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THE ISLAND OF SALINA

ABSTRACT. — The volcanological evolution of the Island of Salina is described to accompany the geological map 1 : 10,000. During the last 0.5 m.y. six volcanic edifices were built up, five stratovolcanoes and one large explosion crater. Four stratocones, Capo, Rivi, Corvo and Fossa delle Felci, form the Middle Pleistocene part of the island. The lavas are predominantly high-alumina basalts with dacites and andesites as the final products. A longer period of inactivity led partly to marine destruction of these cones and to the formation of Quaternary raised beaches in several terrace levels.

During the Last Glaciation (« Würm ») activity started again with a post-erosional cycle building the 860-m-high andesitic cone of Monte dei Porri and ending with the formation of the explosion crater of Pollara 13,000 years B.P.

Among the seven islands of the Aeolian arc Salina exhibits a high-alumina basalt-andesite-dacite suite with the most typical calc-alkaline characteristics of circum-Pacific island arcs, e.g. K_2O content, K_2O/Na_2O ratios, high Al_2O_3, low TiO_2, weak iron-enrichment.

Large cation trace elements (Rb, Sr, Ba together with U, Th, LREE) are markedly enriched compared with andesitic averages from Pacific island arcs. $^{87}Sr/^{86}Sr$ ratios average to 0.7046. Parental high-alumina basalts have $Mg/Mg+Fe^{2+}$, Ni and Cr contents too low for being unfractionated primary mantle melts. But their composition is consistent with a short-way fractionation removing mainly olivine from primary mantle melts. The basalt-andesite-dacite suite is explained as fractionation series under dominantly low pressure.

RIASSUNTO. — L'isola di Salina è costituita dai prodotti di sei principali edifici vulcanici che si sono sviluppati negli ultimi 0,5 m.a.. Cinque di tali edifici presentano strutture tipiche di strato-vulcani centrali ed il sesto è rappresentato da un vasto cratere di esplosione.

Il ciclo di attività riferibile al Pleistocene Medio è costituito dai prodotti degli strato-coni di Corvo, Rivi, Capo e Fossa delle Felci, in cui prevalgono i basalti ricchi in allumina, con subordinate andesiti e daciti nelle fasi finali.

Un lungo periodo di quiescenza nell'attività vulcanica è messo in evidenza da un'intensa fase erosiva, con formazione di livelli terrazzati di abrasione marina a carattere glacial-eustatico.

Solo nel corso della glaciazione Wurmiana si realizzava una ripresa dell'attività eruttiva, che dava luogo al ciclo vulcanico post-erosivo, cui vengono attribuiti lo strato-vulcano andesitico di Monte dei Porri ed il cratere esplosivo di Pollara. Quest'ultimo rappresenta il risultato di una violenta fase esplosiva verificatasi circa 13.000 anni or sono.

Nell'ambito del vulcanismo dell'arco Eoliano l'associazione magmatica di Salina, costituita da basalti ricchi in allumina-andesiti-daciti, presenta caratteristiche tipiche degli archi vulcanici circum-pacifici. Le analogie riguardano il contenuto in K_2O, il rapporto K_2O/Na_2O, l'elevata concentrazione in Al_2O_3, il basso contenuto in TiO_2 ed un debole arricchimento in ferro.

Gli elementi in traccia del tipo Rb, Sr, Ba, LREE, U e Th risultano nettamente arricchiti rispetto ai valori medi riportati per le andesiti degli archi insulari circum-pacifici. Il rapporto

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$^{87}Sr/^{86}Sr$ denota un basso contenuto in Sr radiogenico, presentando un valore medio di 0,7046.
I magmi meno differenziati della serie affiorante sono rappresentati da basalti ricchi in allumina che mostrano un rapporto $Mg/Mg + Fe^{2+}$, nonchè concentrazioni di Ni e Cr troppo basse per rappresentare un liquido di fusione parziale del Mantello che non abbia subìto alcun processo di frazionamento. La loro composizione suggerisce infatti un debole frazionamento a partire da liquidi primari in equilibrio con il Mantello.
La successione basalto-andesite-dacite viene considerata come il risultato di un ulteriore processo di frazionamento realizzatosi in condizioni di bassa pressione, presumibilmente all'interno della Crosta.

1. Introduction

Salina is with 26.75 km² the second largest island of the Aeolian Arc. Its steep volcanic cones of Fossa delle Felci (962 m) and Monte dei Porri (860 m) are amongst the highest elevations of the archipelago. Both volcanoes exhibit a youthful volcanic morphology and have well-preserved summit craters. Their products cover the ruins of three older volcanic edifices of formerly similar dimensions.

These are Monte Rivi, Serro del Capo and Pizzo Corvo.

A large explosion crater occupies the northwestern edge of Salina, and is named after the village of Pollara situated on the floor of the amphitheatre-like crater bowl which is open towards the sea. The coastal section provides an instructive profile through this crater and its pumice deposits.

The bathymetric map reveals a further submarine cone off the northeastern edge of the island, rising from a 2000-m-deep sea floor to only 7.5 m below sea level in Secca del Capo (fig. 1).

The two highest volcanic cones of Salina, Fossa and Porri are separated by the deep saddle of Valdichiesa (290 m). This gives the characteristic morphology, to which the ancient Greek name of the island, Didyme or twin-island, refers.

The recent name Salina refers to salt plants of Lingua in the SE corner of the island. The salt exploitation has now been abandoned, the salt pond still exists.

Salina was inhabited from neolithic times. Obsidian artefacts and flakes carried here from Lipari can be found on all flat lying fields of the island, up to the crater depression of Fossa delle Felci, the highest peak of the islands.

2. Geological evolution

The morphological division of the island reveals the main volcanological units. Distinguishing an eastern and a western part of the island, divided by the incision of the north-south running Valdichiesa, the following volcanic centers are recognized; the numbers refer to age groups:

Eastern Salina	*Western Salina*
Capo volcano (1)	Corvo volcano (1, 2)
Rivi volcano (2)	Monte dei Porri (4)
Fossa delle Felci (3)	Crater of Pollara (5)

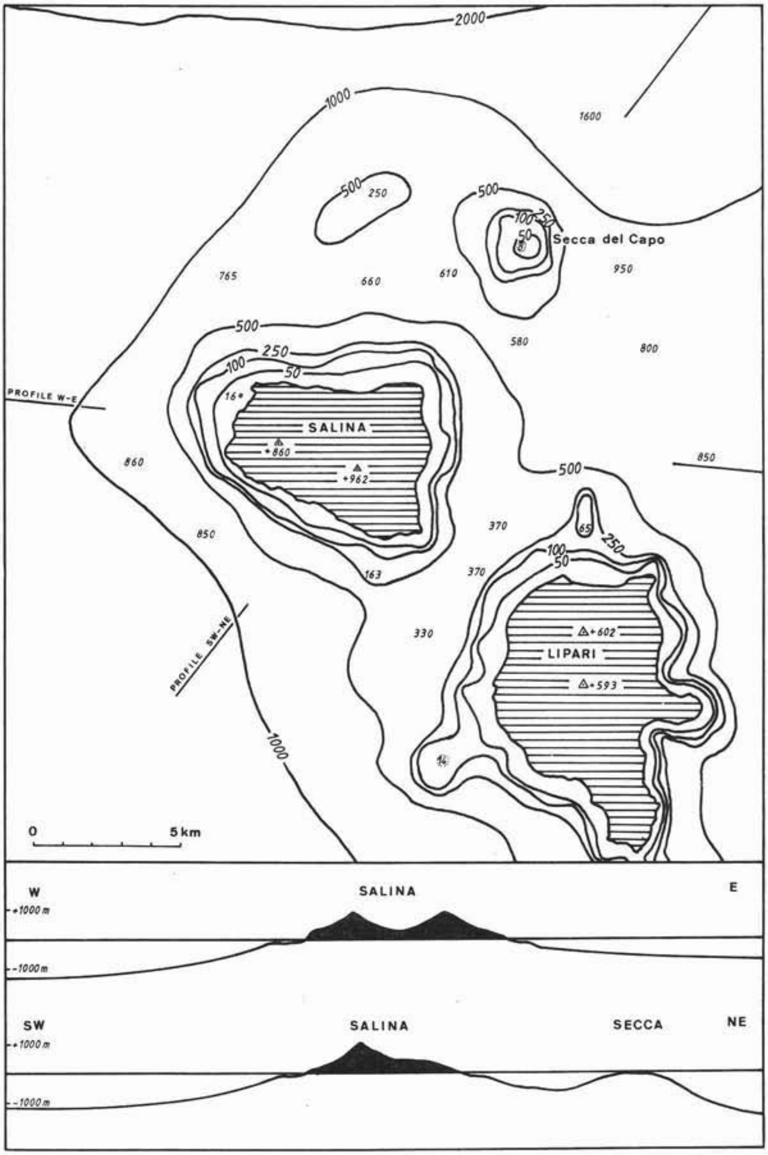

Fig. 1. — Bathymetric map of Salina and surroundings.

Stratigraphical superposition yields age relationships with Capo, Rivi and Corvo as the oldest volcanoes, followed immediately by Fossa delle Felci (age groups 1, 2, 3). The oldest rocks yielded a K/Ar age of 0.5 m.y. B.P. (Barberi et al., 1974). A marked stratigraphical unconformity separates the younger volcanoes, Porri (4) and Pollara (5), from this first group. Accordingly, Capo, Rivi, Corvo and Fossa belong to a pre-erosional cycle and Porri with Pollara form the post-erosional group of Salina.

TABLE 1

High-Al basalts of the three oldest (middle Pleistocene) stratovolcanoes of Salina: Corvo, Capo and Rivi

Sample Sa	127	124	113	91	186	184	108	178
SiO_2	51.4	51.5	50.5	51.8	51.5	50.9	51.75	51.8
TiO_2	0.5	0.5	0.52	0.48	0.49	0.56	0.57	0.55
Al_2O_3	17.0	17.6	16.7	16.7	17.0	19.0	19.1	19.6
Fe_2O_3	4.2	3.6	3.2	3.1	7.1	6.3	3.8	4.7
FeO	5.1	5.7	6.5	5.8	2.7	3.1	5.5	4.8
MgO	6.1	6.4	7.0	7.0	7.3	5.3	4.8	4.5
MnO	0.17	0.18	0.2	0.18	0.19	0.18	0.19	0.18
CaO	11.1	10.7	11.5	10.7	10.1	10.4	10.1	10.0
Na_2O	2.1	2.3	2.0	2.1	2.3	2.5	2.5	2.5
K_2O	1.1	1.0	0.8	1.0	1.1	1.1	1.0	0.9
P_2O_5	0.18	0.21	0.16	0.16	0.15	0.18	0.16	0.16
H_2O^+	0.8	0.4	0.65	0.7	0.2	0.25	0.35	0.25
	99.75	100.09	99.73	99.72	100.13	99.77	99.82	99.94
$Mg/Mg+Fe^{2+}$ (Mol.)+	0.58	0.59	0.60	0.62	0.62	0.55	0.52	0.50
Q	4.52	2.89	1.88	3.45	5.32	5.30	4.54	6.09
or	6.52	5.90	4.74	5.93	6.49	6.52	5.92	5.32
ab	17.81	19.44	16.97	17.82	19.44	21.20	21.19	21.17
an	33.79	34.71	34.32	33.28	32.77	37.46	38.01	39.62
di	16.24	13.68	17.69	15.25	12.68	10.18	9.04	7.21
hy	12.84	16.32	17.74	17.78	12.28	8.51	13.98	12.11
mt	6.11	5.22	4.65	4.51	7.89	8.98	5.52	6.82
il	0.95	0.95	0.99	0.91	0.93	1.07	1.09	1.05
ap	0.43	0.50	0.38	0.38	0.36	0.43	0.38	0.38
C.I.	36.85	36.8	41.7	39.1	35.9	29.35	30.1	27.6

Sa 127 Corvo volcano, lava flow, south of Pollara (*r* 4 8348/h 42 6954).
124 Corvo volcano, dike at P. 470.
113 Capo volcano volcanic bomb in red cinder agglomerates, Serro del Capo (*r* 8790/*h* 42 6970).
91 Rivi volcano, dike south of Malfa (*r* 4 8575/*h* 42 6930).
186 Capo volcano, dike at P. 308 (*r* 487450/*h* 4270100).
184 Capo volcano, lava flow, north of P. 583 (*r* 4 8780/*h* 42 6990).
108 Rivi volcano, dike in Vallone della Fontana (*r* 4 8640/*h* 42 6908).
178 Rivi volcano, lava flow above Valdichiesa (*r* 8585/*h* 42 6863).
+ Fe^{2+} standardized to $Fe_2O_3/FeO = 0.15$.

2.1. THE OLDER CONES

Capo, Rivi and Corvo volcanoes form very similar cones. They are composed of petrographically very similar high-alumina basalts (Table 1).

They have in common that they are deeply dissected and eroded by marine abrasion, exhibiting spectacular insights into the internal volcanic structure.

Figure 2 exemplifies how the northern slopes of Monte Rivi-Serro del Capo are eroded by the sea, whereas the slopes towards Santa Marina exhibit a well preserved volcanic morphology. The marine destruction was acting through changing sea levels forming raised beaches, which now appear as houlder horizons under a younger pyroclastic and alluvial cover (figs 3 and 4).

The marine destruction exposed the centers of all three volcanoes consisting of countless intersecting feeding dikes. The heart of Monte Rivi is well exposed in Vallone della Fontana and insight into the Capo volcano is provided by the coastal section west of Malfa (Loc. Gramignazzo).

The dikes are almost vertical without preferential orientation. Thicknesses average 0.5 to 3 m but reach 10 m in several examples. The matrix between the dikes, as well as early formed dikes, became almost indistinguishable by repeated intrusion, lava-infiltration and hydrothermal alteration.

Undoubtedly, the dike-saturated areas represent insights into the volcanic vent until about 1 km beneath the former craters and it can be inferred from those sections that feeding of the crater occurred mostly through such narrow dikes. This explains crater situations as at Stromboli, where in a large crater-bowl, small ever-changing vents emit their materials. The diameter of the dike area of the dissected cones is of the same order as the 600-m diameter of the crater of Fossa delle Felci.

Outside the dike area the northern slopes of Monte Rivi and Serro del Capo exhibit a poorly exposed cross-section through alternating pyroclastics and lava flows.

The southeastern slopes towards Santa Marina consist of alternating beds of red and black cinder agglomerates similar to the deposits described below for the early Fossa activity. Here the volcanic morphology is well preserved, the agglomerates being the final products of Rivi and Capo.

The Pizzo Corvo forms the western pillar of the island and represents an almost demantled core of a stratocone with internal dike concentrations similar to the centers of Rivi and Capo. Relict stratification dips regularly away from the central block allowing the reconstruction of the former shape (fig. 5). The reconstructed size of the three oldest volcanoes, Rivi, Capo and Corvo, yields dimensions comparable to the morphologically preserved cones Fossa and Porri.

Including the submarine parts the cones are > 2000 m high.

2.2. Monte Fossa delle Felci

Monte Fossa delle Felci — shortly termed the « Fossa » — forms the highest elevation of the Aeolian Islands, a huge stratovolcano with steep slopes up to 40°.

In contrast to the petrographically uniform volcanoes of Rivi, Capo and Corvo, the Fossa exhibits a broad petrographic variation from basaltic to dacitic lavas. Establishing the time sequence of this evolution was a special topic of the geological mapping.

Early Fossa products cover the Rivi volcano and the top of Monte Rivi itself. Thus Fossa is younges than the group of older volcanoes described. However, the same marine destruction with formation of pebbly raised beaches affected this

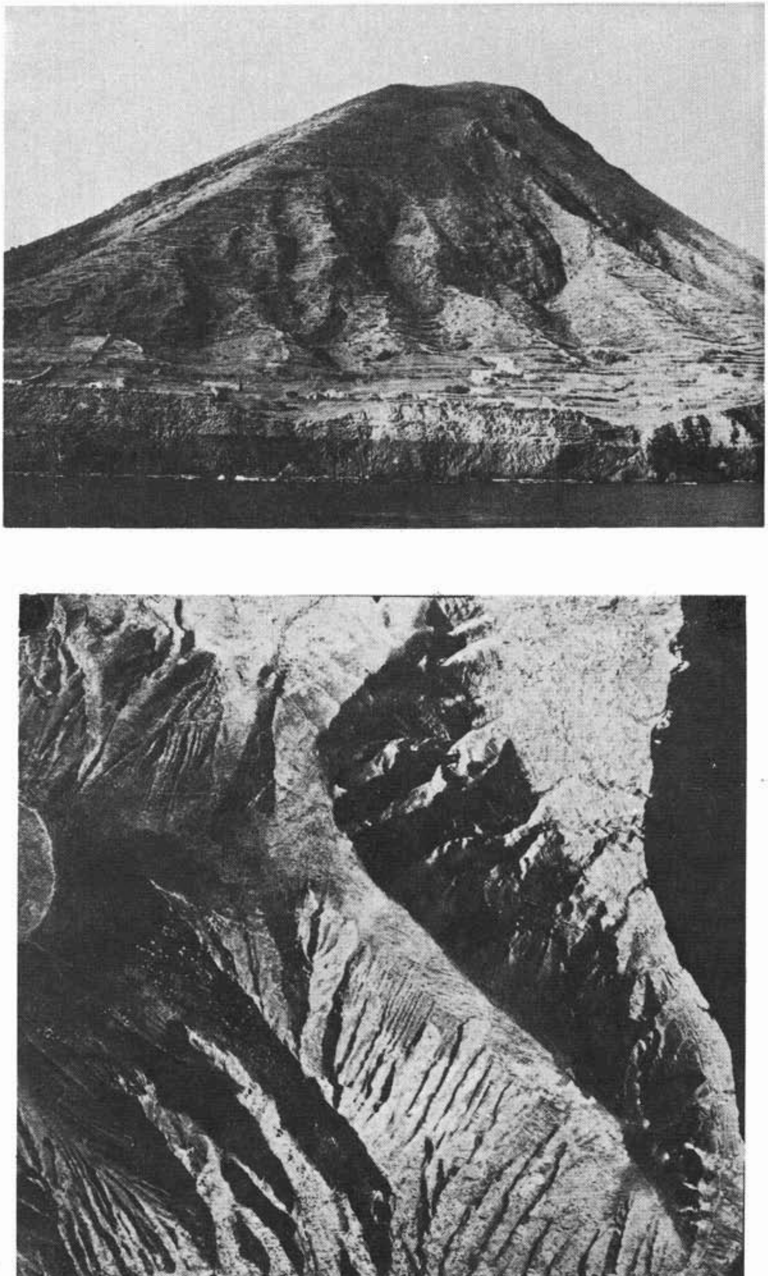

Fig. 2. — Examples of the morphological effects of marine destruction on the northeastern side of Salina: *a*) Capo Volcano from the NE; *b*) Capo and Rivi volcanoes from the aïr. Terrace of Malfa-Gramignazzo-Capo along the lower edge of foto.

volcano, but with minor destructive results due to its position protected against the mainly northerly and westerly wave action.

Fossa is therefore the youngest volcano of the pre-erosional group.

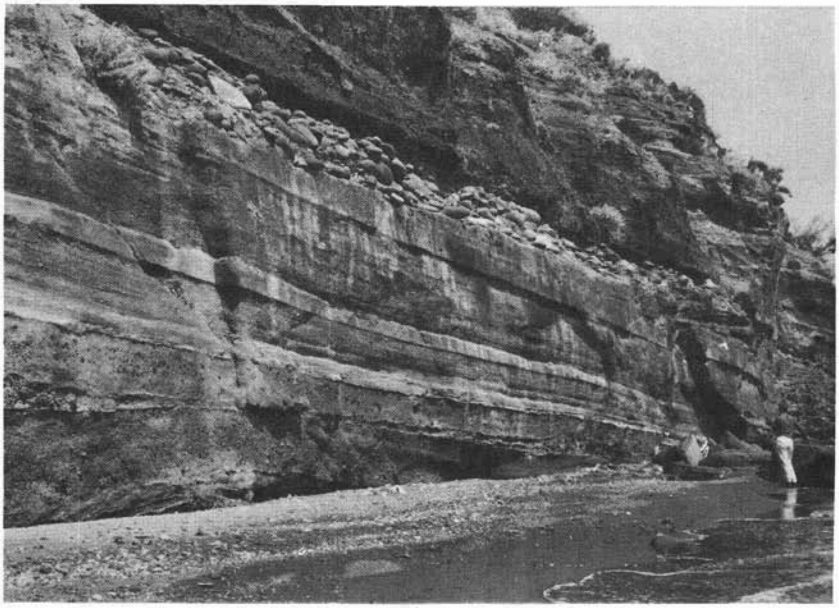

Fig. 3. — Appearance of Quaternary raised beaches on Salina: Boulder conglomerate, south of Santa Marina.

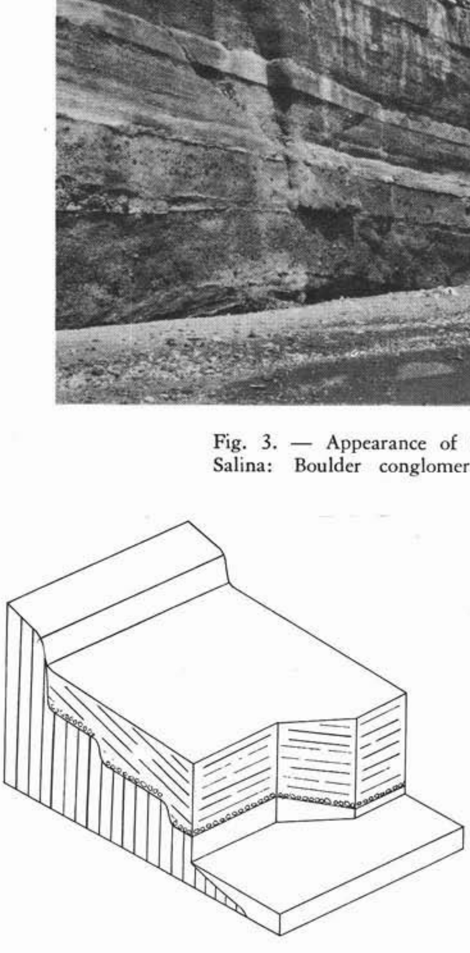

Fig. 4. — Schematic representation of a terrace sequence covered by younger products. The result is one single conglomerate level in recent coastal sections, which are about parallel to former shore lines.

In stratigraphic order the following volcanological units have been distinguished on the geological map: 1) primary cinder cone with minor lava flows (basalts to low-Si andesites); 2) dacitic lavas on the southern slope; 3) pyroclastic rocks called Favarolo-series; 4) andesitic lava flows, intercalated within the Favarolo-series; 5) final lavas of the Fossa, of low-silica andesitic composition.

The primary pyroclastic cone of Fossa delle Felci - The oldest formations of the Fossa activity are black and red cinder agglomerates well exposed in the deep ravines of the valleys Batanà, Casella, Zappini and Mastrognoli between Lingua and S. Marina. In those deep incisions no base of the agglomerates is exposed

TABLE 2

Chemical composition and norm of rocks of the Fossa delle Felci (sequence corresponds to stratigraphical order from older to younger)

Sample Sa	210	164	197	76	17	37	179	16	175
SiO_2	52.0	52.8	65.8	61.4	66.0	62.0	58.2	57.0	54.2
TiO_2	0.54	0.53	0.36	0.45	0.28	0.47	0.54	0.52	0.51
Al_2O_3	19.2	19.3	16.2	17.1	15.2	16.7	17.3	17.5	18.0
Fe_2O_3	3.7	2.7	2.8	3.0	1.2	3.1	2.7	2.6	3.1
FeO	5.7	6.2	1.6	3.1	2.1	2.5	4.6	4.9	5.4
MgO	4.1	4.0	1.7	2.6	1.4	3.1	3.1	3.8	4.5
MnO	0.18	0.17	0.12	0.15	0.1	0.14	0.17	0.17	0.17
CaO	10.4	10.4	4.2	5.6	2.9	5.5	7.8	7.9	8.9
Na_2O	2.4	2.4	3.95	3.7	4.0	3.8	3.2	3.2	2.8
K_2O	0.9	1.1	2.7	2.4	2.9	2.3	1.8	1.8	1.3
P_2O_5	0.18	0.18	0.17	0.21	0.13	0.2	0.2	0.2	0.19
H_2O^+	0.6	0.25	0.45	0.3	3.9	0.2	0.4	0.25	0.65
	99.90	100.03	100.05	100.01	100.1	100.01	100.01	99.84	99.72
$Mg/Mg+Fe^{2+}$ (Mol.)$^+$	0.48	0.48	0.45	0.48	0.47	0.54	0.47	0.51	0.53
Q	6.07	5.51	21.58	14.90	22.50	15.48	11.49	8.73	6.80
or	5.32	6.50	15.95	14.18	17.12	13.59	10.64	10.65	7.70
ab	20.33	20.30	33.41	31.31	33.81	32.15	27.08	27.12	23.76
an	39.00	38.63	18.49	22.96	13.52	21.72	27.52	28.12	32.80
di	9.37	9.70	0.96	2.78	–	3.38	8.08	8.03	8.33
hy	12.50	13.77	4.04	7.89	6.07	7.63	0.40	1.87	14.03
mt	5.37	3.91	4.06	4.35	1.74	4.49	3.91	3.78	4.51
il	1.03	1.01	0.68	0.86	0.53	0.89	1.03	0.99	0.97
ap	0.43	0.43	0.40	0.50	0.31	0.47	0.47	0.47	0.45
C.I.	28.9	28.9	10.2	16.4	9.0	16.9	23.0	25.2	28.5

Sa 210 High-alumina basalt, South coast near Erbe Bianche (*r* 4 8640/*h* 42 6595).
164 Basalt/andesite lava flow north of Lingua (*r* 4 8855/*h* 6677).
197 Dacite, South coast at Punta delle Tre Pietre (*r* 486900/*h* 4265550).
76 Dacite/andesite, lava flow Paolonoci (*r* 4 8730/*h* 42 6540).
17 Dacitic pumice at base of Favarola-series, Timpone Rosso (*r* 4 8830/*h* 42 6800).
37 Andesite, block in Favarolo-pyroclastics, Vallone di Batanà (*r* 8795/*h* 42 6823).
179 Andesite, lava flow Valdichiesa (*r* 4 8600/*h* 42 6855).
16 Andesite, volcanic bomb in Favarolo-pyroclastics, Serro Favarolo.
175 Low-Si-andesite, lava flow above V. del Lupo (*r* 8665/*h* 42 6640).
+ with $Fe_2O_3/FeO = 0.15$.

and it is believed that they represent the earliest products of the Fossa, forming a scoriae mound of about 800 meters elevation above the sea. Lava flows, as distinguished on the map, are subordinate during this stage.

Petrography and chemical composition of the rocks (Table 2) are very similar to the latest products of Monte Rivi (e.g. Sa 178) on which they rest immediately. There are equally strong similarities in volcanological characteristics. Analyses

Sa 210 and Sa 168 classify the early Fossa stage close to the basalt/andesite transition.

The eruptive mechanism which formed these agglomerates seems to be an increased strombolian fire fountaining. Single eruptive units form cinder beds 1-5 m thick, which thicken towards the crater to more than 10 meters. Bombs averaging 2-20 cm in diameter reach more than 1 meter towards the center.

The single beds are rather homogeneous in color (red or black), average grain size and structure, e.g. chaotic or with fine internal bedding. They differ

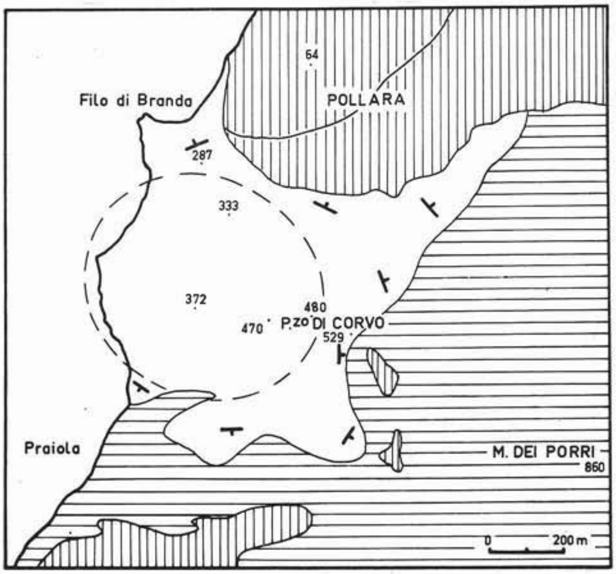

Fig. 5. — Reconstruction of the Pizzo del Corvo massif as core of a demantled stratocone. The central area is composed almost exclusively of narrow-spaced and intersecting dikes.

sharply in these characteristics from layer to layer, which indicates an intermittent activity with changing conditions.

A few layers have higher contents of non-scoriaceous xenoliths, including metamorphosed sedimentary components (tridymite-quartzites, melilite-marbles etc.), and appear as tuff-breccias.

The often-occurring sharp change from red to black cinder beds is explained as due to different degrees of heat oxidation after deposition. Thus the red beds are embedded more quickly, possibly due to a lesser rise during eruption and a more avalanche-like deposition.

The coastal section near Le Canne reveals that two dikes erupted peripherally during this early stage of Fossa. They formed two small parasitic cones which were again covered by Fossa agglomerates (cf. fig. 3 in Keller, 1967). Contrary to suggestions by Bergeat (1899) and Pichler (1967) no indications of submarine deposition of the material of the older volcanoes exist, not even between the present-day sea-level and the raised beach levels. It must be stressed that the red, subaerial cinder agglomerates of Capo and of early Fossa do not change their appearance when merging below the levels of raised beaches. No part of the exposed island consists of submarine volcanics.

Dacitic lava flows of Monte Fossa - Thick lava flows with apparently contrasting viscosity to all other flows described until now form the southern flank of the Fossa between Lingua and Rinella. Single flows piled up to > 100 m thickness. Flow foliation, pseudoignimbritic flow structures and flow brecciation are largely developed.

According to the main rock type (Tab. 2. Sa 197), the series as a whole has been termed « hypersthene dacites ». Some samples (e.g. analysis Sa 76) are transitional andesites.

The stratigraphic position in the sequence of the Fossa activity is clearly given by the superposition *onto* the primary scoriae mound. Raised-beach terraces are cut into the dacites.

Favarolo pyroclastic series and final Fossa lava flows - The term Favarolo series was given to a peculiar pyroclastic unit covering the primary scoriae mound as well as the dacites of southern Fossa. Much of the surface of the Fossa cone consists of this unit.

On the eastern slope of Fossa — named after Serro Favarolo near S. Marina — the series is almost exclusively pyroclastic with variable thickness up to > 50 meters.

Characteristic profiles show a threefold division:

5-10 m: hard top layer of strongly agglutinated scoriae bombs;

10-40 m: chaotic tuff breccia with blocks, bread-crust bombs and cow-dung slags of several meters in diameter;

1-3 m: basal layer of white pumice breccia (the only pumice of Fossa and previous volcanoes).

Lower Serro Favarolo represents an avalanche accumulation of Favarolo pyroclastics which slid down after deposition on the higher slopes (indirect volcanic avalanche). This occurred before the end of the eruption cycle as the top layer of welded scoriae covers the Serro.

A detailed description of Favarolo series is given in KELLER (1960, pp. 32-44).

Whereas the Santa Marina side of Fossa delle Felci exhibits a continuous pyroclastic profile of Favarolo series, on the southern and western slopes several lava flows are intercalated.

A distinctive petrographical feature of the Favarolo eruption cycle is its decrease in SiO_2 content from base to top. Starting with a dacitic pumice (Table 2, Sa 17) SiO_2 drops continuously (Sa 179, Sa 16) to the low-silica andesites characterised by sample Sa 175.

The final andesites of Fossa volcanism breached southwards through the crescent-shaped crater ring of highly welded spatter. These final andesites have been given a separate color on the map.

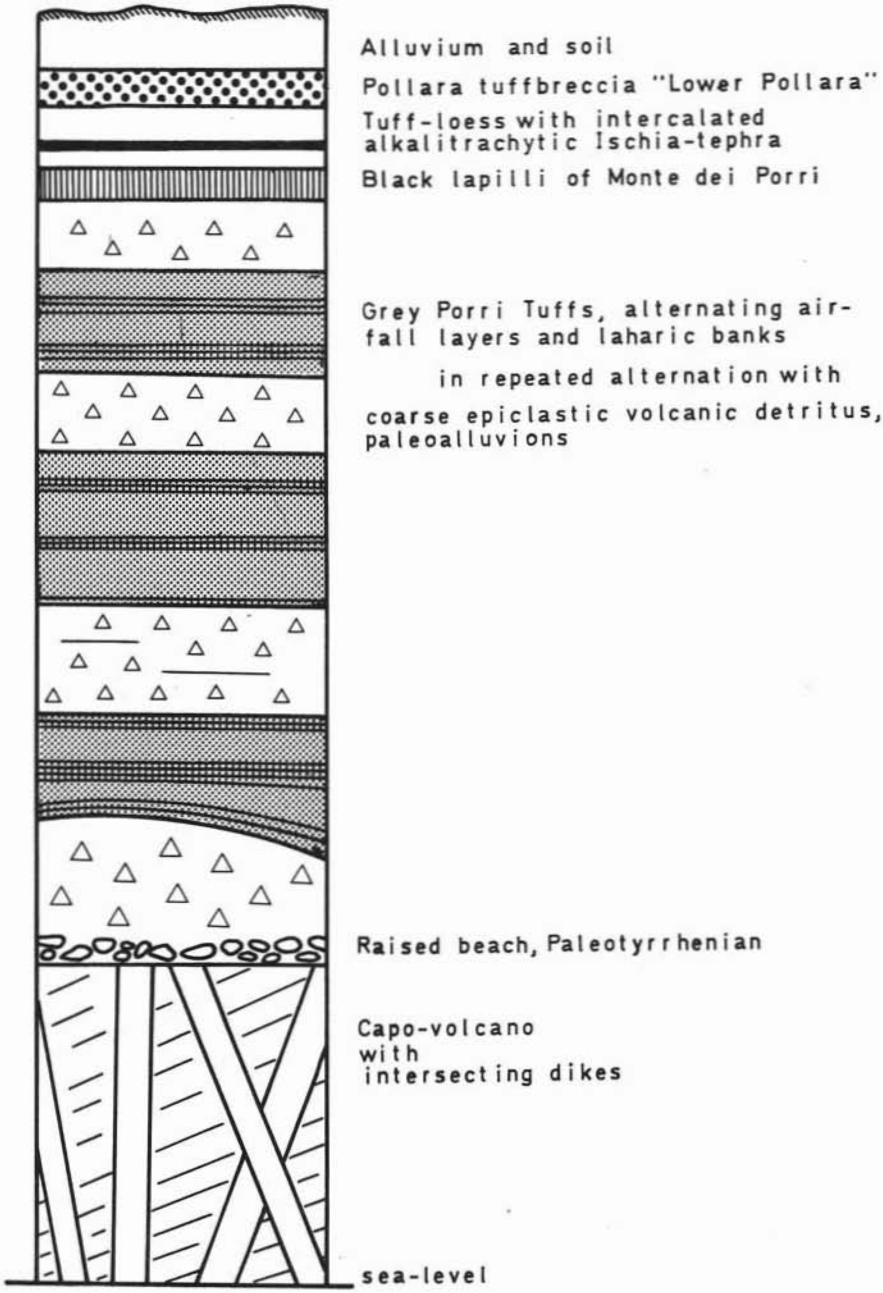

Fig. 6. — Schematic profile of the coastal section of the accumulative terrace of Malfa, near P. 90 in Gramignazzo area.

TABLE 3

Chemical composition and norms of products from Monte dei Porri stratovolcano and Pollara-crater (Upper Pleistocene volcanism of Salina)

Sample Sa	216	70	181	131	162	98	A 1
SiO_2	54.0	54.3	54.2	55.8	60.1	61.3	65.5
TiO_2	0.6	0.54	0.56	0.65	0.42	0.45	0.4
Al_2O_3	18.2	18.0	19.3	18.2	17.8	15.7	14.9
Fe_2O_3	3.1	3.2	2.7	2.7	2.9	2.54	1.5
FeO	6.0	6.0	5.5	5.6	2.7	2.6	2.1
MgO	4.5	4.0	3.1	2.9	3.2	3.1	1.6
MnO	0.18	0.03	0.17	0.18	0.14	0.1	0.13
CaO	8.8	9.3	9.2	8.3	6.8	6.55	4.2
Na_2O	2.7	2.5	2.7	3.1	3.3	3.1	3.5
K_2O	1.4	1.4	1.6	1.6	2.1	2.2	3.1
P_2O_5	0.21	0.21	0.22	0.21	0.16	0.08	0.13
H_2O	0.3	0.55	0.4	0.5	0.25	2.28	3.0
	99.99	100.03	99.65	99.74	99.87	100.66	100.06
$Mg/Mg+Fe^{2+}$ (Mol.)+	0.51	0.48	0.44	0.42	0.55	0.55	0.48
Q	6.33	8.05	7.19	8.72	14.2	17.77	22.15
or	8.27	8.27	9.49	9.48	12.40	12.99	18.31
ab	22.85	21.15	22.93	26.30	27.7	25.82	29.60
an	33.41	33.75	35.94	31.10	27.8	22.67	15.78
di	7.26	9.02	6.95	7.29	4.8	7.44	3.41
hy	15.46	13.07	11.60	10.96	7.8	6.29	4.53
mt	4.50	4.64	3.93	3.93	4.20	3.68	2.17
il	1.14	1.03	1.07	1.24	0.80	0.85	0.76
ap	0.50	0.50	0.52	0.50	0.38	0.19	0.31
C.I.	28.9	28.4	24.2	24.0	18.0	18.5	12.0

Sa 216 Monte dei Porri. Low-silica andesite, lava flow, P. Sallustro (*r* 483000/*h* 42 67600).
70 Monte dei Porri. Low-silica andesite lava flow, Barcone (*r* 4 8420/*h* 42 6733).
181 Monte dei Porri. Low-silica andesite, lava flow, south of Malfa (*r* 4 8515/*h* 42 6943).
131 Monte dei Porri. Low-silica andesite, lava flow, Vallone del Pozzo (*r* 4 8455/*h* 42 6985).
162 Pollara. Andesite, lava flow of Punta di Perciato (*r* 483200/*h* 4270700).
98 Pollara. Pumice, Lower Pollara unit, Sciarato (*r* 484600/*h* 4270600).
A 1 Pollara. Dacitic biotite-bearing pumice, « White pumice of Pollara », Serro di Pollara (PICHLER, 1964, No. 3).
+ with $Fe_2O_3/FeO = 0.15$.

2.3. MONTE DEI PORRI

The ideally cone-shaped Monte dei Porri (860 m) has no terraces above present-day sea level. Pyroclastic rocks of Porri cover the terraced areas all around the island (fig. 6), indicating a major unconformity and age difference which is in the order of 200,000 years (see stratigraphical chapter). The post-erosional formation of Porri is attributed to the Last Glaciation (« Würm »). Only a C-14 age

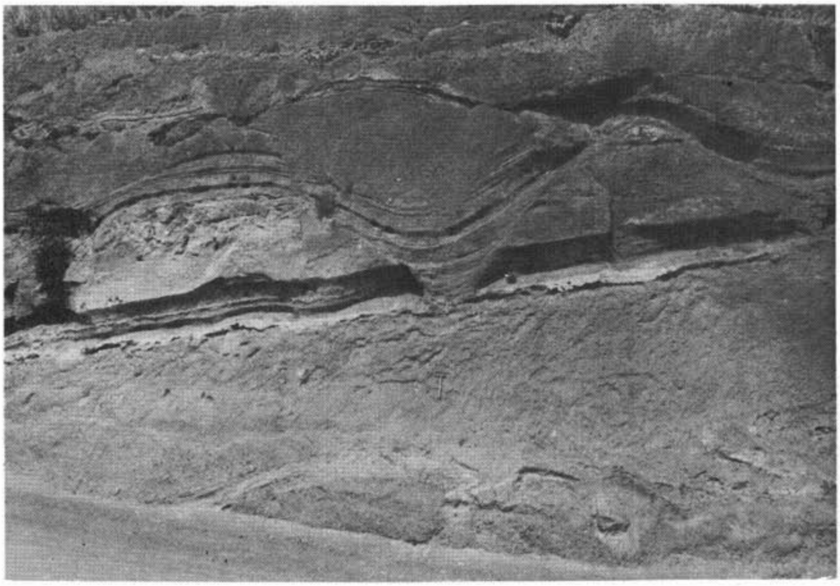

Fig. 7. — Grey Porri Tuffs south of Santa Marina, road to Lingua. Laharic beds alternating with air-fall layers.

Fig. 8. — Pollara crater, seen from Semaforo di Pollara.

limit of $\geqq$ 37,000 years is available (fig. 11). All lavas, pumice and lapilli of Monte dei Porri are uniformly low-silica andesites (Tabs 3 and 6, anal. Sa 216, 70, 181, 131, A2). Phenocrysts are plagioclase, two pyroxenes (cpx and opx), ores and some olivine. The compositions of the Porri lavas are remarkably similar to the last Fossa lavas (Sa 175) despite the long hiatus of activity.

The following units were distinguished on the geological map:

Grey Porri Tuffs
Red cinder agglomerates
Lava flows.

Grey Porri Tuffs - The Grey Tuffs represent the products of extremely powerful initial explosions of Monte dei Porri after the long break in activity on Salina.

It is one of the most explosive eruption cycles in the geological record of the Aeolian Islands. Grey Porri Tuffs covered the whole island of Salina and are found on the neighboring islands Lipari and Panarea (KELLER, 1967). They accumulated especially on the flat terraces of older volcanoes.

Visible thickness on the flanks of Monte dei Porri is 50-70 m, but the Grey Tuffs may constitute a large part of the cone. Basal layers covering the Corvo cone at Valle di Spina are coarse tuff-breccia with meter-sized blocks. With increasing distance from the vent, ash and lapilli grain-size predominate. Olivine-grey pumice layers (Table 6, No. A 2) are often interbedded and accretionary lapilli are common in ash layers.

Special depositional features of the Grey Porri Tuffs are exposed in the road cuts south of S. Marina (fig. 7). The high cone of Fossa delle Felci stands between these deposits and the source volcano (cf. fig. 10). Well bedded ash-lapilli-pumice layers alternate with 1-3 m thick chaotic layers of strongly indurated ash-lapilli tuff. The section is explained as consisting of air-fall layers alternating with lahars of the same material, which was originally air-fall deposited on the higher parts of the slopes of Fossa. Mudflows originated continuously during the eruption cycle. Frequent erosion channels indicate heavy rainfall during the eruptions. The channels are coated by the air-fall beds and filled with horizontally topped lahar units (fig. 7).

Similar lahars occur especially in the coastal terrace between Malfa and Capo, alternating there with coarse alluvial debris (fig. 6).

All areas not adjacent to steep slopes exhibit normally bedded air-fall facies of the Grey Tuffs.

The Grey Tuffs carry large amounts of xenoliths derived from sediments, from the metamorphic and granitic basement, of pyroxenites and skarns and of a wide variety of gabbroic igneous cumulates. They indicate the extreme explosivity and the deep-seated origin of these initial Porri eruptions. Ashy layers often contain imprints of pine cones and leaves especially of *ruscus aculeatus* (cf. KELLER, 1966).

Red cinder agglomerates - Agglomerates of Monte dei Porri are very similar in volcanological characteristics to the early Fossa deposits, except for their higher amount of older volcanics and non-volcanic xenoliths. A black lapilli layer related to these cinders covers the opposite lower slopes of Rivi and Fossa and forms a stratigraphical tracer well beyond Malfa (cf. fig. 6).

Lava flows - Early Porri lavas are already intercalated in the Grey tuffs and lava flows are interlayered with the red agglomerates. The last stage of activity on Monte dei Porri was the flooding of its western and northern slopes with similar andesitic lava flows. This asymmetric distribution with more lava flows towards the west is repeated on every cone on Salina. It is easily explained by asymmetric accumulation of pyroclastics under the influence of westerly winds, thus facilitating the terminal lava overflow towards the west.

2.4. Explosion crater of Pollara

The northwestern edge of the island of Salina is occupied by the large semi-circular crater bowl in which the village of Pollara is situated (fig. 8).

Pollara represents the most impressive crater of the islands, especially well exposed in the coastal profile which provides a central cross-section through the crater. Large masses of light colored pumice are the main products of its activity.

The flat crater bottom on which redeposited pumice material has accumulated in regular beds up to 70-80 m above sea level measures 700-800 m in diameter. The crater rim at 300 m above the sea (Semaforo di Pollara) has a diameter of 1.5 km. The formation of the Pollara crater is the most recent eruptive event on Salina and is dated 13,000 years B.P. (Keller, 1967). Three different eruptive units are distinguished (from top to bottom):

White Pollara pumice tephra, « upper Pollara pyroclastics »;
Pollara tuff-breccias, « lower Pollara pyroclastics »;
Lava flows of Punta di Perciato and Faraglione.

The lavas and pumices of the Pollara crater are riches in SiO_2 than the average rocks of the other centers, ranging from 60-66 % SiO_2. They are classified as dacites and andesites. In Salina, only the products of the Pollara crater contain hydroxyl-bearing phenocrysts of hornblende or hornblende + biotite.

Lava flows of Punta di Perciato and Scoglio Faraglione - Thick hornblende-andesite lava flows are the first products of Pollara volcanism (fig. 9). Their center of effusion was blasted away by the crater-forming explosions.

Thickness and flow characteristics distinguish them clearly from the underlying thin Porri lavas and indicate the more acid composition of the former (analysis Sa 162, Tab. 3). Red-brown oxyhornblende, besides phenocrysts of plagioclase, hypersthene, augite and some olivine, is a distinctive feature and is a further argument not to follow Bergeat's attribution of these flows to the Corvo volcano nor Pichler's to Monte dei Porri.

Tuff-breccias of Pollara - Explosive eruption followed the lava flows. Their products, stratified tuffs and tuff-breccias, cover the Perciato-flow with a thickness of 30-40 m (fig. 9). The primary magmatic components are hornblende-bearing andesitic pumices, identical in mineralogy and chemical composition to the underlying Pollara lavas (analysis Sa 98, Tab. 3). Zenoliths of fassaite-wollastonite-grossularite skarns, marbles, gneisses, granites, Tertiary sediments and gabbroic endogenous blocks comprise up to several percent of the volume of single beds.

Pollara tuff-breccias cover the whole central part of Salina. In the dissected tuff-plateau of Valdichiesa they form a similar air-fall tuff/lahar sequence to that described for Grey Porri Tuffs around S. Marina.

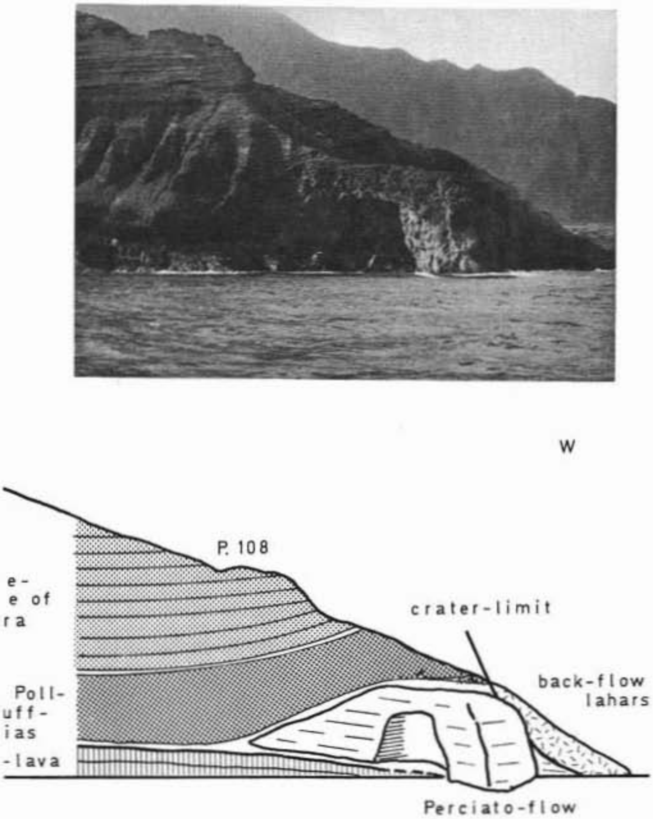

Fig. 9. — Coastal section at the northeastern edge of Pollara crater.

White pumice tephra of Pollara - White pumices form the main volume emitted from the Pollara crater. They are dacites (Tab. 3, A1), characterized macroscopically by biotite as phenocrysts besides pyroxenes, hornblende, olivine and plagioclase (Tab. 4).

The thickness of the White Pollara pumice deposits is 200-250 m on the crater edge at the former light-house (semaforo). In the easternmost outcrop in Vallone Magnano, only 3 km from the crater the thickness has decreased to 1-2 m and only traces of fine tephra have been found as far as Capo Faro. The coastal profile from Pollara to Malfa shows the deposits to be well bedded. Bedding is not strictly parallel, but swelling, diminishing and wedging-out of single layers is typical, with dune-like structures and cross-bedding. Bedding sags show continuous impact of volcanic bombs during deposition of the

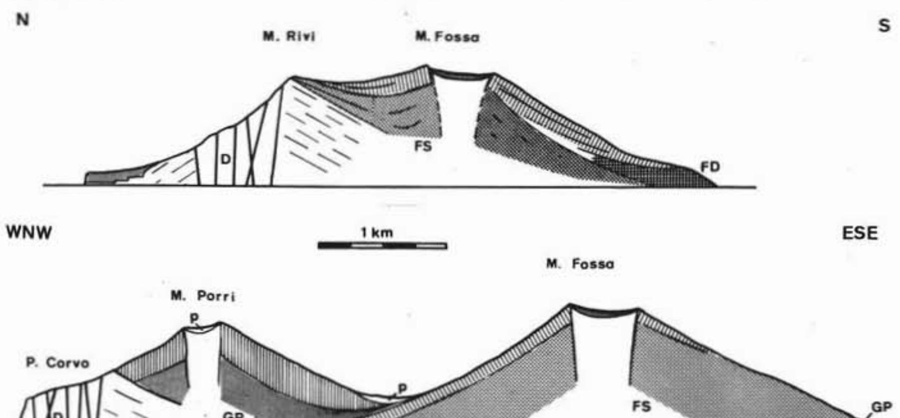

Fig. 10. — Profile sections across the main volcanological units of Salina. *FS* = primary scoriae cone of Fossa; *FD* = Fossa dacites, overlain by Favarolo series; *D* = dike area in the centers of Corvo and Rivi volcanoes; *GP* = Grey Porri Tuffs; *p* = Pollara pyroclastics.

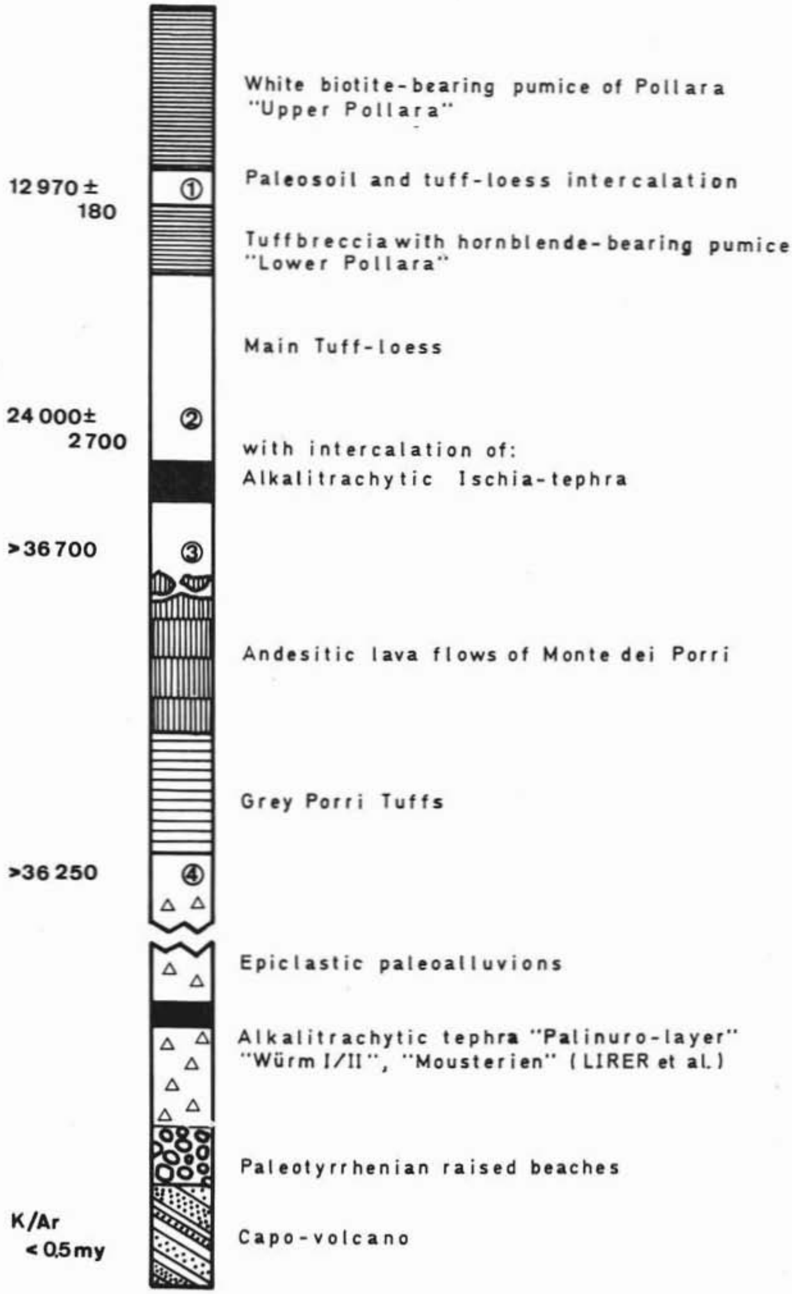

Fig. 11. — Synoptic stratigraphic column for Salina. Upper part refers to the area southwest of Malfa, lower part to Passo di Megna north of Santa Marina.

pumice tephra. All these features are characteristic for base-deposits (MOORE, 1967; FISHER and WATERS, 1970). From topography it is evident that the eruption site

TABLE 4

Femic phenocryst assemblages of the different pumice units from Salina (in addition all samples have plagioclase)

	Biotite	Hornblende	Augite	Hypersthene	Olivine	Apatite	
White pumice, upper Pollara series	29	37.5	15	5	13	1	
Pumice in tuff breccia of lower Pollara series. Base of Semaforo section	–	25	56	8	11	tr	POLLARA
Pumice layer of lower Pollara series, Valdichiesa	–	29	50	6.5	14.5	tr	
Pumice in Grey Porri Tuffs, Rinella.	–	4.5	35	35.5	25	tr	PORRI
Pumice layer at the base of Favarolo series. Fossa delle Felci, near S. Marina	–	48	Sp.	51	–	1	FOSSA

% grains after mechanical separation

was below sea level and sea water must have reached the magma. Phreatic effects may well have influenced and increased the explosivity.

A well-cemented facies of chaotic Pollara tephra covers the inner slopes of the crater as seen in fig. 9. This deposit results from lahars flowing back in the emptied crater. The crater floor is now covered with alluvial Pollara-pumice material.

White pumice of Pollara in places is separated from the underlying Pollara tuff breccia by a ∼ 1-m-thick brown soil-like layer (« tuffloess », see below). This horizon marks an age difference between both pyroclastic units, but the time interval is not necessarily very long because the layer is of wind-borne accumulative origin rather than formed by in-situ weathering.

Charcoal pieces from this layer (fig. 11) yelded a radiocarbon age of 12,970 ± 180 years B.P. (KELLER, 1967). This date is used as an approximate age for the whole Pollara volcanism, with which activity on Salina terminated.

3. Age relationship and stratigraphy of the volcanic events

The relative sequence of volcanic events on Salina is clearly given through the field relationships (e.g. fig. 10) in the following order:

Younger	post-erosional	POLLARA:	White pumice
			Tuff-breccia
			Lava flows
		PORRI:	Lava flows and agglomerates
			Grey Tuffs
	Terracing by marine destruction in levels from 45 to 4 m a.s.l.		
	pre-erosional	FOSSA:	Final andesites
			Favarolo cycle
			South coast dacites
			Primary scoriae mound
		RIVI	VOLCANOES
		CAPO	VOLCANOES
Older		CORVO	VOLCANOES

TABLE 5

Chemical composition of alkali-trachytic tephra-layers found on Salina

	1	2
SiO_2	60.2	56.7
TiO_2	.6	.55
Al_2O_3	17.3	18.45
Fe_2O_3	1.2	3.4
FeO	1.6	1.2
MnO	.23	0.14
MgO	.4	1.3
CaO	1.6	2.8
Na_2O	6.1	4.3
K_2O	6.2	5.1
P_2O_5	.09	.14
H_2O	4.6	5.7
	100.12	99.68

1) Ischia-layer (Anal. WEIBEL); 2) Palinuro-layer, Barcone North of S. Marina (Anal. Min. Inst. Freiburg).

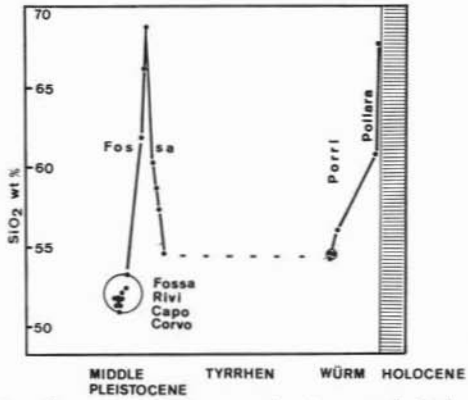

Fig. 12. — Chronodiagram, showing petrological evolution (as SiO_2, waterfree) with time.

Raised beach terraces - There are terraced and terrace-covering volcanoes on Salina, defined as pre-erosional and post-erosional groups respectively. The terraces occur generally as fossil abrasion platforms covered with a layer of beach platform covered with a layer of beach boulders (fig. 3). Later alluvial and pyroclastic covers generally hide the complete sequence which can only be reconstructed in special sections (figs 2-4, cf. KELLER, 1967).

The altimetric position of the marine terraces served as an argument for stratigraphical correlations within the Aeolian volcanism (PICHLER, 1968; KELLER, 1967; ROMANO, 1973; VILLARI, 1972). It was initially a tentative working hypothesis to postulate that the terraces represent unchanged glacioeustatic sea-levels. This was suggested by the amazing coincidence of the altimetric sequence (40-45 m, 25-30 m, 12-18 m, 6-8 m, 3-4 m) with the glacioeustatic sequence in stable areas of the Italian mainland (AMBROSETTI et al., 1972). Further support is the rule that higher terraces are the older ones, in accordance with the glacioeustatic regression. Evidence exists in some sections that sea-level fluctuated through a minus-level before cutting the next terrace.

Adopting the glacioeustatic scheme it has been stated that Corvo, Rivi, Capo and Fossa were formed during a pre-palaeotyrrhenian low sea-level, correlated with the third last alpine glaciation (« Mindel »). Porri and Pollara are then post-neotyrrhenian, i.e. formed after the Last Interglacial. This postulated scheme is now supported by several lines of evidence, which are independent from terrace correlations, such as tephrochronology and radiocarbon-dating. They prove the Würm-age of the younger cycle. A K-Ar dating of the older, Middle Pleistocene group yielded an age limit « less than 0.5 m.y. » (BARBERI et al., 1974, p. 270).

Tephrochronological correlations - At least three alkali-trachytic tephra showers originating in Central Italy reached Salina during the Last Glaciation and formed distinctive white tephra-layers varying from several centimeters to 0.5 m (KELLER, 1969, 1971). Two of them have a distinctive mineralogy and yielded the stratigraphical correlations given in fig. 11. The Ischia-layer is characterized by phenocrysts of aegerine augite, biotite, sphene, sanidine, plagioclase and is now widely used in deep-sea sediment correlations with an age of 25,000-40,000 years (NINKOVICH and HEEZEN, 1965; KELLER et al., 1977).

A layer occurring north of Barcone in palaeoalluvions well below the Porri tuffs (r 4 8900/h 42 6800) can be correlated on the basis of chemical composition (Tab. 5) and distinctive phenocryst content with a tephra-layer described by LIRER et al. (1967) occurring all along the Tyrrhenian coast from Salerno to Sicily. The type locality is Palinuro (Salerno). The mineral association green augite, biotite, sanidine, plagioclase, ± sphene is as in most Campanian trachytes, but hornblende as main constituent and volcanic zircon as highly distinctive accessory phase characterize this layer. LIRER et al. estimated its age as « Würm II » on the basis of sedimentological correlations and connection with Mousterien-artefacts. Hence, an age estimate of approximately 60,000 years is used as the maximum age for the beginning of the activity of Monte dei Porri.

Ischia-tephra has been identified on other islands, e.g. Lipari, Panarea and Filicudi (KELLER, 1969). The stratigraphical correlation with brown, earthy, soil-like deposits called « Tufflöss » by BERGEAT (1899) and intercorrelations with Aeolian pyroclastics of Würmian age is strong evidence that the accumulation profiles over the raised-beach terraces are mostly Würmian and that terracing itself is pre-Würmian.

Tuffloess - The loess-like cover of fine-grained, yellow-brown, weathered, unstratified, earthy masses of several meters thickness occurs typically in post-terrace profiles on Salina, Lipari, Filicudi and Panarea. The origin of these deposits has concerned several authors since Bergeat expressed their doubtful character with the ambiguous name « Tufflöss ». PICHLER (1963, 1967) considered the deposits as palaeosoils and used their thickness to estimate the duration of weathering. Arguments against an in-situ-weathering soil-profile were listed in KELLER (1966, 1967).

The white Ischia-tephra occurs intercalated within a tuffloess bed. Tuffloess develops with sharp contact over different and often unweathered bed-rocks.

Tuffloess is composed of ash-sized volcanic particles. MD-values for a deposit of Salina are 60 μ. Q_1 and Q_3 values (grain-size limits at 25 % resp. 75 %) are 40 μ and 95 μ respectively and indicate the sorting of wind-graded tephra. Tuffloess is explained here as a *shower-soil* as described by TAYLOR (1933) from New Zealand. Shower-soils accumulate over a long time-span from the ash fraction of a distant explosive activity. The mechanism allows a continuous weathering and TAYLOR may be quoted saying that « such deposits are often described as volcanic loess ». The distant volcano producing the ash-showers is Vulcano, mainly the caldera-forming and caldera-filling activity of South-Vulcano (KELLER, this volume). The thick and coarse deposits in Southern Lipari (Vallone del Ponte) and on the peninsula of

Milazzo (Sicily) support this conclusion. In Vallone del Ponte the grain-size of some tuffloess-layers increases to lapilli which contain abundant euhedral augite, olivine and plagioclase crystals, so distinctive for Vulcano (KELLER, this volume).

Tuffloess deposition started on Salina below the first Porri-products ≧ 36,000 years ago. Its main evolution is between Porri and Pollara activity. Radiocarbon dating on a sample from the centre of the main tuffloes-layer yields an age of 24,000 years (fig. 11).

4. Xenolith evidence and basement composition

Explosive eruptions on Salina, mainly initial Porri phases, and the eruptions of the Pollara crater yielded plentiful xenoliths which are good evidence for the constitution of the crust beneath theisland. They further provide some insight into eruptive magmatological processes. Petrographical descriptions of xenolith suites collected from Pollara and Grey Porri Tuffs are published in PICHLER (1964), KELLER (1966) and HONNOREZ & KELLER (1968).

According to their probable origin the xenoliths can be grouped as follows:

Sediments:

- sandstones and quartzites
- Globigerina-marle (Pliocene « trubi »-formation)
- sedimentary conglomerates with gneiss- and schist-components

Metamorphic basement rocks:

- biotite gneisses
- garnet-sillimanite gneisses
- amphibolites, hornblendites
- marbles

Granitic basement rocks:

- biotite-hornblende granites and granodiorites
- leucogranites

Contact metamorphic rocks:

- skarns with wollastonite, fassaite, grossularite, anorthite
- pyroxenites, some with garnet (grossularite/andradite) and/or spinel, phlogopite
- melilite-bearing marbles, melilite-fassaite rocks

From this xenolith assemblage the presence of a sialic crust with great lithological variety can be deduced, whereas the crust becomes dominantly oceanic under the central part of the Tyrrhenian basin (MORELLI, 1970; FINETTI et al., 1970). Given the uncertainty in the type of crustal material involved in the subduction process of the Aeolian island arc, it is at least sure that Aeolian magmas came up through continental crust. On the Ionian side of the trench-arc system the oceanic crust is consumed by the subduction (BARBERI et al., 1974) and the subduction process is therefore in a final state.

Coarse-crystalline endogenous xenoliths of gabbroic appearance are explained

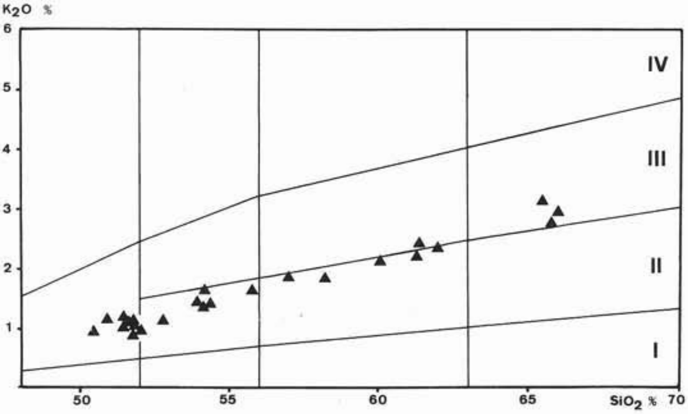

Fig. 13. — K_2O versus SiO_2 relationship. Fields of PECCERILLO and TAYLOR, 1976. I = island arcs tholeiitic series; II = calc-alkaline series; III = calc-alkaline series; IV = shoshonitic series. Basaltic rocks < 52 % SiO_2, andesites 52-63 % SiO_2, dacites > 63 % SiO_2.

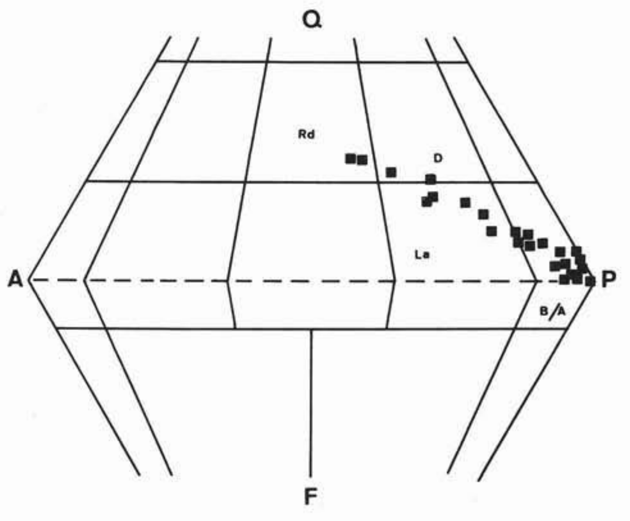

Fig. 14. — STRECKEISEN's double triangle for classification based on chemical composition and calculated with the RITTMANN norm (RITTMANN, 1973). Q = quartz, P = plagioclase, A = alkali-feldspar, F = feldspathoids.

as igneous cumulates of the fractionating basaltic and andesitic magmas within the crust. Plagioclase and clinopyroxene are the dominant minerals. In addition some cumulates contain olivine, orthopyroxene and magnetite. Examples of bulk chemistry of gabbroic cumulates are referred to in Table 8. Microprobing of the phases demonstrated the plagioclase to be almost pure anorthite (An 90-97). Mg-values of ol, opx and cpx are in the range of 75-80, limiting to some extent the chemical composition of the melt from which they crystallized. Amphibole occurs rarely, as a post-cumulus phase.

5. Petrology

The SiO_2 range of all available analyses (Tables 1-3, 6) is 50-68 % (on a H_2O-free basis).

All rocks are quartz-normative and form a continuous basalt-andesite-dacite suite. This is shown in a Harker diagram (fig. 22) and in fig. 13 where a simple SiO_2-K_2O grid for calc-alkaline rocks (PECCERILLO & TAYLOR, 1976), is adopted. Also given for comparison is the traditional nomenclatoric system with the double-triangle for modal quartz-plagioclase-alkalifeldspars-feldspathoid contents (fig. 14). STRECKEISEN's subdivisions are reported and all analyses have been plotted after calculation of a mineral content using the RITTMAN norm (RITTMAN, 1973). Most

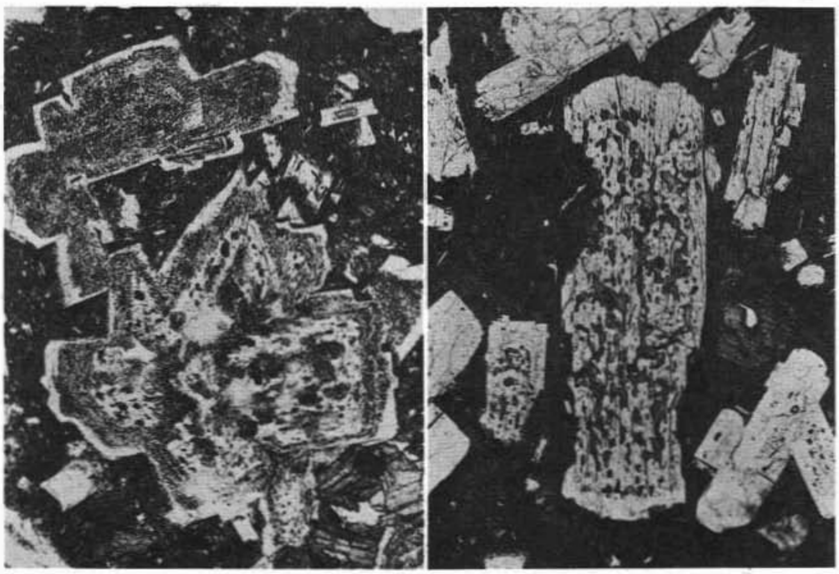

Fig. 15. — Patchy glass zones and dust-zoning in anorthite-rich plagioclase phenocrysts in low-Si andesites, ca. 60 x.

analyses fall in the andesite/basalt field (A, B), some (the SiO_2-rich andesites of the chemical classification) in the latiandesite field (LA). The most acid types are dacites and rhyodacites (D, Rd) in accordance with the SiO_2-K_2O subdivision.

The volumetric proportion of the different rock types is not strictly given by the respective number of analyses. High alumina basalts are predominant by far, with an estimated percentage for Salina of > 80 %, followed by low-Si andesites. Acid andesites and dacites are thus volumetrically subordinate.

The magmatological evolution started from high-alumina basalt and proceeded with time towards more SiO_2-rich rocks. During the Fossa-activity a falling-back in the SiO_2 of erupted magmas occurred. The petrological chronodiagram of fig. 12 explains the geochemical changes during the activity of Salina.

TABLE 6

Chemical analyses of volcanic rocks from Salina from other sources, not used in the petrochemical diagrams

	A2	A3	A4	A5
SiO_2	52.2	53.4	59.8	60.5
TiO_2	.5	.68	.5	.5
Al_2O_3	16.4	17.82	17.1	17.1
Fe_2O_3	4.2	3.56	2.9	2.2
FeO	4.7	5.07	3.75	3.4
MnO	.17	.15	.15	.15
MgO	6.0	4.58	2.9	3.0
CaO	10.9	9.72	6.9	7.0
Na_2O	2.2	2.45	3.2	3.2
K_2O	1.4	1.12	2.1	2.2
P_2O_5	.16	.17	.13	.17
H_2O	.9	1.35	.63	.6
	99.73	100.07	100.06	100.02
		CIPW-NORM		
Q	4.95	8.04	14.27	14.48
or	8.37	6.7	12.48	13.07
ab	18.83	21.0	27.23	27.23
an	31.10	34.76	26.24	25.95
di	18.04	10.48	5.95	6.37
hy	11.20	12.08	8.34	8.33
mt	6.16	5.23	4.23	3.21
il	.96	1.31	.95	.96
ap	.38	.41	.31	.40

A 2 Basaltic lava of Corvo volcano (PICHLER, 1964, No. 1).
A 3 Low-Si andesite, pumiceous scoriae in Grey Porri Tuffs, Monte dei Porri (HONNOREZ & KELLER, 1968).
A 4 Andesitic lava flow of Monte Fossa delle Felci, near Leni. Unpublished analysis made by M. WEIBEL for H. PICHLER (Written Communication by H. PICHLER). This lava most certainly belongs to our Favarolo-series.
A 5 Andesite (PICHLER, 1964, No. 2) « near Punta di Perciato » of Pollara. PICHLER's attribution of this analysis to Monte dei Porri is in error. A 5 corresponds to Sa 162 of Table 3.

Mineralogical composition - The basaltic rocks of Capo, Corvo, Rivi and earlier Fossa and the andesites of Porri and late Fossa are uniformly composed of olivine, plagioclase and pyroxenes. These phenocrysts are set in a pilotaxitic to hyalopilitic groundmass of plagioclase, pyroxene and magnetite grains.

Plagioclase is the dominant mineral phase among phenocrysts and in the groundmass. Anorthite contents in the cores of phenocrysts generally reach An 90. Outermost rims of zoned phenocrysts and groundmass plagioclases display An-contents of 60-55 in basalts and 53-48 in andesites.

Complex twinning of larger plagioclase crystals is common. Zones with dust inclusions and patchy glass zones (fig. 15) show a complex equilibrium - disequilibrium history during crystallization and consolidation of the lavas.

No quartz nor K-feldspar have been recognized in basalts and andesites. In the Fossa-dacites, the groundmass matrix is birefringent in irregular patches (fig. 19) identified as quartz. In all lavas of Salina, tridymite is a common late- and post-magmatic phase in the groundmass pores and vesicles. It is often accompanied by a pale, weakly pleochroitic biotite, also of pneumatolytic origin.

Olivine is a common constituent although all volcanic rocks of Salina are qz-normative. It appears only as phenocrysts but is resorbed to small grains in

SiO_2-rich andesitic lavas. Its composition is Fo 85-60 in basalt (cf. fig. 16).

Clinopyroxene forms the largest phenocrysts of up-to-0.5-cm diameter. Optical properties (colorless, $2V_\alpha$ 50-55°, $Z \wedge c$ 40-45°) define a Fe-poor diopsidic augite (examples for chemical composition in Tab. 7 and fig. 16).

Orthopyroxene (hypersthene, En 70) occurs only occasionally in the high-alumina basalts, but is common in the andesites, which are therefore «two-pyroxene andesites» referring to the coexistence of clino- and orthopyroxene.

Pigeonite - The groundmass pyroxenes are quantitatively the most relevant mafic mineral of the basaltic lavas. Optically they are quasi-uniaxial and are therefore pigeonitic.

Microprobe data of pigeonites are given in Tab. 7.

The alternative occurrence of the different mafic minerals is governed by discontinuous reaction relationships between olivine, pigeonite and hypersthene, whereas augite crystallizes contemporaneously without reaction relation to any member of the olivine-pigeonite-hypersthene series. This crystallization scheme is in accordance with the results of KUNO (1950) and POLDERVAART & HESS (1951) in similar calc-alkaline series. Olivine in state of resorption is mostly rimmed by pigeonitic groundmass-pyroxene grains (fig. 17). Coaxial rimming with hypersthene was observed in a few cases. Pigeonite rims surrounding hypersthene is common in andesites (fig. 18).

Unique among the volcanic rocks of Salina is the presence of hydroxyl-bearing minerals, hornblende and/or biotite, in lavas and pumices of the Pollara center. In the Perciato- and Faraglione-flow a red-brown basaltic hornblende with $Z \wedge c \approx 0$ and opacitic rims (« oxyhornblende ») occurs (together with augite, hypersthene and plagioclase phenocrysts and smaller grains of olivine and pigeonite).

A common green hornblende ($Z \wedge c = 18°$) occurs occasionally in the lavas and is the amphibole of the pumices of Pollara. This suggests that rapid quenching prevents the formation of oxyhornblende and underlines the view of an initial crystallization as green hornblende and oxidation during late stages of consolidation. The white Upper Pumice Series of Pollara are characterized by biotite phenocrysts. The mineral contents of Fossa, Porri and Pollara pumices are given in Table 4.

Major element geochemistry - A total of 27 analyses of volcanic rocks from Salina are now available (Tables 1-3 and 6). In terms of major elements the calc-alkaline nature of the suite is demonstrated by the alkalies-silica relationship in fig. 20 and by the typical pattern in an AFM-diagram (fig. 21). All analyses fall in the subalkaline fields of KUNO's hypersthenic rock series. K_2O/Na_2O ratios scatter around 0.35-0.5 in the basaltic end members and increase steadily to 0.7-0.8 in the most SiO_2-rich types. Lowest K_2O contents characterize Salina amongst all other islands of the Aeolian arc, but they are higher than in Pacific island arcs in general (Table 12). Filicudi which is closest in typical calc-alkaline characteristics has still slightly higher K_2O (VILLARI, 1972; and this volume).

High Al_2O_3 and low TiO_2 are characteristic features of the series. Only very slight iron enrichment can be recognized in early stages of the evolution (fig. 21).

TABLE 7

Pyroxene compositions of olivine-bearing augite-pigeonite high-Al basalt Sa 212 from Vallone Mastrognoli/Fossa delle Felci

Sample Sa 212	PIGEONITES			Ca-AUGITES (average of 3)
SiO_2	51.76	52.31	52.0	51.4
TiO_2	.27	.21	.23	.24
Al_2O_3	1.11	.79	1.04	2.55
FeO	19.67	20.54	20.23	10.06
MnO	.42	.56	.44	.15
MgO	19.91	20.74	20.75	15.83
CaO	6.59	4.47	4.99	19.36
Na_2O	.27	.38	.33	.25
mol.%				
Fe	30.9	32.5	31.8	15.9
Ca	13.3	9.1	10.1	39.3
Mg	55.8	58.5	58.1	44.7
	Formula on the basis of 6 oxygens			
Si	1.945	1.961	1.949	1.916
Ti	0.008	0.006	0.007	0.006
Al	0.049	0.035	0.046	0.112
Fe^{2+}	0.618	0.644	0.634	0.314
Mn	0.013	0.018	0.014	0.005
Mg	1.115	1.159	1.159	0.879
Ca	0.265	0.179	0.200	0.773
Na	0.020	0.028	0.024	0.018
	4.033	4.030	4.033	4.023

Corresponding rock analysis is Sa 210, Table 2. Microprobe data by N. G. WARE, Canberra.

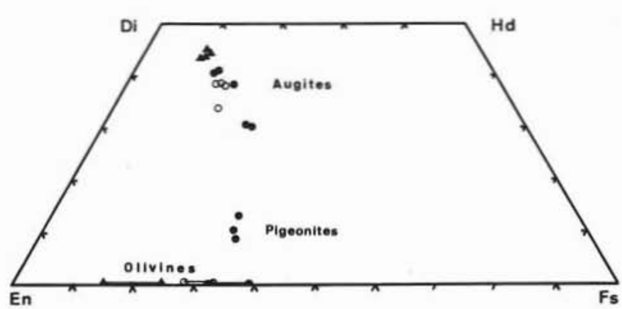

Fig. 16. — Pyroxene quadrilateral and olivine range for high-alumina basalts (triangles = Sa 113, open circles = Sa 124, full circles = Sa 212).

Fe_2O_3/FeO is greater than 0.4 even in the freshest samples. This suggests an elevated pO_2 during crystallization.

The most basic and most common magma type is high-alumina basalt. The

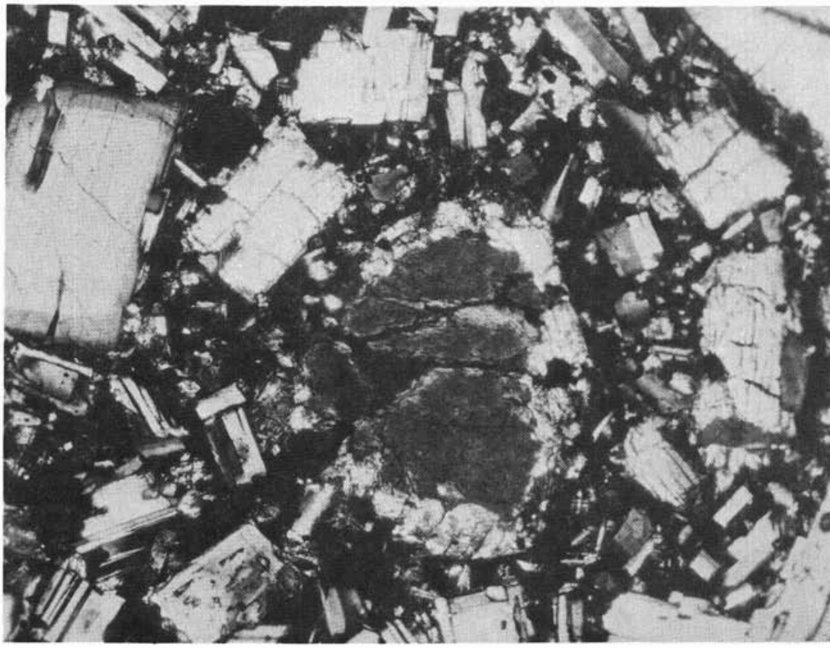

Fig. 17. — Olivine rimmed by pigeonitic augite grains in high-Al basalt of early Fossa (Sa 212, corresponding to analysed unit Sa 210). Magnification 100 x.

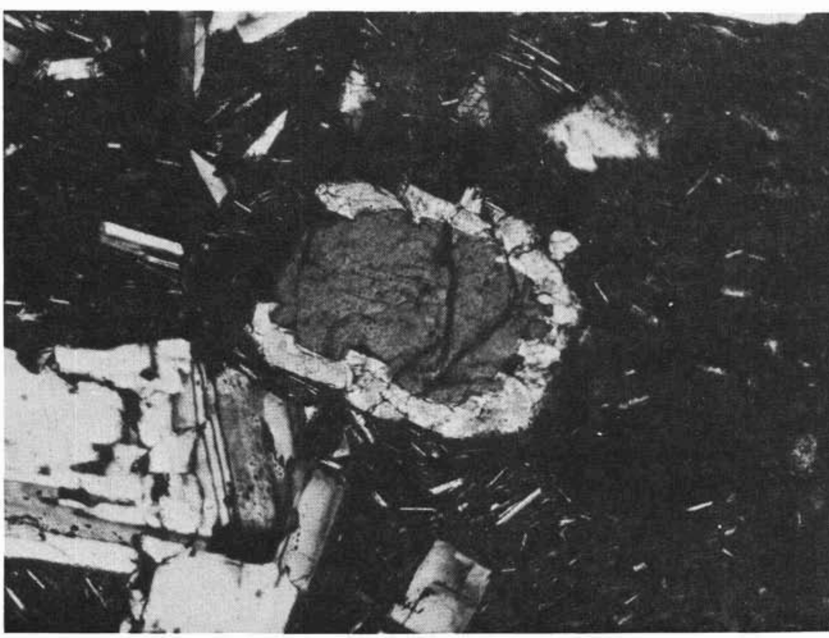

Fig. 18. — Hypersthene, uniaxially rimmed by pigeonite, Sa 179, andesite of Fossa-Favarolo series. Magnification 100 x.

TABLE 8

Chemical bulk composition and mineral analyses for cumulate xenoliths, CIPW-norm assuming $Fe_2O_3/FeO = 0.15$

	Sa 222	Sa 254	Sa 266	Sa 285	Sa 278	Sa 279	Sa 285 Ol	285 Cpx	285 Plag	285 ore
SiO_2	42.3	45.6	46.0	45.0	50.7	47.9	37.9	50.8	44.1	—
TiO_2	1.11	0.72	0.77	0.22	0.35	0.25	—	0.35	—	4.5
Al_2O_3	21.4	17.0	19.5	21.4	15.5	21.4	—	3.9	35.5	8.05
Fe_2O_3	12.3	10.5	8.9	7.5	6.92	6.18	—	—	—	—
FeO	—	—	—	—	—	—	22.6	6.9	—	82.24
MnO	0.1	0.1	0.1	0.1	0.17	0.16	0.38	—	—	0.21
MgO	6.0	8.3	5.2	9.1	7.25	7.15	39.0	15.2	—	4.43
CaO	15.1	17.1	19.1	15.8	16.8	15.1	0.07	22.65	19.1	—
Na_2O	1.0	0.8	0.6	0.6	1.4	1.1	—	—	0.6	—
K_2O	0.3	0.3	0.2	0.1	0.3	0.1	—	—	—	—
P_2O_5	0.1	0.11	—	—	0.11	0.09	—	—	—	—
L.O.I.	0.18	0.14	0.35	0.22	0.83	0.52				
	99.89	100.67	100.72	100.04	100.33	99.95				
An-content							—	—	95	—
Mg-value							75.5	80	—	—
Q	—	—	—	—	1.0	—				
or	1.8	1.8	1.2	0.6	1.8	0.6				
ab	3.0	4.0	3.5	5.1	12.0	9.4				
an	53.8	42.1	50.1	55.9	35.5	53.7				
ne	3.0	1.5	0.9	—	—	—				
di	18.4	35.1	37.1	18.7	38.9	17.3				
hy	—	—	—	2.7	8.7	15.0				
ol	15.6	11.9	4.3	15.1	—	2.2				
mt	2.2	2.2	1.5	1.5	1.2	1.1				
il	2.1	1.4	1.5	0.4	0.7	0.5				
ap	0.24	0.26	—	—	0.26	0.22				

Sa 222 Anorthite - Cpx - Ol - Mt-cumulate with hornblende intercumulus, Pollara.
254 Anorthite - Ol - Cpx-cumulate with interstitial glass, Pollara.
266 Anorthite - Cpx-cumulate (+Mt, sphene) with interstitial glass, Pollara.
285 Anorthite - Cpx - Ol - Mt-cumulate, with interstitial melt, Porri.
278 Anorthite - Cpx - Opx-cumulate with intercumulus hornblende, Porri.
279 Anorthite - Cpx-hornblende cumulate, Porri.

average of 8 analyses (with $SiO_2 < 52\%$) is given in Table 10 together with an average of the 5 samples which form a group with higher MgO and lower Al_2O_3. These averages are compared with high-alumina basalts and island-arc tholeiites from New Zealand, Papua and the New Britanny island arc (KELLER, 1974). Island-arc tholeiites are characteristically lacking on Salina (and in the Aeolian Islands generally). Gradual differences in major elements between the high-alumina basalts of Salina and the examples from the Pacific are mainly a lower TiO_2 of the former and the less femic nature (lower $Fe_2O_3 + FeO + MgO$, lower C.I.). Low total alkalies are connected with higher K_2O/Na_2O (and K-type trace elements).

Fig. 19. — Quartz-patches in the groundmass of dacites. Fossa delle Felci, Sa 197. Magnification 25 x.

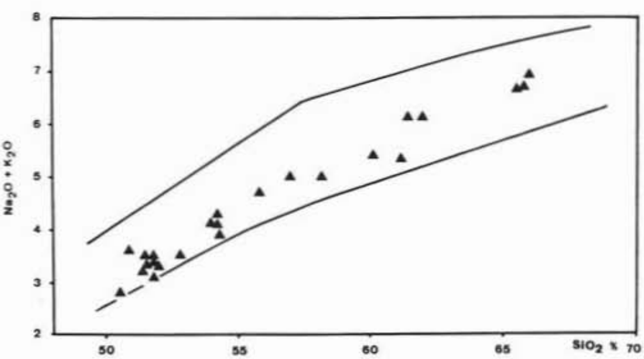

Fig. 20. — Alkalies versus SiO_2 diagram, with limits of KUNO's hypersthenic field.

Even the most primitive basalts of Salina cannot be direct partial melts of a peridotitic mantle but have already undergone appreaciable fractionation. Highest Mg-values (e.g. Sa 113, Sa 91) are as low as 68-66 if computed with the analytical Fe_2O_3/FeO. These are unrealistic upper limits and a more likely approximation is maximum Mg-values of 60-62 by using a corrected $Fe_2O_3/FeO = 0.15$. Low Ni and Cr contents (Table 9) confirm an earlier fractionation before eruption of the most basic end-members of the Salina suite.

In a Harker-type diagram (fig.22) plots of the single oxides fall on smooth curves with regular increase (Na_2O, K_2O) or decrease (total iron, CaO, MgO).

TABLE 9

Trace elements for basalts, andesites and dacites from Salina

Trace element analysis by XRF (Anal. RASCHKA & LODZIAK)
Vanadium by optical spectrometry (Anal. W. STERN)

	SALINA: calc-alkaline association						
	Capo	Corvo	Rivi	Fossa delle Felci	Porri	Fossa delle Felci	
	high-Alumina-Basalts				Low Silica Andesite	Andesite	Dacite
	Sa 113	Sa 125	Sa 178	Sa 210	Sa 181	Sa 76	Sa 197
SiO_2 %	50.5	51.75	51.8	52.0	54.2	61.4	65.8
Na_2O	2.0	1.75	2.5	2.4	2.7	3.7	3.95
K_2O	0.8	1.25	0.9	0.9	1.6	2.4	2.7
Rb ppm	30	34	22	19	38	65	88
Ba	324	357	348	223	492	609	690
Sr	690	683	738	771	740	667	600
K/Rb	223	308	340	393	350	308	254
Rb/Sr	0.04	0.05	0.03	0.025	0.05	0.1	0.15
Ba/Rb	10.8	10.5	15.8	12.0	12.9	9.36	7.85
Ba/Sr	0.47	0.52	0.47	0.29	0.67	0.91	1.15
La	21	18	11	12	26	21	19
Ce	26	35	40	35	46	68	71
Y	17	17	16	18	> 3	23	29
Zr	19	29	22	85	47	100	129
Cu	130	144	134	113	116	56	38
Zn	71	76	73	78	67	59	55
Co	36	28	17	34	17	8	9
Ni	28	24	10	21	4	5	3
Cr	65	42	20	10	14	11	15
V	300	250	-	287	220	180	90
Ni/Co	0.78	0.86	0.59	0.62	0.24	0.63	0.33
V/Ni	11	10	-	14	55	36	30
Cr/Ni	2.3	1.75	2.0	0.5	3.5	2.2	5.0

Al_2O_3 display a sharp rise from 17.0 to 19.0 % within the basaltic end-members of the series. This is related to a sharp drop in MgO content and corresponds with the appearance of plagioclase as a major phenocryst phase. The smooth and regular curves suggest crystal-liquid fractionation processes involving olivine in very early stages and mainly pyroxene with calcic plagioclase over most of the spectrum. This fractionation scheme is supported by numerous cumulate xenoliths of gabbroic mineralogy (anorthite, clinopyroxene, magnetite, ± olivine, ± orthopyroxene, ± postcumulus hornblende).

Trace element geochemistry - Abundances for trace elements are given in Table 9.

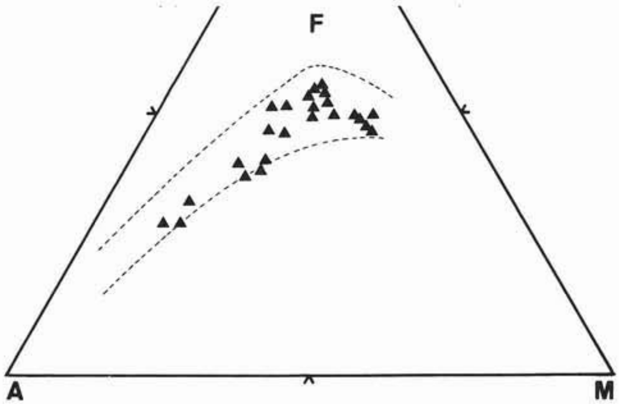

Fig. 21. — *A-F-M* diagram, illustrating slight Fe-enrichment in an early stage and no Fe-enrichment over most of the fractional evolution.

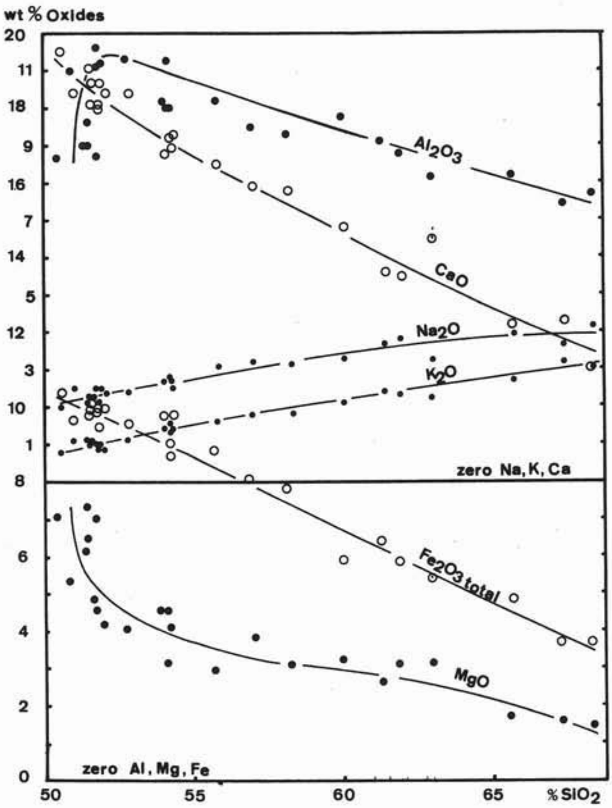

Fig. 22. — Harker-type diagram (in wt%) for major elements of the analysed suite.

Table 11 lists published Sr-isotope data from Barbieri et al. (1974) and Klerkx et al. (1974).

TABLE 10

Group average for basic magma compositions on Salina

	1	2	3	4
SiO_2	51.34	51.85	54.5	46.25
TiO_2	0.5	0.55	0.57	0.57
Al_2O_3	17.0	19.25	18.35	19.4
Fe_2O_3	10.0	9.81	9.2	8.7
MnO	0.18	0.18	0.1	0.12
MgO	6.75	4.55	3.8	7.2
CaO	10.8	10.25	8.9	16.5
Na_2O	2.16	2.46	2.76	0.9
K_2O	1.0	1.0	1.46	0.2
P_2O_5	0.17	0.17	0.21	0.1
Mg-Value x)	60	50.5	47.4	63.5

x) 100Mg/Mg+Fe^{2+} assuming Fe_2O_3/FeO = 0.15

1) primitive high-Al basalts (Sa 127, 124, 113, 91, 186); 2) more evolved high-Al basalts (Sa 184, 108, 178, 210, 164); 3) low-Si andesites (Sa 175, 216, 70, 181, 131); 4) average of 6 gabbroic cumulate xenoliths of Table 8.

TABLE 11

$^{87}Sr/^{86}Sr$ isotopic ratios in lavas of Salina

		$^{87}Sr/^{86}Sr$	
Sa 210	High-Al basalt (1)	0.7040	
Sa 113	High-Al basalt (1)	0.7053	range for all
Sa 124	High-Al basalt (1)	0.7052	Aeolian Islands
Sa 1	Quartz-latiandesite (2)	0.7043	0.7030 - 0.7064
Sa 2	Quartz-latiandesite (2)	0.7042	
Sa 3	Quartz-latiandesite (2)	0.7044	

(1) from BARBERI et al., 1974; (2) from KLERKX et al., 1974 (petrographic denominations of the author's)

The ferromagnesian trace elements (Ni, Co, Cr) have the low concentrations which are typical for the calc-alkaline suite. Maximum Ni is 30 ppm and maximum Cr is $\sim$60 ppm in the basaltic members. All ferromagnesian elements show an inverse correlation with SiO_2. Vanadium (200-300 ppm) is in the range given by TAYLOR et al. (1969) for high-Al basalts and andesites. The restriction as to a possible magma genesis by magnetite fractionation under high pO_2 applies to the suite of Salina, because of the undepleted vanadium contents. The later decrease of V with increasing silica (or differentiation index) can however be attributed to magnetite fractionation. Magnetite occurs as a cumulus phase in several gabbroic cumulate xenoliths. A strong positive correlation between MgO and Ni is explained by olivine fractionation. The extrapolation of this exposed fractionation line towards higher MgO and Ni contents suggests that olivine removal from a primary basaltic magma with higher Mg-values can account for the observed composition of the most primitive magmas from Salina (fig. 23).

The large and highly charged cations (LIL elements - large ion lithophile elements) such as Rb, Sr, Ba, Zr, Y, La and Ce have distintly higher concentrations than TAYLOR's (1969) pacific averages. They are also higher than the «island-arc types» of JAKES and WHITE (1972). Table 12 compares Salina with the island-arc type and the continental margin type andesites as proposed by JAKES and WHITE. Although of island-arc type in major elements and petrography, the trace element concentrations (including K_2O) of the Salina suite are closer to the higher level in Andean andesites. K/Rb ratios are low with a range of 200-350. With fractionation and

TABLE 12

Petrological parameters of calc-alkaline rocks from Salina (Aeolian Islands) compared with the island-arc and continental-margin («Andean») type of JAKES & WHITE, 1972

	Island-arc type	Andean-type	Salina/Aeolian Islands
SiO_2-range	50-66 %	56-70 %	50-68
FeO/MgO (FeO = total iron as FeO)	< 2.0	> 2.0	1.4-2.1
K_2O/Na_2O	< 0.8	0.6-1.1	0.36-0.88
K_2O at SiO_2 60 %	1.6	2.2	2.0
trace elements	lower Rb, Ba, Sr, Zr, Th, U	higher Rb, Ba, Sr, Zr, Th, U	
examples at SiO_2 59-61 : Rb	30	80	60
Ba	270	680	600
Sr	385	700	650
K/Rb	430	230	280
Phenocrysts (with plagioclase)	Cpx, Opx, Hbl, Bi no Qz, Garn, Cord.	Bi, Hbl, Cpx, Opx, rare Qz, Gran, Cord.	Ol, Cpx, Opx, ± Hbl, Bi no Qz, Garn, Cord.
$^{87}Sr/^{86}Sr$	0.703 - 0.704	0.705-0.7077**	0.7040 - 0.7053

Additional data from TAYLOR, 1969**; SIEGERS et al., 1969, MCNUTT et al., 1975.

increasing differentiation index Rb and Ba increase (in correlation with K_2O), strontium decreases (KELLER, 1974). Lanthanum and cerium show concentrations of 30-80 times chondritic (Table 9), which shows a marked enrichment of the LREE.

The most primitive high-Al basalts have 37-45 times chondritic La and around 7 times chondritic Yb. The La/Yb ratio is 7.8-9.6 (KELLER, TAYLOR & MUIR, in prep., KLERKX et al., 1976).

REE data show in accordance with LIL elements that a possible source mantle must be enriched in LREE. On the other hand, they show no definite depletion of HREE. Garnet as a residual phase, as in an eclogitic partial melting model, or participation of garnet in crystal fractionation processes is therefore not supported by the REE data (cf. GILL, 1974; NICHOLLS & WHITFORD, 1976).

None of the samples of calc-alkaline affinity on the Aeolian Islands has a strong europium anomaly which would suggest important plagioclase fractionation. And yet, gabbroic cumulates have anorthitic plagioclase as a major constituent.

Strontium isotopic ratios (Table 11) are slightly higher than in strictly oceanic island arcs and show a considerable range even between samples with quite similar petrography.

Values of 0.7040-42 are considered significant.

Contamination with more radiogenic Sr either from the crust or from the subducted slab can account for the higher values (> 0.7045). However this contamination has not contributed to the origin of the major characteristics of the calc-alkaline series.

6. Magmatological conclusions

The dominant volume amongst the erupted lavas is basaltic. The derivation by partial melting processes from crustal rocks including oceanic-type crust is unlikely considering the required high degree of slab melting. Moreover, eclogitic parenthood is not supported by the HREE concentrations. Consequently the mantle above the Benioff zone is envisaged as source area.

All basalts are Q-normative and have intermediate Mg-values. High-alumina basaltic average 1 in Table 10 is the most primitive composition but still too low in Mg-value to be a likely equilibrium partial melt in a peridotitic mantle.

It is therefore concluded that even the most primitive basalts on Salina had undergone a certain fractionation before erupting. Depleted Ni and Cr contents and the general correlation of these ferromagnesian trace elements with MgO (fig. 23) point to olivine removal (together with minor Cr-spinel) as the dominant fractionation process during this pre-eruptive stage.

Potassium, LREE and LIL elements show higher concentrations than in comparable subalkaline basalts from non-subduction situations. Enrichments of these elements must therefore be related either to higher concentrations in the sub-arc mantle or to a concentration mechanism related to the subduction and magma genesis process. The latter case is explained following the model of RINGWOOD (1974) and NICHOLLS (1974) by adding the relevant elements to the source mantle with water or a highly hydrous melt from the subducted crust. The very high concentration level of potassium and related elements in the shoshonitic lavas of Vulcano (KELLER, 1974) which are connected with a great Benioff depth supports the model of RINGWOOD and of NICHOLLS.

Differences between the more primitive and the more evolved high-alumina basalts (averages 1 and 2 in Table 10) are best explained as continuation of the olivine dominated fractionation. Clinopyroxene takes part in subordinate amounts.

Further differentiation of the exposed suite from basalt to andesite and dacites is explained by fractionative removal of the phases which are dominant in the low-pressure cumulate xenoliths. These are An-rich plagioclase, calcic clinopyroxene, olivine, orthopyroxene, magnetite.

The iron-enrichment vs. silica plot (fig. 24) is interpreted (OSBORN, 1976) as dominantly low pressure/moderate fO_2 fractional evolution. Only the Pollara samples approach the Cascades trend, which developed under distincly higher pressure.

Seismic centers which indicate subductive processes underneath the Aeolian Islands are about 250 km deep below the volcanic islands (CAPUTO et al., 1972). The focal depth increases to 350 km from Calabria towards the Tyrrhenian abyssal plain, where single centers with a focal depth of up to 450 km have been recorded. Thus, the general pattern of the SW Tyrrhenian seismicity defines the Aeolian Islands an island arc with a NW to NNW dipping Benioff zone. A special feature of the present-day seismicity is the lack of craters in the depth range of 35-200 km (SCHICK, 1972; KELLER, 1974). Such gaps in seismic activity are not atypical within active island arcs in the Pacific (OLIVIER et al., 1973) and can be explained with the model of a

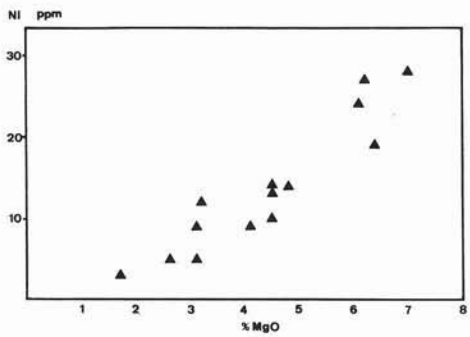

Fig. 23. — MgO-Ni correlation.

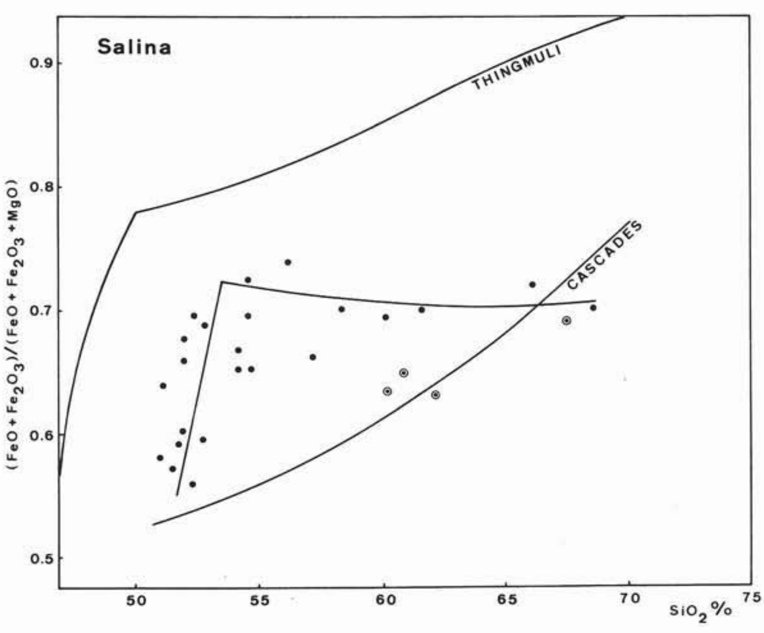

Fig. 24. — Iron-enrichment plot vs. silica for the calc-alkaline suite of Salina. Comparisons after OSBORN, 1976 show for Salina a low-pressure/moderate-fo_2 fractionation. Pollara samples (circled dots) approach a high-pressure trend as e.g. the Cascades.

detached slab (Baranzaghi et al., 1973; Keller, 1974; Biju-Duval et al., 1978).

It is well established that in most island arcs potassium content at constant SiO_2 increases with increasing depth of the seismic Benioff zone (Dickinson and Hatherton, 1969). It is also well established by the most recent considerations (e.g. Whitford and Nicholls, 1976) that level of K_2O and slope of the increase is an individual feature of every arc.

Comparing the Aeolian islands with the range in *K-h* ratio of other arcs it appears that focal depths of 250-300 km correlate more easily with the K_2O content of the shoshonitic lavas in Vulcano and Stromboli than with $K_{55} = 1.4$ of Salina ($K_{55} = K_2O$ at 55 % SiO_2).

Calc-alkaline volcanism and related seismicity appear therefore extinct and present-day seismicity is related to shoshonitic activity which marks a late stage in island arc dynamics.

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