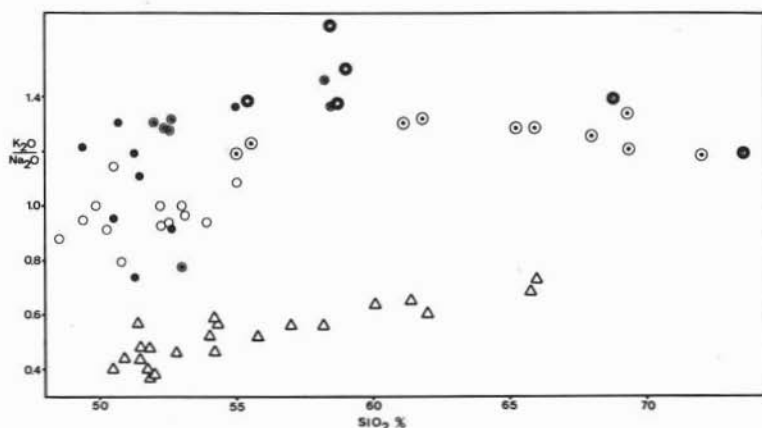


Fig. 17. — K_2O/Na_2O ratio vs. silica. Symbols as in fig. 18. Triangles represent the calc-alkaline series of Salina for comparison (KELLER, 1974).

(STRECKEISEN, 1967). For years, the basic members of Vulcano have been classified as trachybasalts and trachyandesites. In STRECKEISEN's classification (fig. 18) trachybasalt/trachyandesite is a comprehensive group with 10-65 % alkali-feldspar and falling on both sides of the quartz-saturation line. Here, a normative color index of 30 is used to distinguish between trachybasalts and trachyandesites. This limit most favorably corresponds with a SiO_2 -value of 52 % separating basaltic from andesitic rocks in the classification of PECCERILLO and TAYLOR, 1976 (cf. fig. 16).

Basaltic rocks with high alkalis and K_2O/Na_2O greater than 1 generally contain leucite. These rocks are called leucite tephrites, although falling in different STRECKEISEN pigeon holes. As they carry modal olivine they could also be classified as basanites.

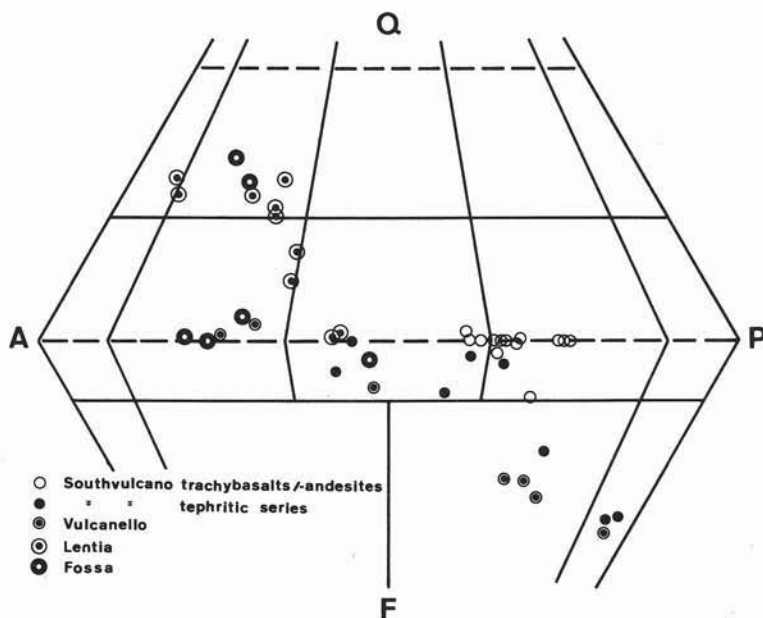


Fig. 18. — Quartz-plagioclase-alkali feldspar-feldspathoid grid of the STRECKEISEN (1967) classification, using the calculated mode of RITTMANN (1973).

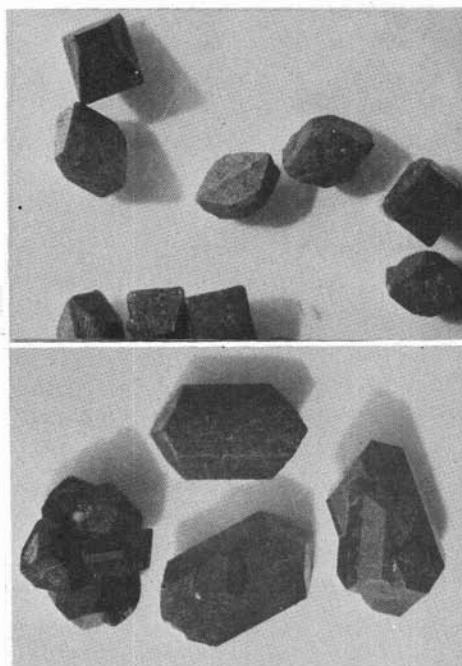


Fig. 19. — Phenocrysts of augite (~ 10 mm $\varnothing$) and olivine (~ 2 mm $\varnothing$) from pyroclastic series of Vulcano Piano (Molineddu Scoriae).

9.2. PETROGRAPHIC COMPOSITIONS

The mineral content of volcanic rocks from Vulcano is rather uniform. Plagioclase is the dominant phenocryst in most rocks and is joined by K-feldspar in the groundmass. Depending on chemical bulk composition, quartz or leucite may occur together with the two feldspars. Olivine, clinopyroxene and magnetite are the femic minerals, biotite is present in very few exceptions. Low-Ca pyroxenes are missing. A short description of the dominant phases is given as follows. Microprobe data are listed in Tables 8 and 10.

Augite - An augitic clinopyroxene is the most common mafic phenocryst and groundmass constituent in all rock types. All optical data (JAKOB, 1958; KELLER, 1972; BALDANZA et al., 1973; BINI et al., 1974) coincide on $Z\wedge c$ $39-44^\circ C$

and $2V_z$ 55-58°. The constant composition appears also from Tables 8 and 10 and from two augite analyses given by MACCARONE (1965). On the surface of altered lapilli-tuffs, especially from Vulcano Piano, euhedral augite can be collected in almost unlimited quantity. These are normally up to 1 cm long and exhibit a simple morphology with 100, 010, 110 and 011 (fig. 19).

Olivine - Olivine is a regular component of all basic lavas and persists in resorbed grains in the rhyolites of the Lentia group. With the loose augites of Vulcano Piano euhedral olivines (up to 4 mm Ø) have been found. They exhibit a simple combination of the faces 110, 010, 021.

Biotite - Presence or absence of biotite played a certain role in early description and volcanological correlations (e.g. MERCALLI, 1892; BERGEAT, 1899). It must therefore be stressed that phenocrystic biotite occurs exclusively in two minor pumice formations: Quadrara-pumice near Gelso and Palizzi-pumice of the Fossa. In scoriae of Luccia- and Quadrara-sheets, in lavas of Timpone del Corvo, in crystallized parts of Alighieri formation and in the latitic lavas of the Lentia group at Cala di Mastro Minico small flakes of pale, yellow, pleochroitic mica occur in groundmass-cavities and -schlieren. The mode of occurrence suggests a late, pneumatolytic origin.

Plagioclase - Most lavas are plagioclase-porphyric and contain plagioclase in the groundmass. Maximum anorthite content is 65 % (compared with An 90-95 in Aeolian calcaline rocks e.g. Salina or Filicudi). Optical determinations (JAKOB, 1958; KELLER, 1972; BALDANZA et al., 1973; BINI et al., 1973) yield the following pattern. Trachybasalts and trachyandesites have phenocrysts with An 65-55 and groundmass-plagioclases of An 60-50, leucite tephrites An 47-60 with lowest reported groundmass values of An 34. Lentia rhyolites carry phenocrysts of An 45-52 with lowest measured groundmass plagioclases of An 35. Lowest reported anorthite contents are from groundmass plagioclase of the trachytic lavas of Fossa and Vulcanello, where An 20-30 have been determined.

K-feldspar - Coexistence of plagioclase with K-feldspar in the groundmass of all rocks of the shoshonitic association has been found as an important feature. In tephrites and trachytes also the plagioclase phenocrysts have narrow rims of alkali-feldspar. K-feldspar forms phenocrysts only in the trachytes of the Fossa and of Vulcanello and sparsely in the Lentia rhyolites. Only in the trachytic Palizzi-pumice, which has the absolute highest K_2O content of 6.8 % (V 227) does sanidine exceed plagioclase in the phenocryst generation.

Leucite - The wide distribution of leucite-bearing lavas in different volcanological units of Vulcano is a new result. Leucite forms groundmass- and microphenocryst-grains of up to 4 mm Ø. Only after secondary analcitisation small whitish dots reveal macroscopically the presence of the feldspatoid. The twinning

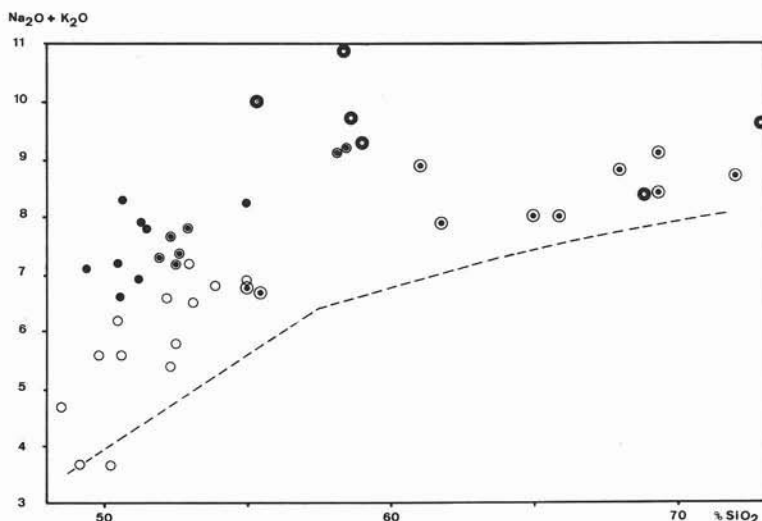


Fig. 20. — Alkalies vs. silica diagram for Vulcano. Symbols as in fig. 18. Broken line is upper limit of Kuno's hypersthenic rock series to which the calc-alkaline series of the Aeolian Islands belong.

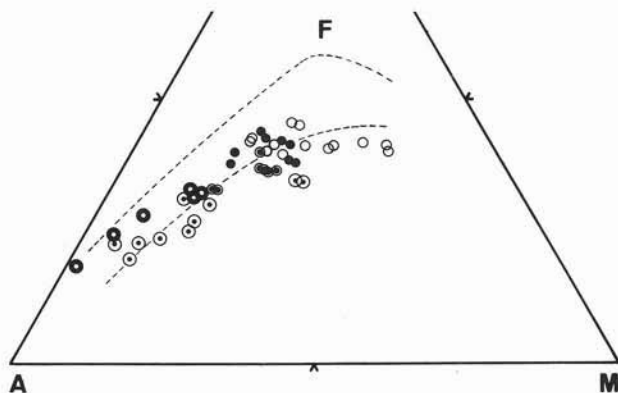


Fig. 21. — AFM diagram (alkalies/total iron/MgO) showing weak iron enrichment. Broken lines: Calc-alkaline field of Kuno (1960).

of anisotropic β -leucite is very rarely encountered; complete isotropy is rather characteristic of these leucites. JAKOB (1958) discusses the discrepancy between a measured refractive index of 1.495-1.503 and a literature value of 1.509. JAKOB's suggestion that a possible Na_2O content could lower the refractive index is not supported by microprobe data of Table 8. It is therefore likely that metastable α -leucite is preserved, whose refractive index is 1.497 (RINNE & KOLBE, 1910).

Quartz - Of the SiO_2 modifications tridymite is rather common as pneumatolytic pore filling. JAKOB (1958) mentions cristobalite. Quartz had never been reported.

It forms however the main part of the groundmass in microcrystalline rhyolites of the Lentia group. This is easily confirmed by total-rock powder-diffractometry.

Accessories - Besides the listed minerals and iron ores only apatite has been detected as primary accessory. Agglomerates, especially in the Quadrara region and Cala di Mastro Minico are often coated with pneumatolytic sublimation products of Fe_2O_3 .

9.3. MAJOR ELEMENT VARIATION

After the discovery of leucite in the lavas of Vulcanello (BÄKSTRÖM, 1896), this «enclave of the Mediterranean Province» was taken as exotic within the frame of the Aeolian Islands.

It now appeared that high-K is the rule on the whole island of Vulcano (and equally on Stromboli). By comparing averages of shoshonitic trachybasalts and

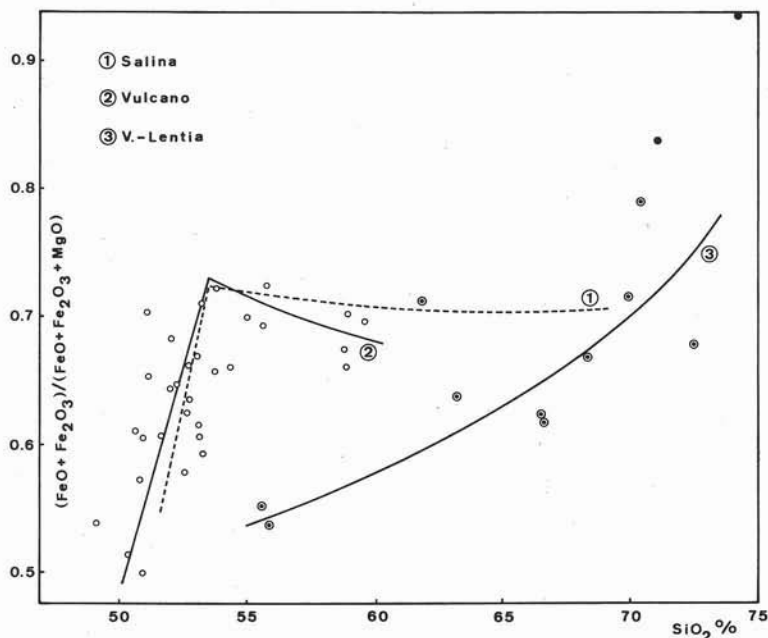


Fig. 22. — OSBORN plot for detailed iron-enrichment trends (OSBORN, 1976). Circles: shoshonite (trachybasalt)-leucite tephrite-trachyte series compared with the low-p/moderate f_{O_2} calc-alkaline fractionation of Salina. The rhyolite trend of Vulcano-Lentia approaches closely the high pressure evolution of OSBORN. Full points: Fossa rhyolites.

trachyandesites from Southvulcano with basaltic members of the calc-alkaline series (e.g. from Salina) it becomes evident, that there exists a close similarity in all element concentrations — excluding K_2O and related trace elements (KELLER, 1974).

In general, both associations are high in Al_2O_3 and low in total iron. Mg-values (molecular 100 $\text{Mg}/(\text{Mg} + \text{Fe}^{2+})$) around 60 are the most common in basic magmas of both series. Only a small group of trachybasalts in Caldera del Piano of Vulcano has low Al_2O_3 and Mg-values up to 68. In both associations, TiO_2 is low as typically found in the circum oceanic environment, but slightly higher with higher K_2O . No strong iron enrichment took place (fig. 21).

Thus, as a first approximation the Aeolian shoshonites are just extremely K_2O -enriched high-Al basalts. The «enrichment» process is open for a magmatological dispute. The main possible explanations to be considered or rejected are as follows:

- 1) crustal contamination;
- 2) low-level gaseous transfer;
- 3) source material differences;
- 4) source condition differences.

According to petrological composition and geological setting the following rock-types on Vulcano can be distinguished:

- 1) Trachybasalts and trachyandesites (Tab. 1) are the only rocks of the primary stratocone of Southvulcano, including the Spiaggia-Lunga unit and the Gelso-Petrulla secondary center. They constitute the dominant volume of lavas from Vulcano. The K_2O/Na_2O ratio is constantly around unity but total alkalis vary from 5.4 to 7.2. Al_2O_3 is high and Mg-values do not exceed 60. They are unlikely candidates for an unfractionated primary partial melt of the mantle. All rocks of Southvulcano are distinctly plagioclase-porphyritic with additional phenocrysts of augite, olivine and magnetite. Basic members can be rather rich in olivine. Hydroxyl-bearing minerals and orthopyroxenes are absent. The groundmass of the thin lava beds and of dikes is very fine-grained holocrystalline. Units which crystallized more slowly due to their thickness, show pilotaxitic textures of small plagioclase- and potassium feldspar laths, with grains of pyroxene and iron ores. The coexistence of plagioclase and potash feldspar in the groundmass is a typical feature of shoshonitic basalts.
- 2) Trachybasalts within Caldera del Piano (Table 2. V 147, V 90, V 194) have high color index, no plagioclase phenocrysts and Mg-numbers up to 68. Their alkalis are the lowest on Vulcano but K_2O/Na_2O is in the same range as always ($\sim$ unity). Al_2O_3 is low and CaO is very high. These are the most primitive magmas on Vulcano.
- 3) Leucite tephrites are distinct from trachybasalts/trachyandesites by still higher alkalis and with K_2O/Na_2O up to 1.4. Secondary transformation of leucite to analcite changes the chemical characteristics to $Na_2O > K_2O$. This explains chemical differences in published analyses. In Table 7 Analyses V 018, V 024, V 027 represent perfectly fresh material, whereas V 042 represents a sample purposely chosen with leucite completely transformed into analcite. The effect on K_2O/Na_2O is obvious. BINI et al. (1973) made 16 major element analyses of the platform lavas, which support the chemical homogeneity of the whole group, but again $K_2O/Na_2O \leq 1$ depends upon analcitisiation of the leucite. The grey and vesicular rocks of Vulcanello platform carry as predominant phenocryst clinopyroxene, with olivine and few but large plagioclases (up to 1 cm $\varnothing$, An 50). Compositions of the phases (by courtesy of Dr. Aldo Cundari - Melbourne) are given in Table 8. The groundmass has a trachytic texture of plagioclase.

TABLE 11
Major element chemistry and trace elements of representative samples

V U L C A N O : shoshonitic association								
	Trachyandesites and Trachybasalts			Leucite-tephrites			Trachyte	Rhyolite
	South-Vulcano			Piano	Fossa	Vulcanello	Fossa	Lentia
	V 46 ¹⁾	V 147 ¹⁾	V 62 ¹⁾	V 85 ²⁾	V 154 ¹⁾	VO 24 ²⁾	V 40 ¹⁾	VL 39 ²⁾
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 ₂ O ₃	15.9	13.0	18.5	16.0	18.3	15.8	16.3	13.85
Fe ₂ O 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 ₂ O	2.8	2.5	3.6	3.20	4.2	3.8	4.1	4.15
K ₂ O	2.8	2.2	3.6	3.90	5.8	4.85	5.6	4.95
P ₂ O ₅	0.3	0.32	0.42	0.4	0.52	0.39	0.34	0.09
H ₂ O ⁺	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

1) Anal. M. WEIBEL, Zürich (wet methods); 2) Anal. RASHKA & LODZIAK (BfB Hannover, RFA methods). Trace elements as 2); Vanadium by W. STERN, Basel, with optical spectrometry.

clase and potassium feldspar, with interspersed grains of pyroxene and magnetite. Leucite occurs as isotropic round grains of up to 0.4 mm Ø. More seldom it is

- represented by xenomorphic patches. Near the present-day sea-level, the flow surfaces are chilled and vitrophyric, without groundmass crystallisation. No leucite is present and clinopyroxene, olivine and plagioclase are the only phenocrysts.
- 4) Alkali-rich trachytes are final products of Vulcanello (Roveto flow and Vulcanello III) and constitute an important part of Fossa di Vulcano. They follow the leucite tephrites in direct evolution and appear to be late stage fractionation products of the latter. Their Mg-values are the lowest of all non-rhyolitic rocks of Vulcano and several trace elements have their highest concentrations in these trachytes (e.g. Zr, La, Ce).
- 5) The rocks of the Lentia group range from latites to rhyolites with SiO₂ 55-72 % (Tab. 4). Rhyolites predominate. The Lentia suite forms a petrochemically distinct group compared with the rest of Vulcano. This fact is most clearly elucidated from differences between the low-silica members, the latites of Mastro

TABLE 12
Uranium and Thorium contents of major rock types of Vulcano
(from CIVETTA & GASPARINI, 1973)

Vulcano island			Th ppm	U ppm	K%	Th/U
Vu 7	Cala Mastro Minico	Latite	18.4	7.9	2.06	2.3
Vu 28	Lentia	Rhyolite	47.8	14.6	4.53	3.3
Vu 29	Lentia	Rhyolite	34.2	11.9	3.44	2.9
Vu 84	P.ta Pietre Nere	Rhyolite	35.8	11.8	4.55	3.0
Vu 30	Mt. Seraceno	Trachyandesite	7.9	2.7	2.08	2.9
Vu 37	Spaggia Lunga	Trachyandesite	8.7	2.6	2.72	3.4
Vu 48	P.ta Bardiera	Trachyandesite	10.1	3.7	2.56	2.7
Vu 80	P.ta Pennata	Trachyandesite	7.8	2.7	1.97	2.9
Vu 79	Pietre Cotte	Rhyolite	57.5	17.0	4.03	3.4
Vu 45	P.ta Ufala	Trachyandesite	9.3	3.0	2.27	3.1
Vu 54	Passo del Piano	Trachyandesite	9.6	3.0	2.83	3.2
Vu 95	Spaggia del Piano	Trachyandesite	8.0	3.1	2.17	2.7
Vu 90	Vulcanello plateau	Leucite-tephrite	38.0	12.0	4.22	3.2

Minico, and lavas of South Vulcano. In latites from the Lentia complex the potassic character is more pronounced, Al₂O₃ is lower and Mg-values are generally higher than in rocks of Southvulcano with comparable SiO₂. K/Rb is lower and K/Ba is very low. Fig. 22 gives a separate evolution line for the Lentia rocks.

The petrographical composition of the rhyolites is characterized by the same minerals that occur in the more basic rocks of Vulcano: Plagioclase (An 45-50), more rarely K-feldspar, augite and small rounded grains of resorbed olivine are the phenocrysts. They are frequently glomerophyrically grouped. The groundmass is a microgranitic to microgranophyric intergrowth of quartz and K-feldspar. These crystalline rhyolites with a lithoidal aspect predominate by far over glass-rich vitrophyric and microvitrophyric varieties. Advancing devitrification forms radially fibrous, spherical patches. The latites of Cala di Mastro

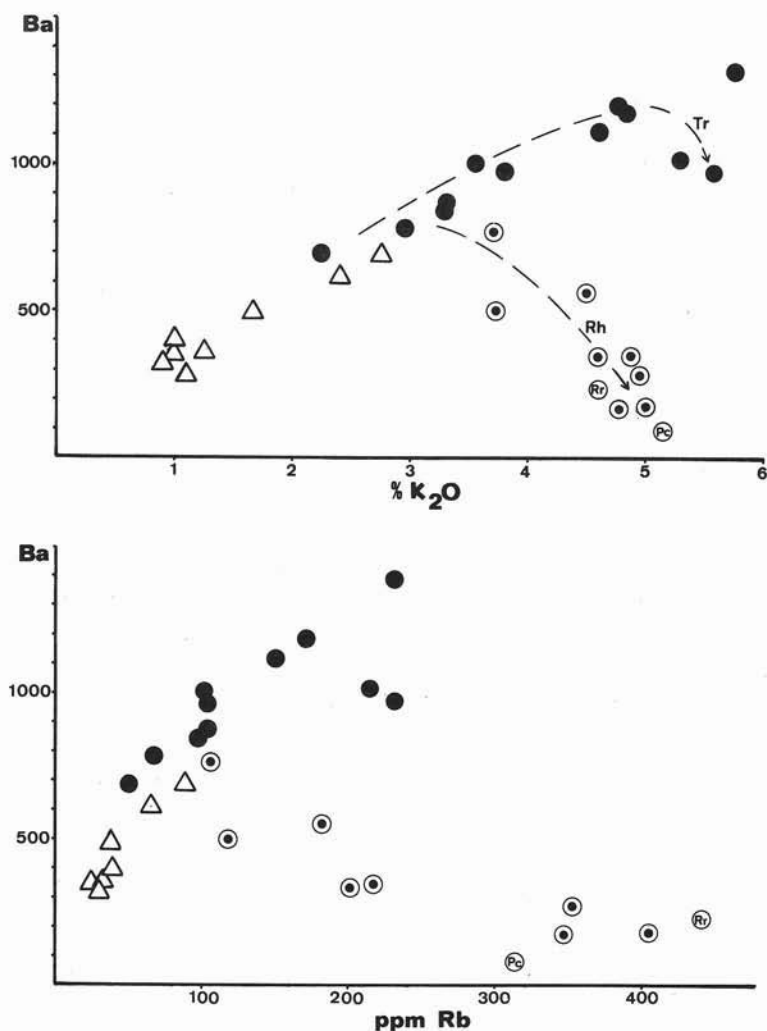


Fig. 23. — Ba/K₂O and Ba/Rb variations, showing a positive correlation with late-stage Ba depletion in trachytes (Tr) and in the Lentia series (circled dots, Rh for rhyolitic trend). Rr and Pc are samples of Rocche Rosse obsidian, Lipari and of Pietre Cotte obsidian, Fossa di Vulcano. Triangles: calc alkaline series of Salina.

Minico (anal. VL11 and VL23) have phenocrysts of augite, olivine and few plagioclase in an almost aphanitic groundmass.

9.4. MINOR AND TRACE ELEMENTS

Trace elements for the representatives of the main rock types are reported in Table 11. A first interest lies in comparison of trace elements with shoshonitic series outside the Mediterranean area (e.g. CHAPPEL & MACKENZIE, 1972, or the averages in JAKES & WHITE, 1972). Given the close neighborhood with calcalkaline series of the Aeolian arc, emphasis is also laid upon the differences in the trace element content of both associations (KELLER, 1974).

TABLE 13
 $^{87}\text{Sr}/^{86}\text{Sr}$ isotopic ratios in lavas from Vulcano

		$^{87}\text{Sr}/^{86}\text{Sr}$	Ref.
V 52	Shoshonitic trachybasalt, Southvulcano	0.7041	1
VL 5	Shoshonitic latite, Lentia	0.7045	1
It 18	Alkali-rhyolite, Lentia	0.7045	2
VL 5	Rhyolite, Lentia	0.7050	1
VL 25	Rhyolite, Lentia	0.7061	1
VO 18	Leucite tephrite, Vulcanello	0.7042	1
Vulc 72	Leucite tephrite, Vulcanello	0.7046	2

(1) from BARBIERI et al., 1974; (2) from KLERKX et al., 1974. Petrographic denominations of the author's, full chemical data for all samples from ref. (1) are given in the respective sections of this paper.

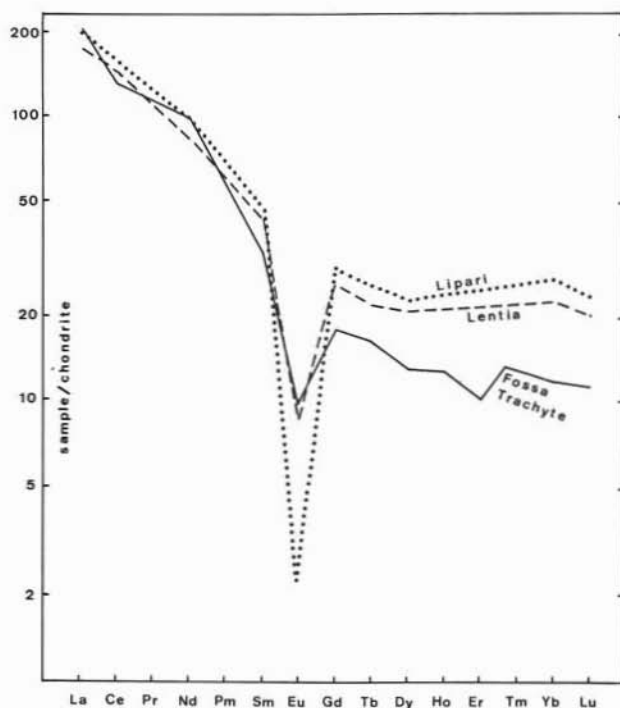


Fig. 24. — Rare earth element pattern of trachytic and rhyolitic late-stage fractionation products of Vulcano, compared with Rocche Rosse obsidian from Lipari. Data from KLERKX et al., 1976 and KIESEL et al., 1978.

The ferromagnesian trace elements (Co, Ni, Cr) show the low concentrations of the circum-oceanic environment. Vanadium is around 200 ppm in the basic end members. There is thus a close similarity in this element group between Vulcano and the calc-alkaline suite, e.g. Salina.

As expected, high K_2O is connected with high LIL element concentrations. Rubidium is strongly correlated with K_2O yielding K/Rb ratios which extensively overlap the range found for calc-alkaline rocks (KELLER, 1974). K/Rb decreases

from 400-300 for trachybasalts to 250-200 in leucite tephrites and associated trachytes. The Lentia forms a group with distinctly lower K/Rb. Ba, Sr, La, Ce, Zr show a regular increase with increasing K_2O . Only the trachytes of Fossa and Vulcanello, explained as late-stage fractionation products of the leucite tephrites, show a decrease in Ba and Sr, while Rb, La, Ce, Zr concentrations are amongst the highest values on Vulcano. The Lentia rhyolites have Rb up to 350 ppm and very low Ba and Sr, showing the most fractionated trace-element pattern on the island (fig. 23). Comparison of LIL element concentration in Vulcano shoshonitic basalts with the average given in JAKES & WHITE for the western Pacific shoshonites reveals similarly high Rb and Ba, distinctly higher Sr, La, Ce and Zr. Most prominent is the high level of U and Th which amount to 8-10 ppm Th and 2.6-3.7 ppm U in the shoshonitic basalts (CIVETTA & GASPARINI, 1973, see Table 12). In the step from shoshonitic basalts («trachybasalts and trachyandesites») to leucite tephrites, e.g. from Vulcanello, all LIL elements further increase with increasing K_2O . Thorium (24-38 ppm) and Uranium (7-12 ppm) have extreme concentrations in the leucite tephrites (KLERKX et al., 1974; CIVETTA & GASPARINI, 1973). As demonstrated, the high K_2O of Vulcano is strictly connected with high LIL element concentrations. Among the LIL elements it is interesting to note that the high level of strontium is not caused by apport of radiogenic Sr (Table 13). If, as it seems, high K and high Sr are genetically connected then a crustal-contamination explanation for the potassic character is excluded.

Available Sr isotopic data (Table 13) give as the most primitive ratio for all major rock groups (i.e. shoshonitic basalts, leucite tephrites and rhyolites) values of 0.7040-0.7045. An isotopically similar source for all series on Vulcano can be assumed from this fact. However, for single samples with higher $^{87}Sr/^{86}Sr$, contamination must be accepted.

Few data are available for complete sets of rare earth elements. KLERKX et al. (1974, 1976), KIESEL et al. (1978) give REE spectra for a leucite tephrite of Vulcanello, a trachyte and for alkali-rhyolites from the Lentia mountains. Moreover, XRF data can be used to evaluate the extent of LREE fractionation. As an approximation we may deduce from all available Aeolian data that an average of 8-10 times chondritic HREE can be extrapolated for the basic end members of the exposed series of Vulcano.

Along with LIL element enrichment in the potassic suite the LREE increase to ~ 100 x chondritic in shoshonitic basalts and ~ 170 x chondritic in leucite tephrites. This contrasts with values of 40-70 x chondritic in the calc-alkaline basalts. The europium anomaly of leucite tephrites with $Eu/Eu^* = .78$ reported by KLERKX et al. (1974) points to a plagioclase effect in the evolution of these magmas. A negative europium anomaly is very pronounced in the Lentia rhyolites and in the trachytes (fig. 24). We have however, in the moment of writing this report, no data for Eu in the shoshonitic trachybasalts/trachyandesites. They might lack any Eu anomaly if we take samples from Stromboli (KLERKX et al., 1974) as possibly analogous.

9.5. MAGMATOLOGICAL CONCLUSIONS

A great chemical variety of rocks and several distinct evolutionary series participate in the composition of the Island of Vulcano with Vulcanello. Common feature for all is the potassic character with K_2O/Na_2O around unity even in the less alkaline, most femic and most magnesian members and increasing ratio in the more fractionated types. The most primitive, less fractionated magmas are trachybasalts of the intra-caldera activity represented by the analyses V 90, 194 and 147. Dominantly clinopyroxene (with minor olivine) fractionation leads to the most common lavas of Vulcano, the trachybasalts/trachyandesites of South-vulcano stratocone with their high-Al, increasing alkalinity, constant K_2O/Na_2O and lower Mg-value characteristics.

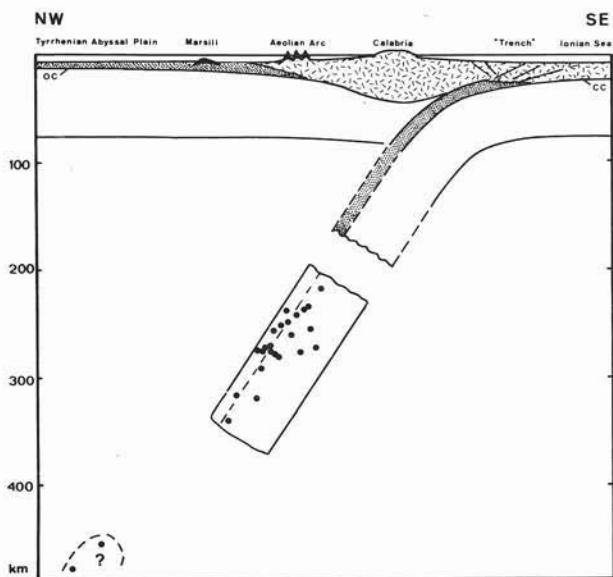


Fig. 25. — SE-NW section through the Aeolian Island Arc system. All subcrustal earthquake centers (> 50 km deep) in a 100 km strip along profile line in fig. 1 are given as dots. Gap in seismic activity between 50 and 200 km is interpreted as detached slab. From KELLER, 1979 c. oc = oceanic crust; cc = continental crust.

A line of obviously low-pressure fractionation (fig. 22) links trachybasalts with leucite tephrites and the late stage trachytes of Fossa and Vulcanello, where alkalinity and potassic character reach a maximum. Clearly, clinopyroxene-plagioclase fractionation played a role in the evolution of the leucite tephrites. This series is characterized by maintaining high Mg-values in intermediate members, low Al_2O_3 level throughout the range and early increase of K_2O/Na_2O ratio. Trace elements are characterized by steady decrease of Ba and Sr with increasing silica (fig. 23). For rhyolitic end members a very pronounced Eu anomaly is demonstrated (KLERKX et al., 1974). Early participation of plagioclase in the fractionation is sug-

gested. The iron-enrichment plot of the Lentia Series (fig. 22) is interpreted as high-pressure fractionation (> 8 kb, OSBORN, 1976).

The most magnesian trachybasalts of Vulcano, with Mg-values of 67-68, come close to the range of possible melts in equilibrium with a hydrous mantle peridotite. A mantle source for the primary magmas is in accordance with reported $^{87}\text{Sr}/^{86}\text{Sr}$ isotopic abundances. Characteristic features of the shoshonitic series, as high K, Rb, Ba, Sr, LREE are already present in the most unfractionated members.

In the light of all presented data the shoshonitic trace element concentrations appear to be magma source characteristics. But the closely related calc-alkaline basalts of the neighboring islands would not support the postulate of a LIL enriched mantle on a regional scale. Only with progressing arc evolution did the mantle become capable of yielding the LIL enriched pattern. The increase in K_2O and related trace elements and in $\text{K}_2\text{O}/\text{Na}_2\text{O}$ ratio of the most primitive members of the different series of the Aeolian Islands has shown to be time-controlled within the broader evolution of the island arc. The major differences are not successfully explained by different degrees of partial melting within similar mantle source material.

The remaining possibility is to relate K_2O content to the vertical depth of the underlying BENIOFF zone. This is the $K-h$ model of DICKINSON & HATHERTON (1967). NIELSON & STOIBER (1973), MARSH & CARMICHAEL (1974) and WHITFORD & NICHOLLS (1976) established and refined such correlations for different island arcs. A genetic explanation of that correlation for mantle-derived island arc magmas given by NICHOLLS & RINGWOOD (1973) and RINGWOOD (1974) suggests introduction of K_2O and related trace elements to the partial melting source mantle with H_2O or H_2O -rich melts. These fluids are scavenged from the slab and mantle and their ultimate element concentration is controlled by the increasing depth of the slab and by the different thickness of traversed mantle.

For the Aeolian islands a simple K_2O -depth correlation is not given, due to the clustering of low-, intermediate- and high-K volcanoes (KELLER, 1974). If related to a single BENIOFF zone a very steep, almost vertical configuration of the BENIOFF plane must be expected. The observed deep-focus earthquakes (fig. 25) underneath the Aeolian Islands are > 200 km deep and reach depths of > 350 km (PETERSCHMITT, 1956; CAPUTO et al., 1972; NINIKOVICH & HAYS, 1971; SCHICK, 1972). Extrapolating from other island arcs this depth range broadly fits with the potassic nature of Vulcano whereas any seismicity in a depth range expected to be related to strictly calc-alkaline activity is missing. This compares favorably with the geological result of an older age and earlier ceasing of calc-alkaline volcanism with its lower K_2O level. Discontinuity in the subduction process with a gap in present-day seismicity between 50-200 km is explained with the model of a detached slab (fig. 25).

