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# THE ISLAND OF FILICUDI

ABSTRACT. — The island of Filicudi is the summit part of a complex volcanic structure extending widely below sea level. The island is located in the Southern Tyrrhenian Sea, where it forms, with the neighboring island of Alicudi, the western branch of the Aeolian island arc.

Volcanic activity developed in Pleistocene and was exhausted by Tyrrhenian, giving rise to several volcanic centers consisting of strato-cones and endogenous domes. Pyroclastics and lava flows alternate in a sequence forming a typical orogenic rock association, ranging in composition from basalts to high-K andesites; high-K basaltic andesites are the dominant member of the suite.

The petrography, mineralogy (microprobe data), major, trace and rare earths element distribution all coherently suggest a magmatic differentiation mostly controlled by fractional crystallization in a shallow magma chamber, under high $f_{O_2}$ conditions. The parental magma is inferred to proceed from a relatively fractionated mantle source. An alternative hypothesis accounting for the high $K_2O$, LREE and LIL element concentration is the contribution to the « normal » mantle of the relevant elements from the subducted slab.

RIASSUNTO. — L'isola di Filicudi rappresenta la parte sommitale di una struttura vulcanica complessa che si sviluppa in gran parte al di sotto del livello del mare. L'isola è situata nel Tirreno Meridionale dove essa forma, con la vicina isola di Alicudi, l'estremità occidentale dell'arco insulare delle Eolie.

L'attività vulcanica si è sviluppata nel Pleistocene e si è conclusa prima dell'inizio del Tirreniano, dando luogo alla formazione di numerosi centri eruttivi costituiti da strato-vulcani centrali e cupole di ristagno. Prodotti piroclastici e colate laviche si alternano in una successione di vulcaniti che appartengono ad una tipica serie orogenica, la cui composizione è compresa tra i basalti e le andesiti ricche in potassio; le andesiti basaltiche ricche in potassio sono i termini dominanti della successione.

I caratteri petrografici, mineralogici (analisi alla microsonda), nonchè la distribuzione degli elementi maggiori, in traccia e delle Terre Rare, suggeriscono che la differenziazione magmatica che ha condotto alla formazione della serie, si sia realizzata essenzialmente attraverso processi di cristallizzazione frazionata in una camera magmatica superficiale, in condizioni di elevata pressione parziale di $O_2$. Si ritiene inoltre che il magma capostipite derivi dalla fusione parziale di una zona del Mantello relativamente frazionata. Un'ipotesi alternativa che possa ugualmente render conto delle elevate concentrazioni di $K_2O$, LREE e LILE è rappresentata da un probabile arricchimento degli elementi in argomento, ceduti dallo « slab » in subduzione al sovrastante Mantello.

## Introduction

The island of Filicudi extends over about 9.5 km² with its maximum elevation of 774 m a.s.l. the strato-cone of Fossa Felci.

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Several isolated rocks emerge from the sea at about 1 km from the north-western coast (Canna, Montenassari, Scoglietto), suggesting the previous occurrence of a western extension of the present island, severely affected by sea erosion in view of the prevailing westerly winds. The island itself represents the summit part of a huge volcanic structure, extending widely below sea level. Bathymetric contour lines down to 1100 m b.s.l. indicate the roughly conical shape of the structure, with an elliptical base about 18 km across, following the NW-SE trending main axis. Further evidence of such an elongated setting is the occurrence of a 39 m deep shoal, located about 4 km to the NW of the island. The whole structure rises on the surrounding sea floor — from a depth slightly exceeding 1000 m — which extends laterally both in E and W directions to form the relative basement for the

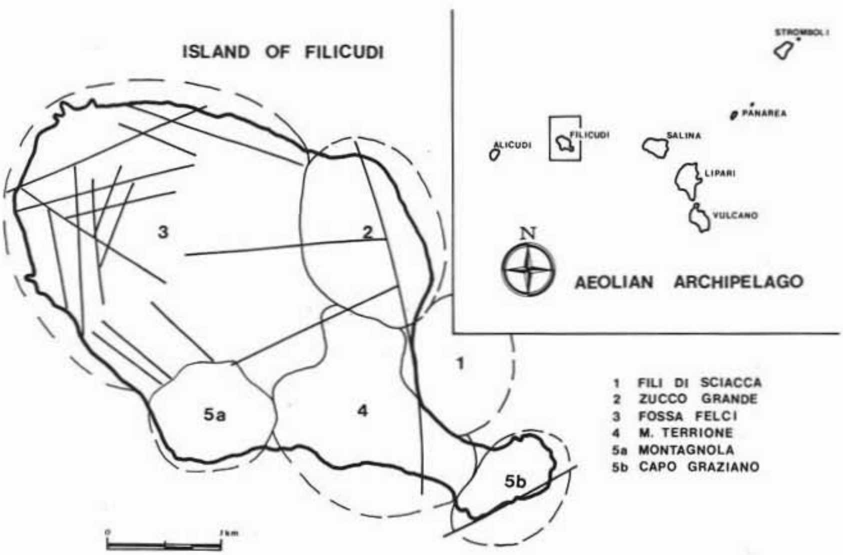



Fig. 1. — Location map of the island of Filicudi. The main linear structures are schematically indicated as well as the domain of each volcanic edifice: numbering is according to the chronological succession.

neighboring volcanoes. Quite similar volcanic structures are sited, in fact, about 15 km distant, culminating in the islands of Salina, to the East, and Alicudi, to the West.

Since Cortese and Sabatini published their geological map in 1892, a few papers have been published dealing with the geology and the petrology of the island (Villari, 1969; Villari, 1972; Klein et al., 1975; Villari & Nathan, 1978). A new geological survey was carried out by the Author in 1969-1970 and the related geological map, printed in 1971, is folded in the back of this issue.

Several accounts concerning the island of Filicudi have also been contributed as part of more general papers devoted to the description of the Aeolian Islands volcanism (Bergeat, 1899; Bergeat, 1918; Keller, 1967; Pichler, 1967; Pichler, 1970; Barberi et al., 1973; Barberi et al., 1974; Keller, 1974; Keller, 1979).

The present paper aims to describe in some detail the geological and structural features that can be observed on the island and to supply the reader with an adequate comment to the enclosed geological map. An up-to-date review of the present knowledge about the petrology and the geochemistry of Filicudi volcanics is also given in order to fill the picture with those elements needed for a substantial view of the evolution of this rock suite.

## Geology

The island is made up exclusively of volcanic rocks erupted from different vents in a sequence which was reconstructed from the observed stratigraphical relationships. At least six distinct volcanic structures were recognized (fig. 1) four of which show typical characters of strato-cones (1 to 4) consisting of lava flows and pyroclastics, alternating according to variable relative proportions.

Tephra layers prevail over lava flows in the older volcanic edifices while lavas clearly dominate in the younger ones. Dome structures (5 *a* and 5 *b*) mark the later stages of volcanic activity on the island, pointing to an increased viscosity of the outpoured magma.

A stratigraphic section is schematically given in fig. 2.

1 - Fili di Sciacca volcanic center

The earliest eruptive activity on the island took place along the eastern section of the coast, presumably related to a volcanic center located not far east of the present coast line. Lavas coming from this early volcanic edifice are well exposed in the cliff at Fili di Sciacca, dipping inland about 18°.

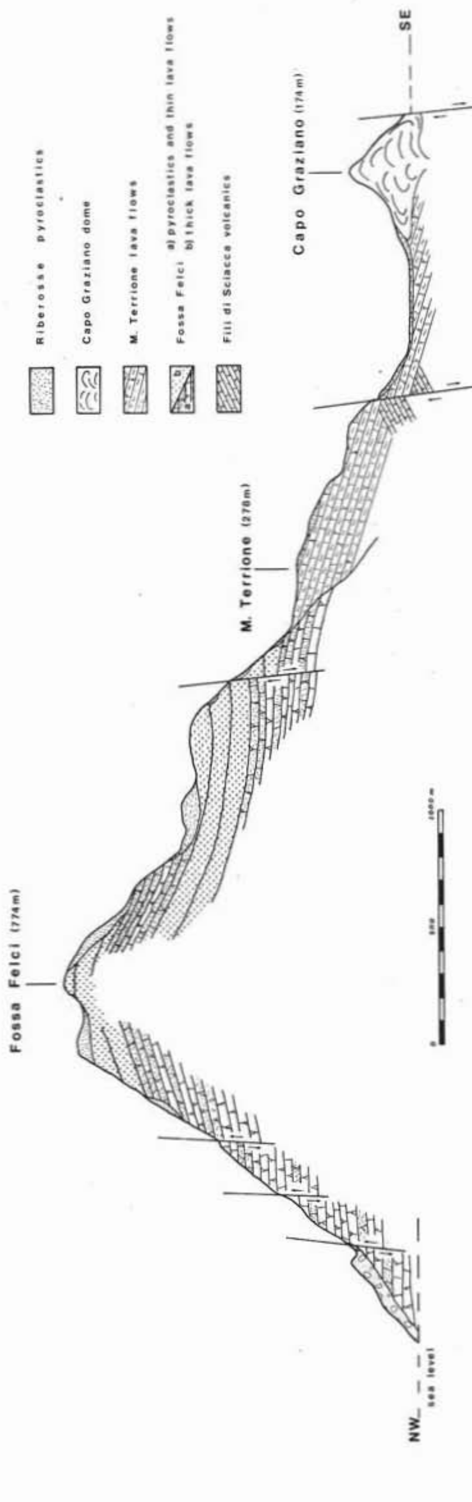



Fig. 2. — Shematic stratigraphic profile across the main geological units of the island of Filicudi.

The eruptive sequence is formed here by a pile of thin lava flows showing a scoriaceous crust and a poorly vesiculated innermost portion; intercalations of pyroclastic layers were not observed. Hand specimens of lavas are characterized by the constant presence of olivine and pyroxene phenocrysts.

The cliff wall is locally covered by short lava tongues proceeding from the neighboring volcanic center of M. Terrione and unconformably resting on the lavas of Fili di Sciacca. The formation of the cliff and the partial foundering (eastern portion) of this volcanic center was probably due to movements along a NNW--trending fault which cut the edifice (fig. 1). The southern extension of the same fault is also visible at Piano del Porto, where the offset is partially obscured by an overlying pyroclastic layer which was erupted during the last eruptive activity on the island.

Minor exposures of pyroclastics and thin lava flows were however observed along the southern section of the fault line, indicating a northeast location for the source vent, coherently with the suggested occurrence of a volcanic center to the Est of the Fili di Sciacca shore.

A closer examination of pyroclastic products (fig. 3) outcropping at the base of M. Guardia, near P. 39, revealed that the pyroclastic sequence to be attributed to the Fili di Sciacca volcanic center is locally interbedded with surge-type deposits from a different vent. The presence of well developed sand-wave structures (fig. 4) within the surge layers suggests, in fact, their emission from a western source.

It is therefore concluded that more than one volcanic vent was active during this early eruptive stage, giving rise to volcanic products now mostly obscured by volcanics from the younger volcanic centers.

The very limited and partial exposure of the products belonging to this eruptive phase prevents any further inference about the characters of the early volcanic activity on the island.

## 2 - Zucco Grande volcanic center

The lava flows exposed at Fili di Sciacca were followed in time by lavas and pyroclastics from the Zucco Grande eruptive center, located in the northeastern portion of the island. Clear stratigraphic relationships can be observed along the lowermost section of a dip gully, i.e. V. La Fossa, where seaward-dipping lava flows with minor interbedded pyroclastics and scorie unconformably cover the lavas of Fili di Sciacca.

The volcanic edifice of Zucco Grande shows on the whole a distinct strato-cone structure, consisting of lava flows with locally interbedded lenses of poorly-welded scoria, generally of limited extent. Thick pyroclastic deposits occur on the eastern and northeastern flanks of the volcano, deeply dissected by gulleys.

The maximum elevation of the structure is presently attained at P.ta Lazzaro (510 m a.s.l.), where the main vent was probably located. In spite of the lack of diagnostic evidence as far as the morphology is concerned, such an inferred location is supported by a regular outward dipping of lava flows and pyroclastic layers.

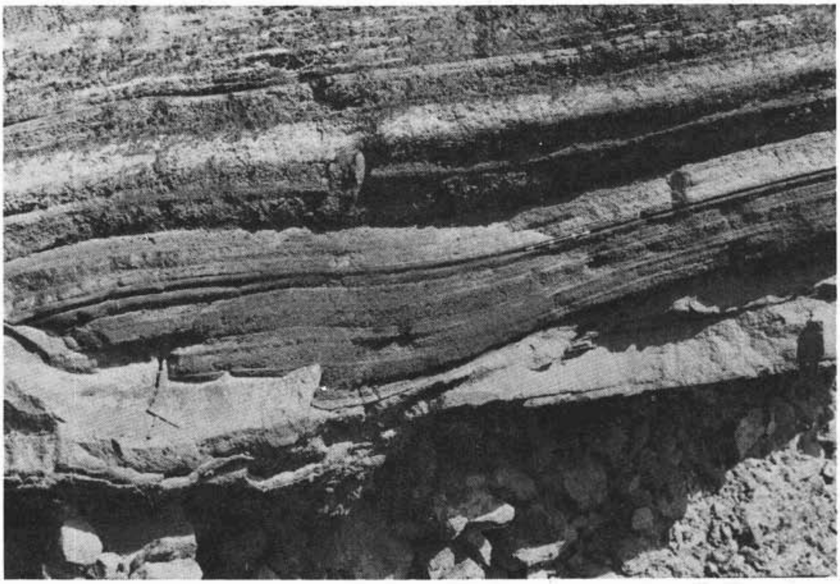


Fig. 3. — Piano del Porto, island of Filicudi. Pyroclastic layer sequence belonging to the Fili di Sciacca volcanic center.

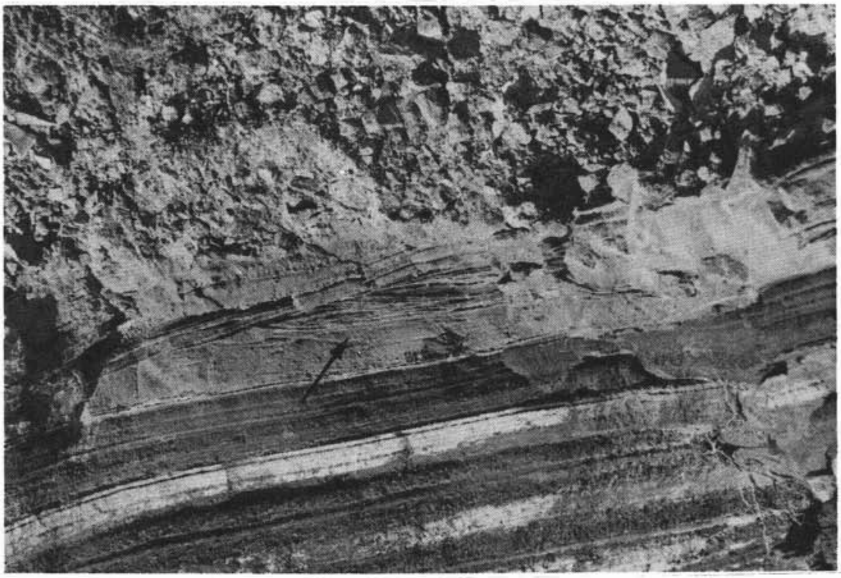


Fig. 4. — Piano del Porto, island of Filicudi. Base-surge deposits (center of the picture) interbedded with the pyroclastic products from Fili di Sciacca, point out the occurrence of a volcanic vent located to the W of the outcrop and now mostly obscured by younger volcanics.

Lava flows usually range in thickness between 1 and 4 m. They show in general a poorly developed scoriaceous crust and a highly dense innermost portion; more vesiculated lava flows were only occasionally observed. Hand specimen examination

Fig. 5. — The island of Filicudi from Capo Graziano dome. The large depression indicated by the black arrow is the remnant of a wide asymmetrical crater which formed during the late evolution of the Zucco Grande strato-cone (to the right).

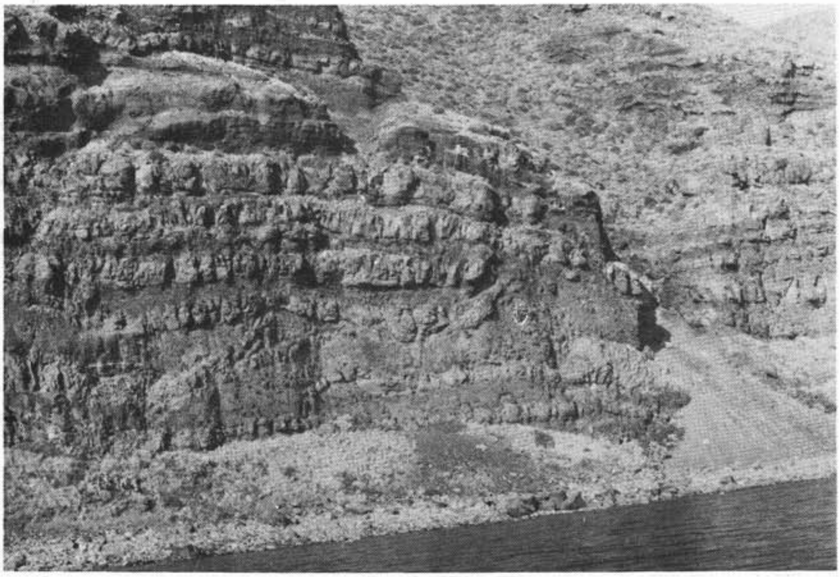


Fig. 6. — Costa dello Sciarato, island of Filicudi. The basal part of Fossa Felci volcanic center consists of a pile of thin lava flows, with locally interbedded lenses of pyroclastic products.

reveals the constant presence of plagioclase and pyroxene phenocrysts, associated with occasional olivine. Minor lenses of poorly-welded black scoria are frequently associated with lava flows.

Pyroclastic product piles, ranging in thickness up to several tens of meters, consist of both fall- and flow-type units. Pyroclastic flows are mostly developed in the uppermost section of the sequence, where glowing avalanche deposits can also be recognized, e.g. at Chiumento.

The eruptive products belonging to the Zucco Grande volcanic center are mantled by a discontinuous cover consisting of pyroclastic deposits erupted during the last explosive activity on the island. Several patches of these late tephra layers, ranging in thickness between a few centimeters and a few meters, can be observed on the flanks of the edifice. They appear to be preferentially accumulated and better preserved on gentle slopes.

The activity of Zucco Grande seems to have been accomplished by a violent degassing phase, which took place in the middle-southern part of the edifice, producing a wide asymmetrical crater (fig. 5). Within this explosive volcanic depression there later developed the activity of M. Terrione, a younger volcanic center.

### 3 - Fossa Felci volcanic center

Volcanic rocks of Zucco Grande are overlain by products from Fossa Felci, the main volcanic structure on the island. Pyroclastic ejects and lavas emitted by Fossa Felci cover over two-thirds of the island, forming a well-shaped andesitic strato-volcano (774 m a.s.l.). The average dip of this edifice is about 35°-38°, because of the marked prevalence of pyroclastic materials among its products. The basal portion of the structure consists of a pile of thin lava flows (fig. 6) characterized by a well developed scoriaceous crust, both at the base and on top of each flow. Higher in section the pyroclastic components are increasingly more voluminous and become largely predominant in the summit area (fig. 7). The most recent volcanic phase of this eruptive center gave rise to the formation of short and thick lava flows, indicating an increasing viscosity of the outflowing magma with eruptive succession.

Large glowing avalanches were erupted on the northwestern flank of the volcano, reaching the sea to the south of P. La Zotta.

Lava flow sequences are better exposed on the south-western lower slopes of the structure, where quite a regular succession of flow units occur with minor and locally interbedded lenses of pyroclastic products. On the northern flank of the volcano deep gulleys cut into the structure showing an alternation of pyroclastic layers with minor lava flows. Numerous dikes and sills were observed cutting across the pile of volcanic products: dikes do not appear to trend according to a preferential direction, but fit into a roughly radial pattern. Pyroclastic products, which predominate in the upper part of the sequence, are well exposed in the southern wall of Riberosse and mainly consist of poorly-welded scoria and lapilli.

Short and thick lava tongues are locally interbedded to the upper pyroclastic series and they outcrop on the northwestern and southeastern slopes of the strato-cone, according to the main axis of the island.

The products of Fossa Felci, as was observed for those of Zucco Grande, are discontinuously mantled by the pyroclastic layers attributed to the last volcanic activity on the island. The maximum thickness of this pyroclastic series is reached at Riberosse, on the eastern upper slope of Fossa Felci, but otherwise it is hardly preserved on the steep flanks of the volcano.

### 4 - M. Terrione volcanic center

Lava flows from the eruptive center of M. Terrione also show the same morphological changes observed for the last effusive products of Fossa Felci. They are confined to the southeastern sector of the island, where a succession of thick lava tongues, often overlapping, resulted in dome-like accumulations generally several tens of meters in height and breadth. Pyroclastics are practically absent among the products of this volcanic center and the scoriaceous parts of the flows are generally very poorly developed.

The best exposure of this lava sequence can be observed at Filo di Lorani, along the southern coast of the island.

Lavas form M. Terrione are partly covered by the late pyroclastics marking the end stages of the volcanism at Filicudi.

### 5 - Montagnola and Capo Graziano volcanic centers

The lavas of Montagnola and Capo Graziano form two well-shaped endogenous domes, respectively located along the southern coast (Montagnola) and at the southeastern corner of the island (Capo Graziano) (fig. 8). They both show well-developed laminar flow structure (fig. 9), pointing out the high viscosity of the extruded lavas.

It is impossible to assess a precise time succession between the two domes because of the lack of diagnostic relationships, but field evidence indicates that both overlie lavas from M. Terrione. It seems however reasonable to consider the Capo Graziano dome as the product of the most recent effusive event on the island, because of its well preserved shape, only minimally modified by weathering and erosion. The southeastern part of the Capo Graziano dome is intersected by a N 60° E-trending fault, which displaced downward about half of the dome, exposing its internal structure and allowing a better reconstruction of its growth (Villari, 1969).

The lavas from Capo Graziano are characterized by the presence of abundant amphibole phenocrysts, easily identified in hand specimens, while the lavas from the Montagnola dome only occasionally show the occurrence of this hydrous phase.

On both domes pyroclastic products were observed, attributable to the last volcanic activity on the island.

The last eruptive event on the island of Filicudi was a major explosive episode that produced a widespread pyroclastic sequence. The maximum observed thickness of this pyroclastic pile is reached at Riberosse, on the eastern side of the main topographic high. No reliable data exist about the volcanic structure which produced

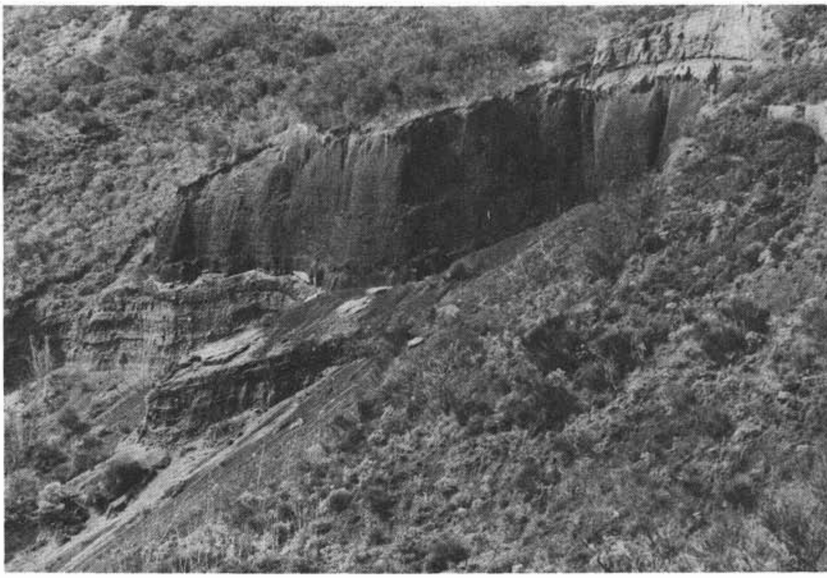


Fig. 7. — Riberosse, island of Filicudi. Pyroclastic layers dominate in the uppermost section of the eruptive sequence forming the strato-cone of Fossa Felci.

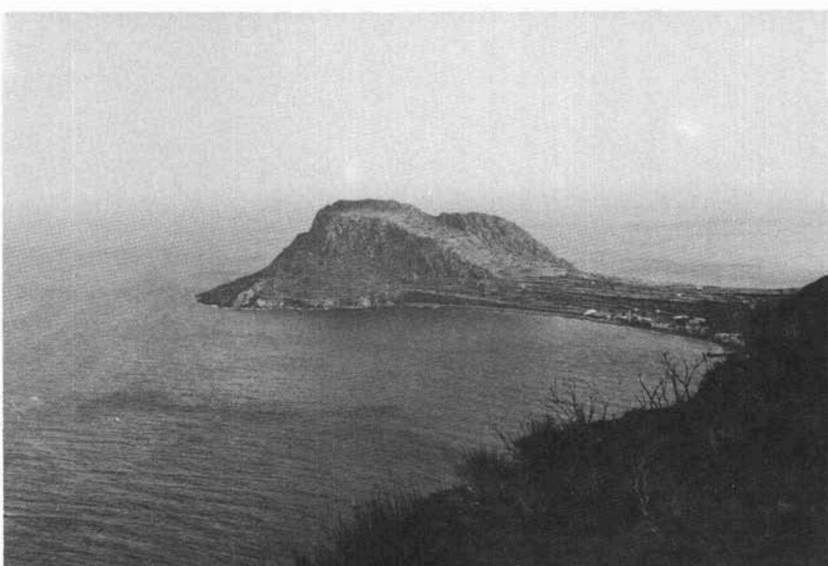


Fig. 8. — Capo Graziano, island of Filicudi. The endogenous dome of Capo Graziano probably represents the most recent effusive event of the island.

this final eruptive phase, but the distribution pattern of its products is consistent with a vent located somewhere within the summit area of Fossa Felci.

The Riberosse pyroclastic series (named after the site of maximum thickness) mainly consist of pyroclastic flow units which erupted in a late sequence, when

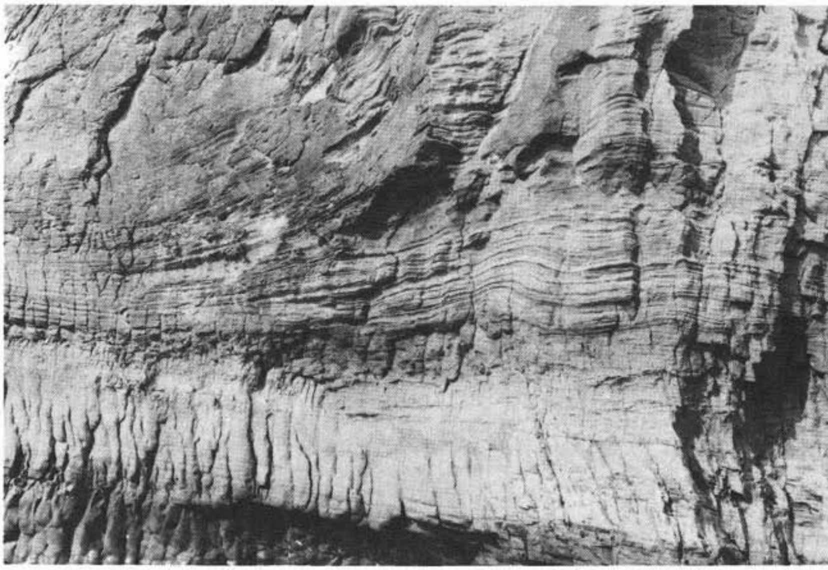


Fig. 9. — M. Montagnola, island of Filicudi. Laminar flow structures are well exposed on the SW flank of the Montagnola endogenous dome.

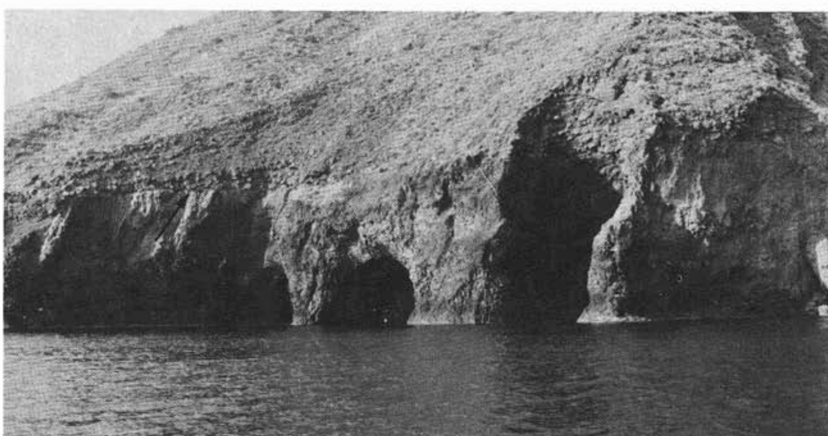


Fig. 10. — Grotta del Bue Marino, island of Filicudi. A Quaternary raised beach ($40 \div 45$ m a.s.l.) cuts the lavas from Fossa Felci.

the older volcanic structures were deeply affected by erosion. Pyroclastic flows covered the preexisting slopes and, rapidly losing their energy on the flat ground, were accumulated in depressions.

Significant textural changes are observed within a single flow unit, according to variations in the preexisting morphology of the relative basement. Large, partly rounded boulders are concentrated at the foot of steep slopes and only occasionally were found, in a prevalently fine-grained matrix, further downward. In spite of the very local concentration of lithic fragments the most common appearance of these pyroclastic flow units is characterized by an ash grain-size and a brownish earthy colour. Coarser pumice lenses are locally interbedded.

Several Quaternary raised beaches were observed along the coast of the island (KELLER, 1967; PICHLER, 1968; VILLARI, 1972), cutting the products erupted by the described volcanic centers. The correlation attempted among marine terraces located at different height allowed them to be put into four groups according to the elevation above the present sea level (VILLARI, 1972). The oldest group of raised beaches was observed ranging between 40 and 45 m a.s.l., along the southwestern coast of the island, near Grotta del Bue Marino, cutting the lavas from Fossa Felci (fig. 10). Younger marine terraces are clearly exposed at Piano del Porto and Filo di Lorani, in the southeastern sector of Filicudi, ranging in elevation between 6 and 30 m a.s.l.. They cut the pyroclastic products from Riberosse, supplying an upper limit to the volcanic activity, which is believed to have been accomplished before 0.23 m.y. ago (VILLARI, 1972).

K/Ar dating has been attempted on the oldest volcanic products from Filicudi (BARBERI et al., 1974) giving only a lower limit (1.0 m.y.) because of the high atmospheric Ar contamination.

It is concluded therefore that the volcanic activity on the island of Filicudi is Pleistocene in age and presumably comprised between 1.0 and 0.23 m.y. ago.

## Petrology

The volcanic rocks from Filicudi define a fairly homogeneous sequence of high-K calc-alkaline lavas (VILLARI, 1972; VILLARI and NATHAN, 1978), consisting of basalts - high-K basaltic andesites - high-K andesites, according to the classification suggested by PECCERILLO and TAYLOR (1976). Basaltic andesites are by far the most abundant rocks on the island, while basalts and andesites were erupted mainly during the beginning and the end stages of volcanism.

The petrography, mineralogy and geochemistry of this rock suite were widely discussed in VILLARI (1972) and VILLARI and NATHAN (1978). The present section of the paper does not represent an original contribution, but a summary of the present knowledge.

### 1 - PETROGRAPHY AND MINERALOGY

*Basalts* generally contain a large proportion of phenocrysts, ranging from 30 % to 40 % of the total rocks. A few samples, however, contain 50 %-60 % phenocrysts (e.g., sample F 42i) and approximately 20 % more clinopyroxene than specimens of similar $SiO_2$ content. These peculiar rocks were collected as xenoliths at Riberosse, in the thickest portion of the tuff layer which marks the end of the volcanic activity. Because of their occurrence, abundance of phenocrysts and texture, the specimens are believed to be cumulative in origin.

Plagioclase phenocrysts are largely predominant over ferromagnesian minerals,

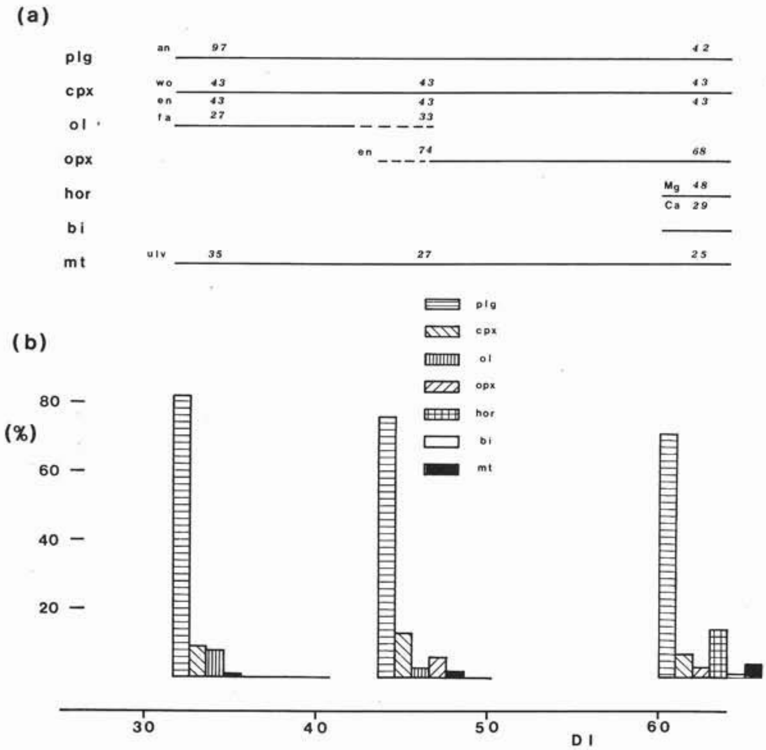



Fig. 11. — Persistence (*a*) and relative abundance (*b*) of phenocrysts in the orogenic rock suite from the island of Filicudi. Composition ranges in (*a*) are indicated according to microprobe data from VILLARI and NATHAN (1978).

TABLE 1

*Average chemical composition of Filicudi phenocrysts*

| | Olivine | Clinopyroxene | Orthopyroxene | Hornblende | Magnetite |
|---|---|---|---|---|---|
| $SiO_2$ | 37.28 | 50.56 | 52.78 | 44.14 | .05 |
| $TiO_2$ | .02 | .49 | .16 | 2.16 | 9.05 |
| $Al_2O_3$ | .33 | 3.32 | 2.18 | 9.84 | 4.10 |
| FeO | 27.02 | 8.77 | 17.30 | 12.41 | 79.70 |
| $Cr_2O_3$ | - | - | - | - | .10 |
| MgO | 34.15 | 15.10 | 25.08 | 13.89 | 1.74 |
| CaO | .28 | 20.88 | 1.28 | 11.60 | .24 |
| $Na_2O$ | .03 | .25 | .04 | 1.88 | - |
| $K_2O$ | .02 | .02 | .02 | .83 | - |

Data from VILLARI and NATHAN (1978).

and they represent 65 % to 85 % of the total phenocrysts. Most of the crystals show strong normal zoning with superimposed weaker oscillatory zoning, but many of the larger crystals have wide homogeneous calcic cores, surrounded by a narrow normally zoned rim. The An content determined by optical methods ranges from

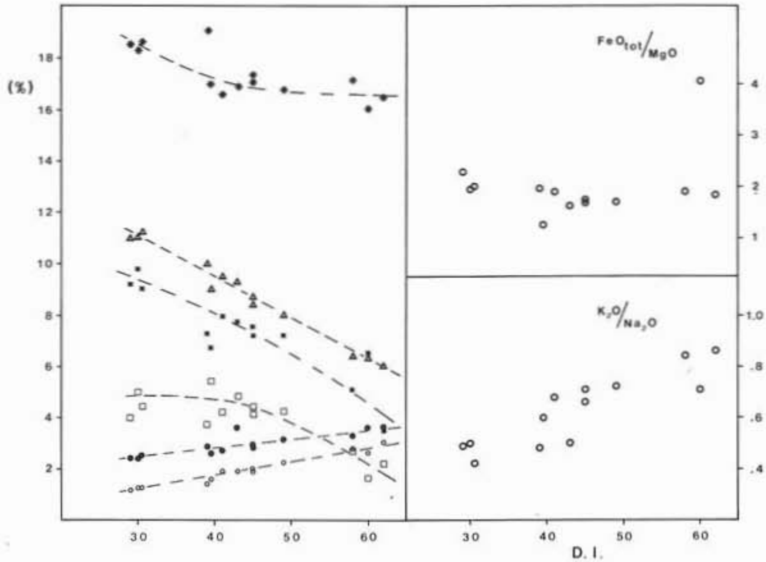



Fig. 12. — Variation diagram of major elements vs. Differentiation Index (THORNTON and TUTTLE, 1960) for the Filicudi rock suite. ✻ $Al_2O_3$; △ $FeO_{tot.}$; ★ CaO; MgO; ● $Na_2O$; ○ $K_2O$.

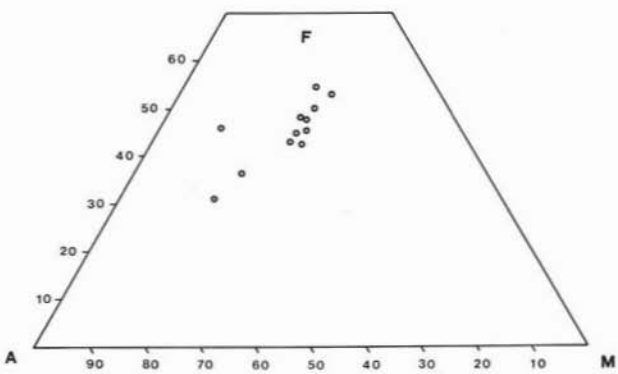



Fig. 13. — AFM diagram for Filicudi samples.

85 % to 70 % for the phenocrysts, while groundmass plagioclase are usually between $An_{75}$ and $An_{65}$ in composition.

Clinopyroxene represents 5 %-15 % of the phenocrysts and, in most of the cases, its optical properties (2V$\gamma$ 56°-58°; $c \wedge \gamma$ 40°-43°) are those for augite. However, in samples with lower $SiO_2$ content (F 42i, F 36, F 136), many of the larger crystals show optical characteristics (2V$\gamma$ 22°-26°; $c \wedge \gamma$ 38°-40°) typically found for a subcalcic clinopyroxene.

Subhedral to anhedral olivine (5 %-10 % of phenocrysts) is present throughout the series of basalts, but it is rarely fresh; most commonly, it is partially resorbed and almost completely transformed into alteration products of the serpentine group. A few phenocrysts (F 42i) were found to be optically recognizable (2V$\gamma$ 98°-100°),

TABLE 2
*Major elements of Filicudi Volcanics (Aeolian Islands)*

| | 1 | | | 2 | 3 | | | |
|---|---|---|---|---|---|---|---|---|
| | FILI DI SCIACCA | | | ZUCCO GRANDE | FOSSA FELCI | | | |
| | F 37 | F 36 | F 136 | F 8 | F 119 | F 19 | F 16 | F 40a |
| $SiO_2$ | 47.90 | 47.93 | 48.90 | 52.83 | 53.35 | 53.45 | 51.82 | 55.00 |
| $TiO_2$ | .90 | .88 | .75 | .57 | .90 | .70 | .87 | .75 |
| $Al_2O_3$ | 18.53 | 18.32 | 18.60 | 16.88 | 17.00 | 16.56 | 19.11 | 17.36 |
| $Fe_2O_3$ | 3.85 | 6.43 | 4.99 | 4.91 | 4.39 | 4.75 | 4.97 | 5.48 |
| FeO | 5.74 | 4.02 | 4.52 | 3.37 | 2.80 | 3.80 | 2.87 | 2.72 |
| MnO | .18 | .20 | .15 | .10 | .15 | .21 | .16 | .14 |
| MgO | 4.03 | 5.04 | 4.43 | 4.83 | 5.44 | 4.23 | 3.73 | 4.43 |
| CaO | 10.93 | 10.93 | 11.21 | 9.25 | 8.97 | 9.53 | 9.95 | 8.41 |
| $Na_2O$ | 2.44 | 2.42 | 2.52 | 3.56 | 2.64 | 2.72 | 2.86 | 2.86 |
| $K_2O$ | 1.20 | 1.22 | 1.22 | 1.86 | 1.60 | 1.86 | 1.38 | 1.90 |
| $P_2O_5$ | .31 | .32 | .17 | .15 | .15 | .33 | .26 | .20 |
| $H_2O^-$ | .49 | .51 | .37 | .17 | .59 | .41 | .75 | .38 |
| L.O.I. | 2.92 | 2.31 | 2.38 | 1.63 | 1.71 | 1.23 | 1.40 | .96 |
| | 99.42 | 100.53 | 100.21 | 100.11 | 99.69 | 99.78 | 100.13 | 100.59 |
| $Mg/Mg+Fe^{2+}$ | .47 | .51 | .50 | .56 | .62 | .51 | .51 | .54 |
| | | | | CIPW-NORM | | | | |
| Q | 1.24 | 2.31 | 2.01 | 2.19 | 7.81 | 7.50 | 6.45 | 9.54 |
| or | 7.09 | 7.21 | 7.21 | 10.99 | 9.45 | 10.99 | 8.15 | 11.23 |
| ab | 20.64 | 20.47 | 21.31 | 30.11 | 22.33 | 23.00 | 24.19 | 24.19 |
| an | 36.07 | 35.52 | 35.84 | 24.59 | 29.81 | 27.49 | 35.23 | 28.92 |
| di | 13.13 | 13.03 | 14.90 | 15.99 | 10.69 | 14.00 | 9.67 | 8.94 |
| hy | 9.84 | 7.44 | 7.13 | 5.89 | 8.88 | 6.17 | 4.83 | 6.88 |
| mt | 5.58 | 9.32 | 7.23 | 7.12 | 6.37 | 6.89 | 7.21 | 7.05 |
| il | 1.71 | 1.67 | 1.42 | 1.08 | 1.71 | 1.33 | 1.65 | 1.42 |
| ap | .74 | .76 | .40 | .36 | .36 | .78 | .62 | .47 |
| D.I. | 31.73 | 32.15 | 30.54 | 45.68 | 39.59 | 43.59 | 40.91 | 46.43 |

Wet chemical analyses by M. CARÀ and L. VILLARI.

suggesting a composition of $Fa_{30\text{-}35}$. Smaller olivine grains were also sometimes observed in the matrix.

Magnetite generallly forms less than 1 % of the phenocrysts. Small subangular to rounded interlocking aggregates of the main phenocryst minerals are present in most of the samples throughout the Filicudi trend. In some samples, plagioclase is not present among aggregate solid phases, but, more frequently, it is present in fairly large proportions.

*High-K basaltic andesites* are similar to the basalts described above, and the main distinctive characteristics can be summarized by the following petrographic features:

*a*) slightly lower content of plagioclase phenocrysts (65 %-80 %) with more sodic composition ($An_{75\text{-}60}$); calcic cores are still present in large crystals;

*TABLE 2: continued*

| | 4 M. TERRIONE | | 5 CAPO GRAZIANO MONTAGNOLA | | |
|---|---|---|---|---|---|
| | F 30 | F 25 | F 5 | F 22 | F 1 |
| $SiO_2$ | 54.35 | 55.85 | 59.45 | 59.72 | 60.87 |
| $TiO_2$ | .73 | .55 | .77 | .90 | .82 |
| $Al_2O_3$ | 17.14 | 16.88 | 17.20 | 16.05 | 16.57 |
| $Fe_2O_3$ | 4.02 | 4.87 | 3.60 | 3.19 | 1.63 |
| FeO | 3.59 | 2.87 | 1.81 | 3.66 | 2.58 |
| MnO | .15 | .12 | .17 | .16 | .09 |
| MgO | 4.13 | 4.23 | 2.65 | 1.61 | 2.21 |
| CaO | 8.69 | 7.99 | 6.42 | 6.31 | 6.03 |
| $Na_2O$ | 2.86 | 3.14 | 3.30 | 3.58 | 3.56 |
| $K_2O$ | 2.02 | 2.26 | 2.78 | 2.56 | 3.06 |
| $P_2O_5$ | .96 | .20 | .22 | .27 | .21 |
| $H_2O^-$ | .28 | .14 | .35 | .40 | .62 |
| L.O.I. | .73 | .84 | .88 | 1.28 | 1.79 |
| | 99.65 | 99.94 | 99.60 | 99.69 | 100.04 |
| $Mg/Mg{+}Fe^{2+}$ | .54 | .54 | .51 | .33 | .52 |
| CIPW-NORM | | | | | |
| Q | 8.78 | 8.66 | 13.95 | 14.66 | 13.65 |
| or | 11.93 | 13.35 | 16.42 | 15.12 | 18.08 |
| ab | 24.19 | 26.56 | 27.91 | 30.28 | 30.11 |
| an | 27.97 | 25.29 | 23.91 | 20.17 | 20.20 |
| di | 7.05 | 10.20 | 5.05 | 7.67 | 6.71 |
| hy | 9.28 | 6.33 | 4.25 | 3.15 | 4.48 |
| mt | 5.83 | 7.06 | 4.16 | 4.63 | 2.36 |
| il | 1.39 | 1.04 | 1.46 | 1.71 | 1.56 |
| ap | 2.28 | .47 | .52 | .64 | .50 |
| D.I. | 46.73 | 50.30 | 60.27 | 62.85 | 64.31 |

Wet chemical analyses by M. CARÀ and L. VILLARI.

*b*) augites show more homogeneous optical characters ($2V\gamma$ 56°-58°; $c \wedge \gamma$ 40°-43°) and their concentration ranges from 10 % to 15 % of total phenocrysts;

*c*) the appearance of orthopyroxene phenocrysts (4 %-7 %) showing an average composition $Fs_{20\text{-}25}$ ($2V\alpha$ 70°-75°). In samples with higher $SiO_2$ content (55 %-56 %), orthopyroxene appears sometimes to be mantled with a thin clinopyroxene rim;

*d*) the almost total lack of olivine.

*High-K andesites* are limited to two dome-shaped structures (Montagnola and Capo Graziano). Their plagioclase content is highly variable (55 % to 80 % of total phenocrysts) with an estimated composition that ranges from $An_{70}$ to $An_{60}$. Two pyroxenes represent 8 %-15 % of phenocrysts and they show rather similar optical properties to those in the basaltic andesites; no olivine occurs.

TABLE 3
*Trace element analyses of Filicudi volcanics*

| | F 421 | F 37 | F 36 | F 16 | F 19 | F 8 | F 40a | F 30 | F 26 | F 5 | F 22 | F 1 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| U | – | 1.3 | 1.28 | 1.6 | 2.6 | 2.0 | 2.2 | 2.6 | 2.6 | 3.4 | 2.7 | 3.6 |
| Th | 7.8 | 4.1 | 4.4 | 5.2 | 6.4 | 5.9 | 7.3 | 6.9 | 8.2 | 8.5 | 8.2 | 11.0 |
| Zr | 43.5 | 52.3 | 54.1 | 69.4 | 70.1 | 68.9 | 82.2 | 82.0 | 96.8 | 100.0 | 112.6 | 112.2 |
| Hf | – | – | 2.3 | 3.1 | – | – | 3.2 | 3.3 | 3.6 | – | – | 4.6 |
| Ta | – | – | – | – | – | – | .49 | .45 | .64 | – | – | .66 |
| Ba | – | 270 | 255 | 365 | 450 | 410 | 510 | 500 | 481 | 570 | 535 | 610 |
| Rb | 22 | 34 | 35 | 35 | 47 | 47 | 48 | 54 | 66 | 77 | 79 | 87 |
| Sr | 594 | 755 | 770 | 688 | 723 | 757 | 641 | 669 | 632 | 599 | 699 | 541 |
| Cs | – | – | – | – | – | – | .83 | .97 | 1.39 | – | – | 1.95 |
| Sc | 45 | 27 | 27 | 25 | 26 | 28 | 24 | 27 | 23 | 18 | 15 | 15 |
| Cr | 100 | 15 | 13 | 21 | 12 | 12 | 10 | 15 | 12 | 9 | 7 | 9 |
| Co | 37 | 30 | 29 | 23 | 24 | 23 | 22 | 22 | 20 | 13 | 14 | 12 |
| Ni | 36 | 19 | 15 | 14 | 9 | 9 | 10 | 12 | 7 | 6 | – | 4 |
| Cu | 109 | 150 | 145 | 132 | 110 | 97 | 95 | 107 | 98 | 80 | 52 | 43 |
| Zn | 64 | 75 | 77 | 75 | 68 | 66 | 72 | 65 | 60 | 62 | 60 | 56 |
| /Rb | 385 | 293 | 289 | 327 | 329 | 329 | 329 | 311 | 284 | 300 | 269 | 292 |
| /Sr | .04 | .045 | .045 | .05 | .065 | .06 | .07 | .08 | .1 | .13 | .11 | .1[illegible] |
| /Rb | – | 7.9 | 7.3 | 10.4 | 9.6 | 8.7 | 10.6 | 9.3 | 7.3 | 7.4 | 6.8 | 7.0 |
| a/Sr | – | .36 | .33 | .53 | .62 | .54 | .80 | .75 | .76 | .95 | .77 | 1.1[illegible] |
| Ni/Co | .97 | .63 | .52 | .61 | .38 | .39 | .45 | .55 | .35 | .46 | – | .33 |
| Cr/Ni | 2.8 | .8 | .9 | 1.5 | 1.3 | 1.3 | 1.0 | 1.25 | 1.7 | 1.5 | – | 2.25 |

Zr, Rb, Sr and Ni by XRF; Cu and Zn by A.A.: the other trace elements determined by INAA. Data from VILLARI and NATHAN (1978).

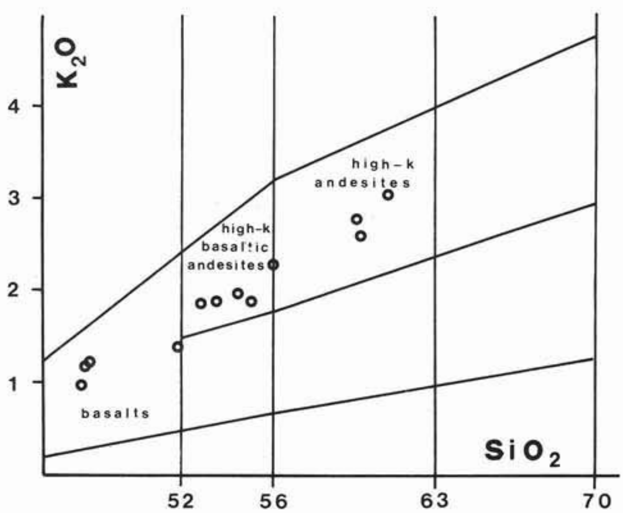



Fig. 14. — $K_2O$ vs. $SiO_2$ diagram for Filicudi samples. Boundary lines according to PECCERILLO and TAYLOR (1976).

Two new mafic phases appear in this group of rocks: a more widely distributed, strongly pleochroic oxyhornblende (up to 10 %-15 % of phenocrysts) and, less commonly, biotite (2 %-3 %). The presence of these hydrous phases attests to increasing $P_{H_2O}$, probably related to the increasing viscosity of the magma.

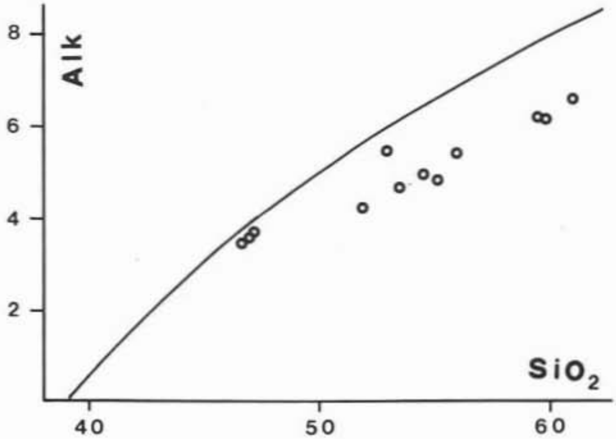



Fig. 15. — Alk ($Na_2O + K_2O$) vs. $SiO_2$ plot for Filicudi samples. Boundary line between the alkaline and subalkaline fields traced according to IRVINE and BARAGAR (1971).

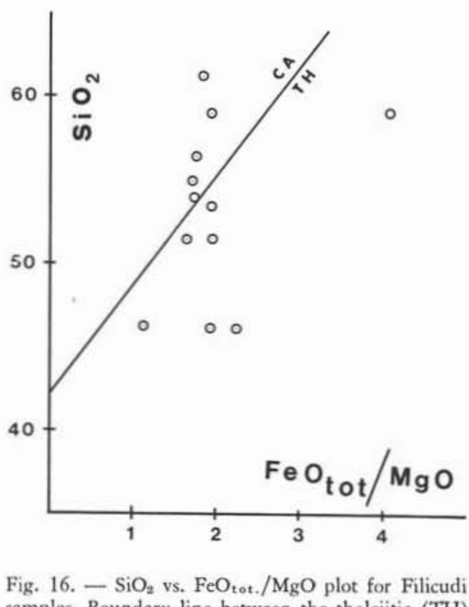



Fig. 16. — $SiO_2$ vs. $FeO_{tot.}/MgO$ plot for Filicudi samples. Boundary line between the tholeiitic (TH) and calc-alkaline (CA) fields after MIYASHIRO (1974).

Microproble analyses of Filicudi rocks (phenocrysts and groundmass) are given in VILLARI and NATHAN (1978) and summarized in Tab. 1.

They show a peculiar homogeneity of the ferromagnesian silicate phenocryst throughout the suite. Despite a general decrease of both Fe and Mg in the bulk rock, with increasing differentiation, the $FeO_{tot.}/MgO$ ratio of mafic minerals remains constant, coherently with the $FeO_{tot.}/MgO$ ratio in the bulk rock. The average composition of clinopyroxene is $Wo_{43}En_{43}Fs_{14}$, while olivine and orthopyroxene range from $Fo_{67-73}$ and $En_{68-74}$ respectively. The amphibole is classified as a Ti-rich hornblende, according to its Ca, Mg and total Fe content.

The only oxide phase which is present in the Filicudi samples is titanomagnetite. The main feature observed in the chemistry of this phase is the decrease of $TiO_2$ with increasing differentiation, matching a similar $TiO_2$ depletion in the total rock analyses.

Plagioclase is characterized by the constant presence of calcic cores in the larger phenocrysts throughout the suite. The composition of these cores is consistently in the range $An_{82-97}$, in spite of variations of the rims down to about $An_{42}$. CaO content of the rims in larger phenocrysts, as well as microphenocrysts appears to

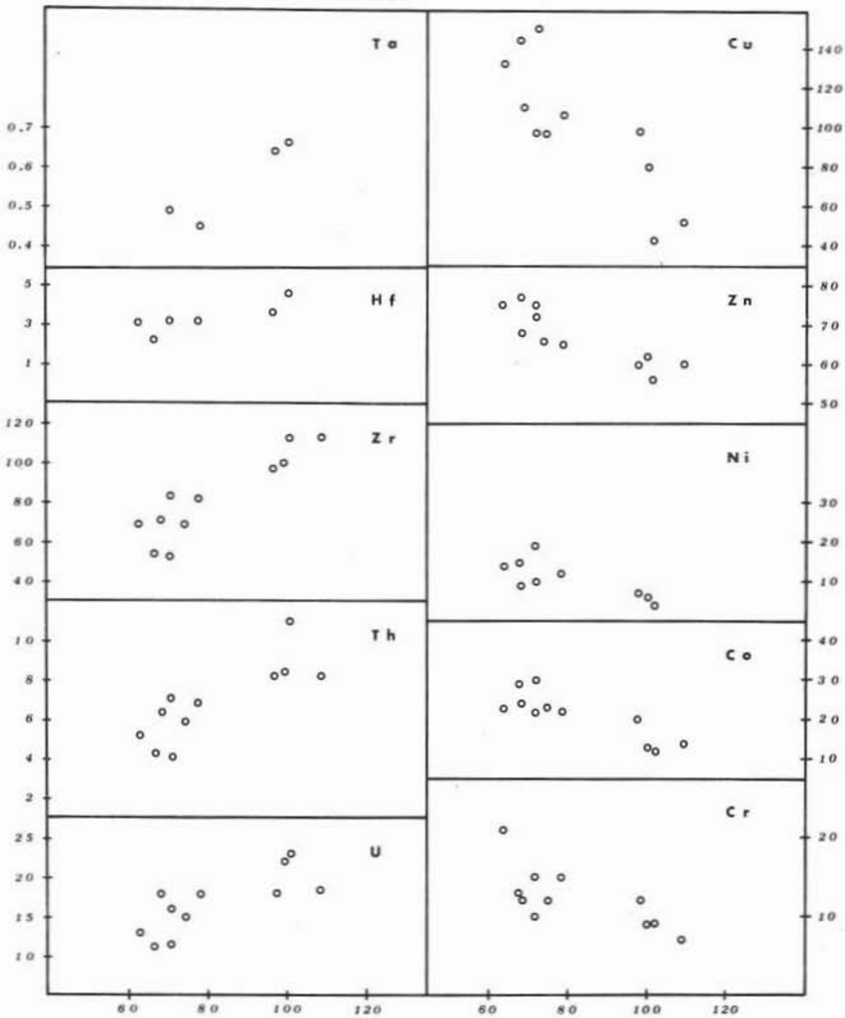



Fig. 17. — Variation diagram of trace elements vs. La + Ce for Filicudi samples. Sample (cumulate xenolith) F 42i omitted.

be correlated with CaO of bulk rock analyses. It is suggested therefore that calcic cores in the more differentiated samples may be either xenocrysts or relicts from a more basic parent.

The persistence and relative abundance of phenocrysts throughout the rock suite is reported in fig. 11.

## 2 - Major elements

Major element analyses of a set of representative samples are reported in Tab. 2. Variation diagrams (fig. 12) show a good linear correlation of $Al_2O_3$, $FeO_{tot}$, MgO, CaO, $Na_2O$ and $K_2O$ when plotted against Differentiation Index, suggesting

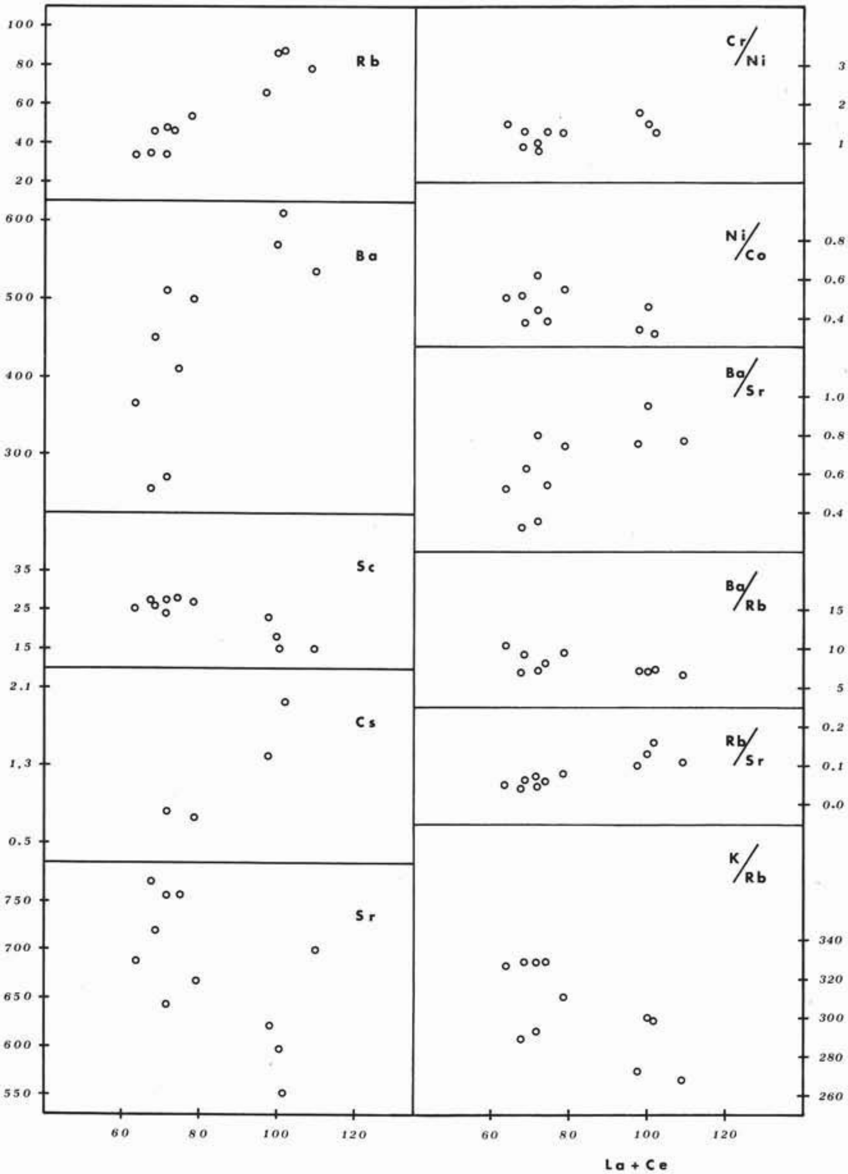



Fig. 18. — Variation diagram of trace elements vs. La + Ce for Filicudi samples. Sample (cumulate xenolith) F 42i omitted.

a comagmatic origin for the rock suite. $Na_2O$ and $K_2O$ both increase with increasing D.I., while $Al_2O_3$, $FeO_{tot.}$, MgO and CaO regularly decrease.

Plots on the AFM diagram (fig. 13) show a trend which is typical for most calc-alkaline suites, lacking any iron enrichment even in the earliest stage of differentiation. The $K_2O$ vs. $SiO_2$ diagram (fig. 14), used for the classification (Peccerillo and Taylor, 1976), shows a distinct high-K character for the Filicudi rock

TABLE 4
*REE analyses of Filicudi volcanics*

| | F 42i | F 37 | F 36 | F 16 | F 19 | F 8 | F 40a | F 30 | F 25 | F 5 | F 22 | F 1 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| La | 19.6 | 21.8 | 21.4 | 20.0 | 22.5 | 23.4 | 22.3 | 23.2 | 26.4 | 29.0 | 32.3 | 30.6 |
| Ce | 3.3 | 49.5 | 46.2 | 43.6 | 46.3 | 51.0 | 49.2 | 55.2 | 71.2 | 70.9 | 77.2 | 70.7 |
| Sm | 4.24 | 4.70 | 4.48 | 3.87 | 4.08 | 4.23 | 3.68 | 4.32 | 4.62 | 4.29 | 4.78 | 4.19 |
| Eu | 1.16 | 1.30 | 1.28 | 1.12 | 1.13 | 1.23 | 1.06 | 1.18 | 1.17 | 1.15 | / | 1.07 |
| Tb | / | / | / | / | .47 | / | / | .48 | .51 | .58 | / | .39 |
| Yb | 1.7 | 1.9 | 1.8 | 2.0 | 1.7 | 1.9 | 1.8 | 1.7 | 1.9 | 2.0 | 2.3 | 1.5 |
| Lu | .29 | .35 | .33 | .34 | .32 | .35 | .34 | / | .38 | .36 | .47 | .37 |

Ce by XRF; the other REE determined by INAA. Data from VILLARI and NATHAN (1978).

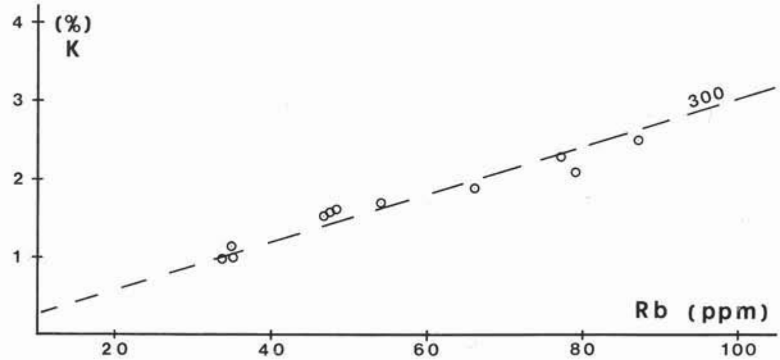



Fig. 19. — K vs. Rb plot for Filicudi samples. Sample (cumulate xenolith) F 42i omitted.

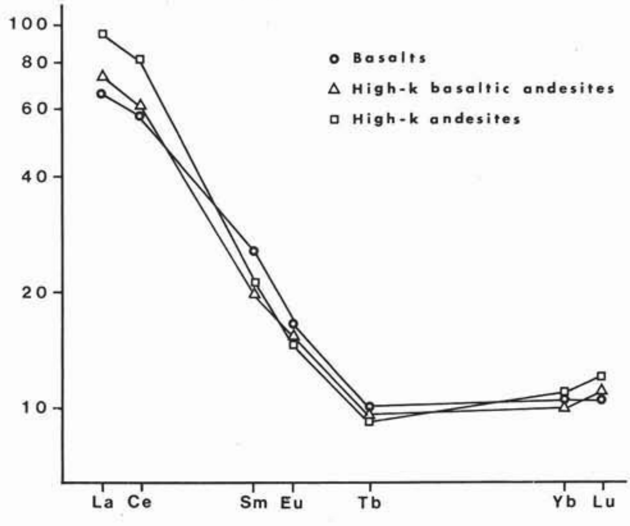



Fig. 20. — REE distribution (normalized to chondritic abundances) for the different members (average) of the Filicudi rock suite.

suite, while Alk vs. $SiO_2$ plots (fig. 15) point out a definite subalkalic affinity of the association.

One of the most peculiar features to be stressed in the Filicudi rocks is the constant $FeO_{tot.}/MgO$ ratio throughout the suite, matching the already mentioned homogeneity of the ferromagnesian silicate phenocrysts. The value of the $FeO_{tot.}/MgO$ ratio is constantly below 2, with very few exceptions (e.g. sample F 22), suggesting a magmatic affinity similar to the island arc type volcanics, as defined by JAKES and WHITE (1972).

The $K_2O/Na_2O$ ratio, ranging between 0.42 and 0.86, coherently points out a closer affinity of Filicudi volcanic rocks with magmatic products commonly occurring in island arc structures (JAKES and WHITE, 1972). $TiO_2$, CaO, $Na_2O$ and $P_2O_5$ abundances also show values which are in good agreement with the average concentrations reported by EWART (1976) for the island arc group and considered to be consistently different relative to their continental margin compositional equivalent.

The samples from Filicudi plot, on the $SiO_2$ vs. $FeO_{tot.}/MgO$ diagram (fig. 16), across the boundary line between CA and TH fields (MIYASHIRO, 1974), which is a common feature observed in most island arc series.

### 3 - TRACE AND RE ELEMENTS

Trace element concentrations are reported in Tab. 3 and they show an overall behaviour which is coherent with major element variations.

Residual trace elements (Ta, Hf, Zr, Th, U, Rb, Ba and Cs) show a steady increase with increasing La + Ce concentrations (figs 17 and 18). An inverse correlation with La + Ce is observed for the ferromagnesian trace elements (Ni, Co, Cr and Sc), Cu, Zn and Sr (figs 17 and 18). Trace element abundances are largely in the range suggested for most calc-alkaline to shoshonitic associations (TAYLOR, 1969; JAKES and WHITE, 1972) and are characterized by low concentration of ferromagnesian elements, which is typical of orogenic association. The K/Rb ratio ranges closely about 300 (fig. 19), coherently with the high-K character (JAKES and WHITE, 1970) of Filicudi volcanics.

The overall feature of trace element distribution is dominated by a relatively high concentration of the potassium-type elements (Rb, Ba and Sr) and other large highly charged cations (U, Th, Zr and Hf). This peculiar character is what one can expect from members of an island arc association which is transitional from calc-alkaline to shoshonitic, namely high-K calc-alkaline (JAKES and WHITE, 1972).

REE distribution (fig. 20) is characterized by a strongly enriched in light REE pattern. Very minor changes in HREE through the rock suite have been observed. while LREE slightly increase with increasing differentiation; Eu anomalies were not observed (VILLARI and NATHAN, 1978). Similar patterns are reported for samples from the other islands of the archipelago (KLERKX et al., 1975).

$Sr^{87/86}$ data are given in BARBERI et al. (1974) and KLERKX et al. (1974) and they range between 0.7030 and 0.7054.

## Conclusion

The island of Filicudi is the summit part of a 2000-m-high composite volcano, partly extending below sea level. The eruptive activity, which took place during Pleistocene, gave rise to the formation of several volcanic structures consisting of strato-cones and endogenous domes. Lava flows and pyroclastics alternate in variable proportions, depending upon the viscosity of the outpoured magma which mostly controls the explosivity of the volcanic activity.

The time succession from older to younger volcanics shows an overall coherence with the magmatic differentiation from basalts to high-K andesites; high-K basaltic andesites are the dominant members of the suite. It has been shown that the observed compositional evolution is mostly to be attributed to crystal fractionation, involving the settling of early formed phenocrysts (VILLARI and NATHAN, 1978). A large participation of plagioclase in the settling has been suggested in order to explain the petrographic and chemical features which characterize the series, i.e. the steady decrease of Sr with increasing differentiation. Olivine, pyroxenes and magnetite participate in the fractionation in a minor proportion.

The lack of any Eu negative anomaly, which is a common feature of many calc-alkaline associations (TAYLOR, 1969), is believed to reflect high $f_{H_2O}$ conditions in a shallow magma chamber, which could inhibit the entry of Eu into the plagioclase (DRAKE and WEILL, 1975). Further evidence supporting the presence of a shallow magma chamber operating during the fractionation history is the iron/magnesium pattern, matching the experimental trend obtained for a basaltic liquid crystallizing under $f_{H_2O} = 10^{-0.7}$ atm. (HAMILTON and ANDERSON, 1967).

The petrography, major and trace elements distribution point out, on the whole, the orogenic affinity of the volcanic products from Filicudi, strongly suggesting a magma genesis and evolution dominated by an island arc structural setting.

The high concentration of $K_2O$, LREE and LILE, which is typical of the Aeolian Islands magmatism, may reflect a relatively fractionated mantle source, such as is to be expected beneath a continental crust (KELLER, 1974), or, alternatively, it may be due to a contribution of the relevant elements from the subducted slab (RINGWOOD, 1974; NICHOLLS, 1974).

Geological, structural and geophysical evidence (CAPUTO et al., 1972; SCHICK, 1972; KELLER, 1974; BARBERI et al., 1973; BARBERI et al., 1974) suggest that the island arc structure is presently undergoing a senile stage of evolution, as inferred from the seismic gap between 35 and 200 km depth, i.e., detached slab model (BARANZANGI et al., 1973; KELLER, 1974; BIJU-DUVAL et al., 1978).

It is concluded therefore as entirely sharing the suggested rapid evolution of the arc dynamics (BARBERI et al., 1973; BARBERI et al., 1974), which led to the present depth of seismic foci (250-300 km) correlating with the shoshonitic composition of the active volcanoes (Vulcano and Stromboli).

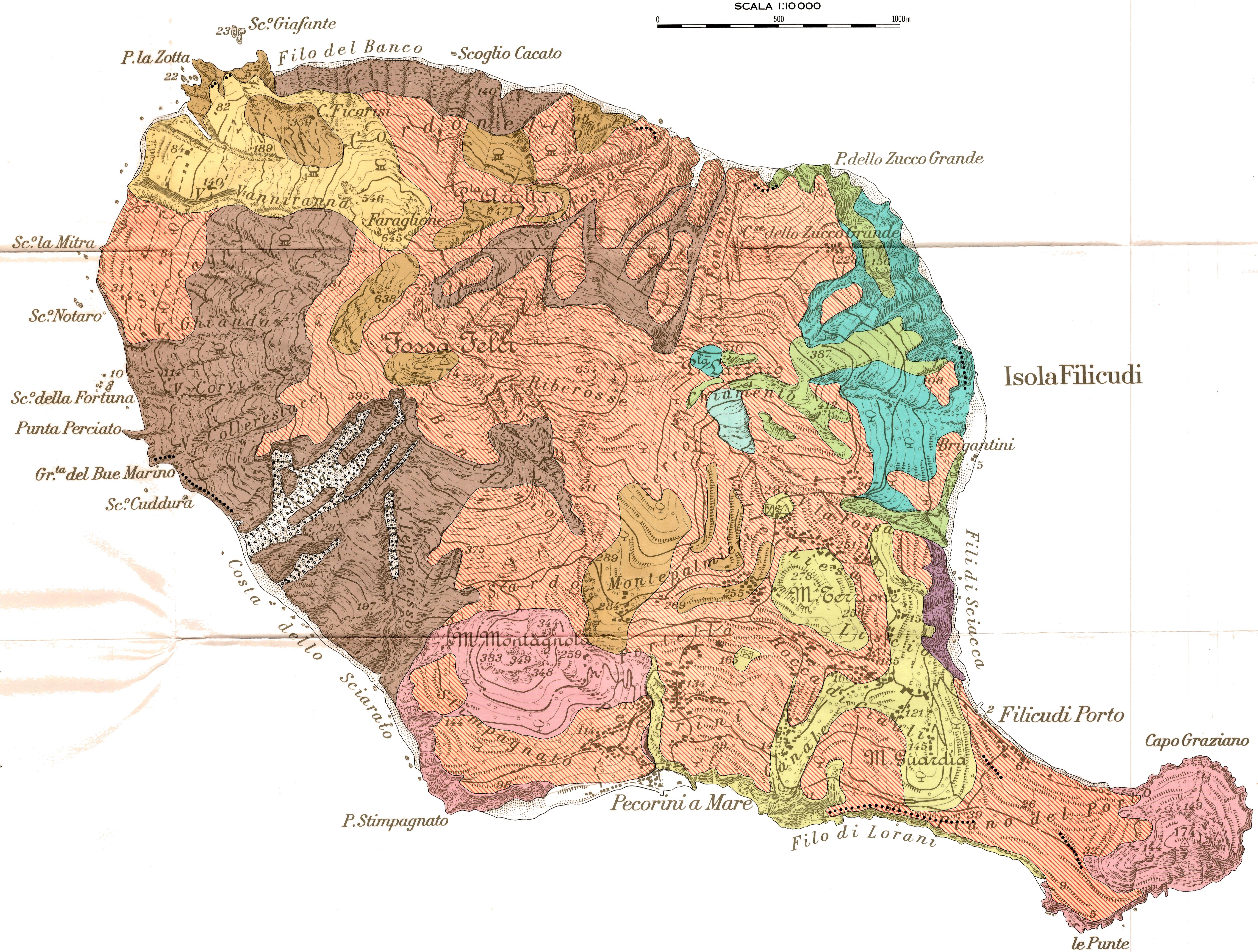
CONSIGLIO NAZIONALE DELLE RICERCHE – ISTITUTO INTERNAZIONALE DI VULCANOLOGIA - CATANIA

# CARTA GEOLOGICA DELL' ISOLA DI FILICUDI

## (ISOLE EOLIE)

Secondo la Carta topografica " ISOLA DI FILICUDI Foglio 244 III NO 1 : 25000 della Carta d' Italia ."

SCALA 1:10 000




| | | |
|---|---|---|
| Piroclastiti delle Riberosse.<br>Pyroclastics of Riberosse. | | |
| Lave dei duomi di Capo Graziano e della Montagnola.<br>Lavas of the endogenous domes of Capo Graziano and Montagnola. | Latiti e latiandesiti quarzifere.<br>Quarz bearing latites and latite-andesites. | |
| Lave di Monte Terrione con subordinate intercalazioni piroclastiche.<br>Lava flows of Monte Terrione with subordinate quantities of interbedded pyroclastic layers. | Latiandesiti quarzifere.<br>Quartz bearing latite-andesites. | |
| Depositi di valanghe incandescenti.<br>Glowing (mixed) avalanche deposits. | Andesiti e latiandesiti quarzifere.<br>Andesites and quartz bearing latite-andesites. | Centro eruttivo della Fossa Felci<br>Fossa Felci volcanic center |
| Colate di lava.<br>Lava flows. | | |
| Lave con importanti intercalazioni di banchi di scorie.<br>Lava flows with interposed beds of scoriae. | | |
| Colate di lava con subordinate intercalazioni di banchi di scorie.<br>Lava flows with subordinate quantities of interposed beds of scoriae. | Andesiti e latiandesiti.<br>Andesites and latite-andesites. | Centro eruttivo dello Zucco Grande<br>Zucco Grande volcanic center |
| Depositi di valanghe incandescenti.<br>Glowing (mixed) avalanche deposits. | | |
| Piroclastiti (banchi di scorie, tufi, ecc...) con intercalazioni laviche.<br>Pyroclastics (beds of scoriae, tuffs, etc...) with interbedded lava flows. | | |
| Lave dei Fili di Sciacca.<br>Lavas of Fili di Sciacca. | Andesiti femiche con olivina.<br>Dark olivine-andesites. | |
| Conglomerati quaternari d' abrasione marina.<br>Quaternary raised beaches. | | |
| Detrito di falda<br>Debris fan | | |

Rilevamento geologico: Letterio Villari, 1969 - 1970

REPARTO RIPRODUZIONE E STAMPA E.I.R.A. FIRENZE

Base topografica ricavata dai tipi dell' Istituto Geografico Militare ( autorizzazione n° 474 in data 20/4/1971 )