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MORPHOLOGIC EVIDENCE FOR ANCIENT VOLCANIC CENTRES AND INDICATIONS OF MAGMA RESERVOIRS UNDERNEATH MT. ETNA, SICILY (*)

ABSTRACT: CRISTOFOLINI R., PATANÈ G. & RECUPERO S., *Morphologic evidence for ancient volcanic centres and indications of magma reservoirs underneath Mt. Etna, Sicily* (IT ISSN 0084-8948, 1982). The overall morphologic features of Mt. Etna, such as the acclivity field distribution (fig. 1) and the slope line pattern, indicate that below the recent strato-volcanoes of the Mongibello and Trifoglietto systems, at least other four edifices partly overlapping each other can be recognized, scattered over an area of some hundreds square kilometres (figs. 2, 3). These centres developed probably at the intersections of several distinct fault systems, and their areal distribution is consistent with a complex magma storage system at depth, that fed their activity, the presence of which is also supported by recent sismological and petrologic data.

RIASSUNTO: CRISTOFOLINI R., PATANÈ G. & RECUPERO S., *Testimonianze morfologiche di antichi centri vulcanici e indicazioni sull'esistenza di serbatoi magmatici sotto l'Etna (Sicilia)* (IT ISSN 0084-8948, 1982). I caratteri morfologici complessivi dell'Etna, come la distribuzione dei campi di acclività (fig. 1) e l'andamento delle linee di massima pendenza, indicano che, al di sotto degli strato-vulcani appartenenti ai complessi del Mongibello e del Trifoglietto, esistono almeno altri quattro edifici parzialmente sovrapposti l'uno all'altro, dispersi su una superficie di alcune centinaia di chilometri quadrati (figg. 2 e 3). Questi centri, sviluppatisi probabilmente all'intersezione di faglie appartenenti a sistemi diversi, mostrano una distribuzione areale che si accorda con la presenza di un complesso sistema di serbatoi, che ne hanno alimentato l'attività, suggerito anche da recenti dati sismologici e petrologici.

TERMINI-CHIAVE: morphology; composite volcano; magma reservoir; Mt. Etna.

INTRODUCTION

Mt. Etna, one of the most active volcanoes in the world and the largest in Europe, is placed on top of an E-W uparched structure, parallel to the northern chain of Sicily (Peloritani - Madonie), just where several regional fault systems intersect: here local systems, partly linked to the volcanic activity itself are superimposed to the regional framework of tectonic structures (CRISTOFOLINI & *alii*, 1977; 1978; 1979; 1980a; OGNIBEN, 1966; RITTMANN, 1963; 1973).

On the whole the Etnean region has been and still is actively uprising in recent times (CRISTOFOLINI, 1967; CHESTER & DUNCAN, 1979; DI GERONIMO & *alii*, 1979; GHISETTI & VEZZANI, 1979; KIEFFER, 1972; WEZEL, 1967), as shown by various orders of river and marine terraces, and by lower Pleistocene marly clays at elevations up to 400 m a.s.l. and 700 m a.s.l. along the SE and NE flanks of the volcano respectively. Several hundreds of parasitic vents can be observed all around the volcano at altitudes as low as 200 m a.s.l. (at Paternò) (RITTMANN, 1963; FRAZZETTA & ROMANO, 1978; LO GIUDICE, 1978); their generally well preserved morphology shows that many of them erupted in very recent and even historic times.

Above a thin sequence of sheets of subalkaline to transitional basalts representing the first stages of volcanic activity, Mt. Etna shows an important succession of volcanics belonging to an alkalic suite: though richer in alumina and not as alkalic and titaniferous as the oceanic hawaiites and mugearites, and with a Peacock's index of about 53, these rocks are generally undersaturated in silica, with normative nephelite (CRISTOFOLINI, 1973; PUGLISI & TRANCHINA, 1977). The alkalic succession is mainly composed of moderately to strongly differentiated varieties, often strongly porphyritic.

The composite (or multiple) nature of Mt. Etna has been recognized even by the first geologists working there (GEMMELLARO, 1860; LYELL, 1859; WALTERSHAUSEN, 1880), who found geological evidence for two different edifices in the Etnean area, named Trifoglietto and Mongibello respectively. In the last decades geological and petrological investigations in the large depression of the Valle del Bove and in the neighbouring areas indicated that several volcanic centres had been active there, that have been grouped here into the Trifoglietto system (Calanna, Trifoglietto 1, Trifoglietto 2, Belvedere, Vavalaci centres) and Mongibello system (Ellittico, Leone, Recent Mongibello centres) (KLERKX, 1968; LO GIUDICE, 1970; LO GIUDICE & *alii*, 1974; ROMANO & GUEST, 1979; ROMANO & STURIALE, 1975; *Geol. Map Mt. Etna*, 1979).

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MORPHOLOGIC ANALYSIS OF THE ETNEAN REGION

The morphologic features of the Etnean area give further convincing evidence that other centres have been active there, even if their products are largely concealed by a cover of younger flows and tephra. KIEFFER (1974; 1975) suggested that one single shield volcano developped at first, inside whose caldera (about 15 km across) grew the above mentioned strato-volcanoes of the Trifoglietto and Mongibello systems. Later a preliminary examination of the distribution of the acclivity fields and of various morpho-tectonic elements in the eastern part of the Etnean area showed features consistent with smaller volcanic edifices with their summits near Piano Provenzana and Tardaria respectively (CRISTOFOLINI & *alii*, 1978) and a still more complicated pattern of volcanic structures is shown here by means of a detailed analysis of the morphology over the whole Etnean region.

The morphologic study has been conducted by defining the acclivity fields, according to the method already used for the Piedimonte Etneo quadrangle (CRISTOFOLINI & *alii*, 1977): slope angles, expressed as tg α, have been measured on the 1:25 000 scale quadrangles of the official topographic map of Italy covering the Etnean area, by centering first a 500 m long segment (2 cm on the map), along the line of highest slope, at each of the knots of a square network with cells 250 m by side (1 cm on the map), and attributing then to every knot the ratio between the elevation difference at the ends of the segment and its length as slope value (tg α). Classes of acclivity have been defined examining the frequency distribution of the slope values: modes of this distribution have been found for tg α less than 0.05, between 0.05 and 0.10, 0.10 and 0.20, 0.20 and 0.35, 0.35 and 0.50 and over 0.50: the classes have been chosen accordingly with their boundaries at tg α 0.05, 0.10, 0.20, 0.35 and 0.50.

The results of this analysis, showing the areal distribution of the classes of acclivity, are summarized in fig. 1, reduced from the original 1:25 000 scale map.

Here a low slope-angle area can be observed, particularly wide at low elevations (less than 8-900 m a.s.l.), along the southern flank of Mt. Etna. At higher altitudes, field observations and examination of the distribution of the slop-angle fields show some features that cannot be accounted for by accumulation of volcanic products emitted from one single central axis volcano: some minor flat areas (tg $\alpha \leq 0.1$) have been recognized, with a distribution of higher slope-angle fields and a pattern of the contour lines around them that show slope directions radiating downslope from their centres (figs. 1 and 3). These observations have been summarized in fig. 2, where the overall set of morphologic data has been interpreted as due to various truncated cone or broad shield-like volcanic structures, whose summits should correspond with the above mentioned flat areas, between 1 000 and 2 000 m a.s.l., at Piano Provenzana (PP), Tardaria (TD), near Monte Fontana - Monte Denza (FD), and around Sciara del Follone (SF). These volcanic structures, interpreted as volcanic edifices, rise with gently sloping flanks ($0.1 < \text{tg}\,\alpha < 0.2$) above a base of volcanics from the earlier stages of the Etnean activity, and partly overlap each other. They are in turn widely overlaid by products from the more recent and steeper centres of the Trifoglietto and Mongibello systems.

Along the eastern flank of Mt. Etna other similar volcanic structures probably developped too, but cannot be clearly recognized, because of the deep dissection by strong tectonic activity and subsequent erosion: near St. Alfio an arcuated morphologic element, giving origin to a locally anomalous drainage pattern (CRISTOFOLINI & *alii*, 1977) can be interpreted as a buried rim of a caldera (? in fig. 2), filled with soft volcaniclastic rocks as shown by the strong absorption of the seismic energy (PATANÈ, under preparation).

Though widely covered by flows and tephra from the youngest centres and their parasitic vents, products of some of these volcanic edifices can be found, especially in the eastern sector of Mt. Etna, along fault scarps and steep slopes (e.g. Ripa della Naca) among the lavas and tephra of the ancient volcanic centres, and maybe among some of the volcanics recently mapped as belonging to the Trifoglietto system (*lta* and *vt* respectively in *Geol. Map Mt. Etna*, 1979) outcropping between Puntalazzo and Moscarello, as already suggested by CRISTOFOLINI & *alii* (1977) for the area in the Piedimonte Etneo quadrangle. Further research is needed to define the areal distribution and petrochemical features of these units, but, on the grounds of the general morphology of Mt. Etna a preliminary scheme of the position and relationship of the various centres is given in fig. 2 and 3, with some of the most prominent morphotectonic and structural elements that have been recognized. The analysis of the acclivity map, integrated with field observations, shows a possible age sequence for the centres rising above the basal unclassified volcanic levels and underlying the Trifoglietto and Mongibello systems, that is tentatively given here in order of increasing age:

a) Serra del Follone centre (SF);

b) Monte Fontana - Monte Denza centre (FD);

c) Tardaria centre (TD);

d) Piano Provenzana centre (PP).

CONCLUSIONS

The overall resulting pattern is given by irregularly superimposed simple volcanoes, with their axes scattered over an area approximately 200 km^2 wide, with no evidence for a systematic migration of the eruptive axes along any preferred trend. This volcanic structure is quite more complex than that shown even in the recent scheme of the *Geol. Map Mt. Etna* (1979), where the bulk of the Etnean volcanics has been attributed to the activity of centres inside the Valle del Bove or next to its western edge (Mongibello).

The suggested scheme conforms with the regional tectonic framework, with several tensional fault systems intersecting in the Etnean region, following chiefly the

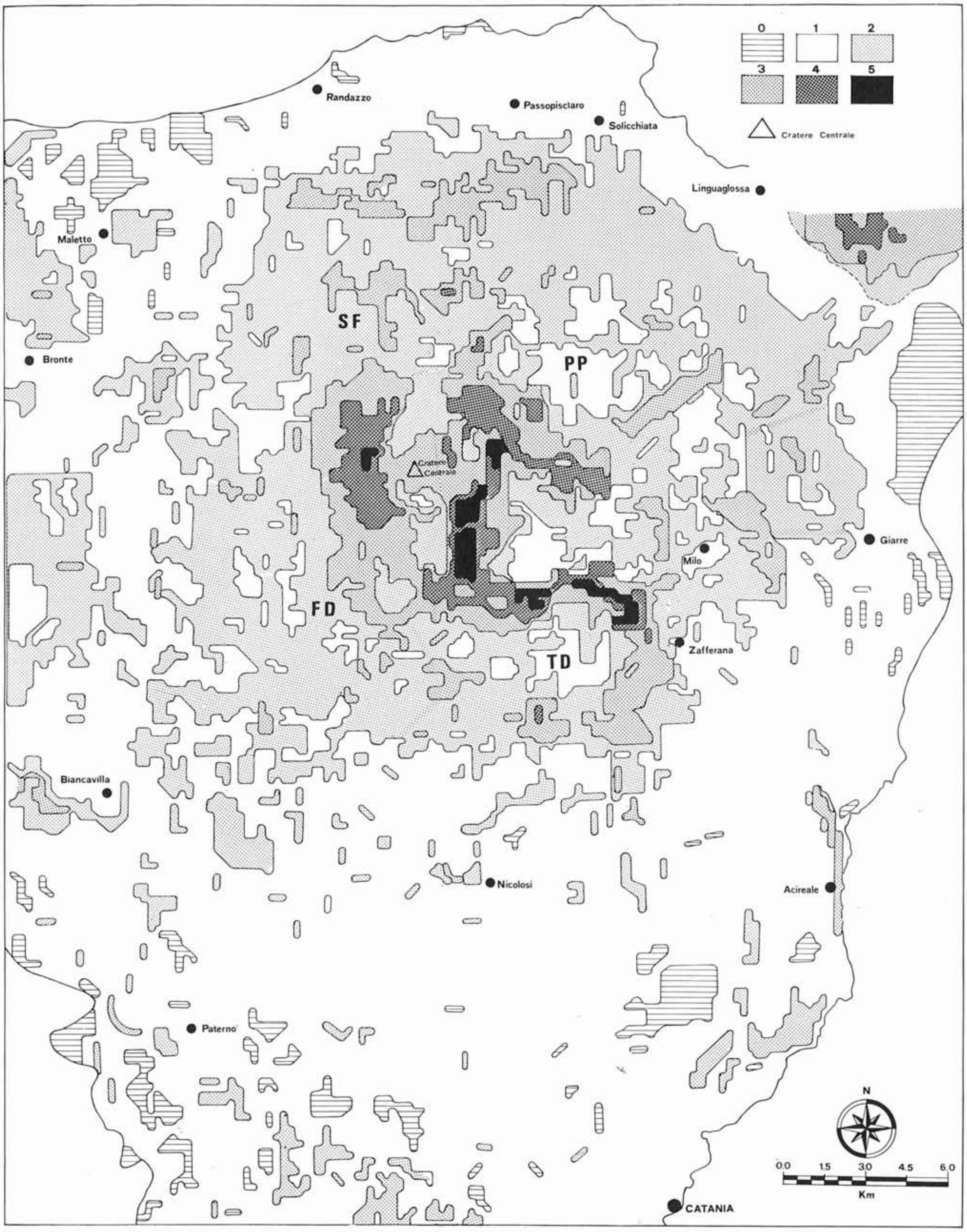

FIG. 1 - Acclivity map of the Etnean region. The area with highest slope-angle are found motsly along the walls of the complex caldera depression of the Valle del Bove and along the escarpments related with very active fault systems.

Acclivity classes: 0) $tg\alpha \leq 0,05$; 1) $0.05 < tg\alpha \leq 0.10$; 2) $0,10 < tg\alpha \leq 0.20$; 3) $0.20 < tg\alpha \leq 0.35$; 4) $0,35 < tg\alpha \leq 0.50$; 5) $0.50 < tg\alpha$.

Symbols: SF: Sciara del Follone; FD: Monte Fontana - Monte Denza; TD: Tardaria; PP: Piano Provenzana.

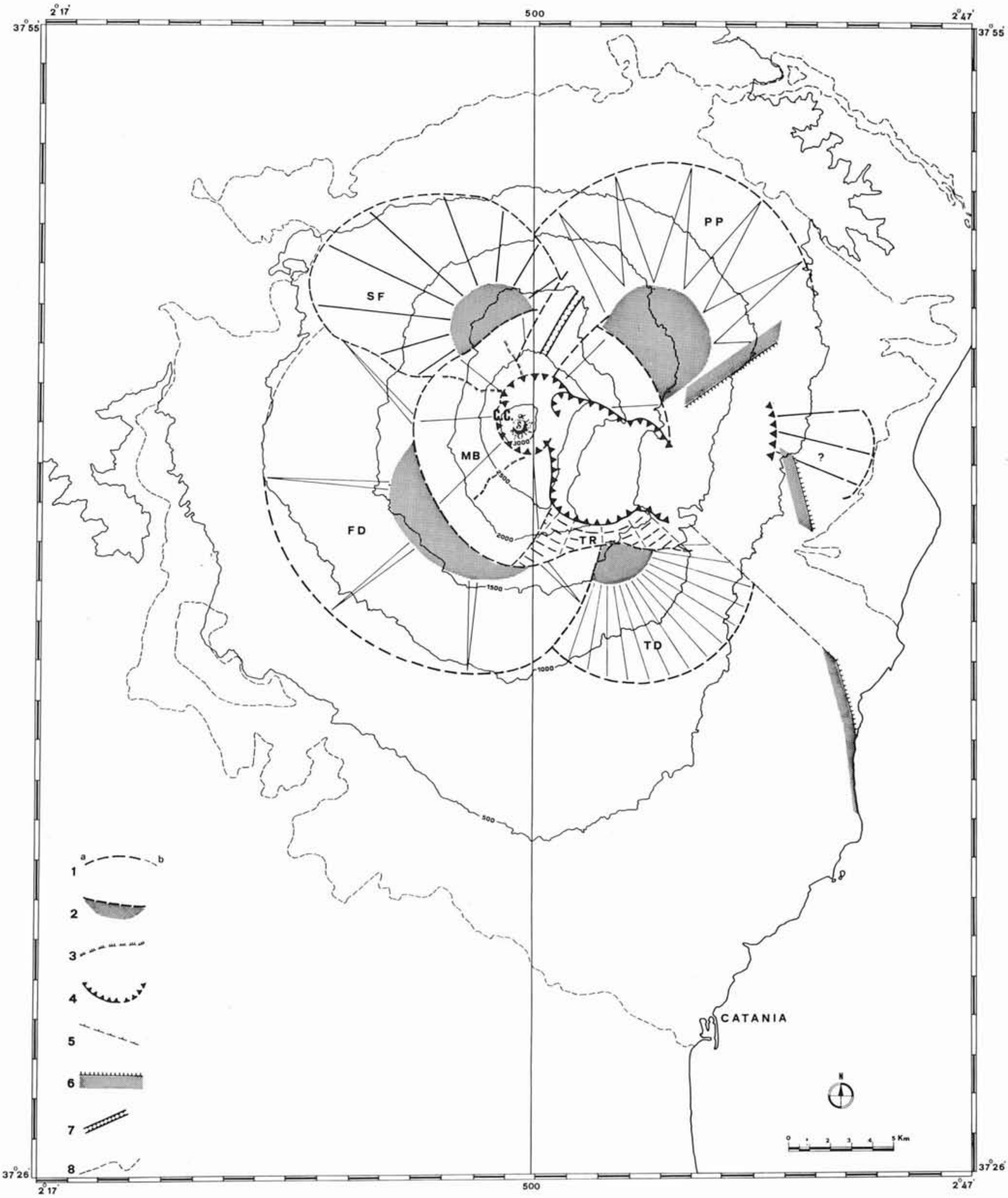

FIG. 2 - Sketch map of the distribution of the volcanic centres recognized on the basis of the morphologic features of Mt. Etna. MB: Mongibello system; TR: Trifoglietto system; SF: Sciara del Follone centre; FD: Monte Fontana - Monte Denza centre; TD: Tardaria centre; PP: Piano Provenzana centre.

1) Approximate boundaries and 2) flat areas interpreted as summits of the various edifices; 3) radially developed irregular scarps in the summit region of Etna; 4) caldera rims (dashed where uncertain); 5) morphologically little distinct boundary of the collapsed eastern sector of the volcano; 6) escarpments alined following active fault systems (ticked toward downthrow side); 7) north-eastern "rift zone" (KIEFFER, 1972; ROMANO & GUEST, 1979); 8) edge of the volcanic cover.

Coordinates at the corners, according to the Italian grid (International spheroid oriented to Monte Mario). Longitude of Mt. Mario referred to Greenwich: 12° 27' 08" E.

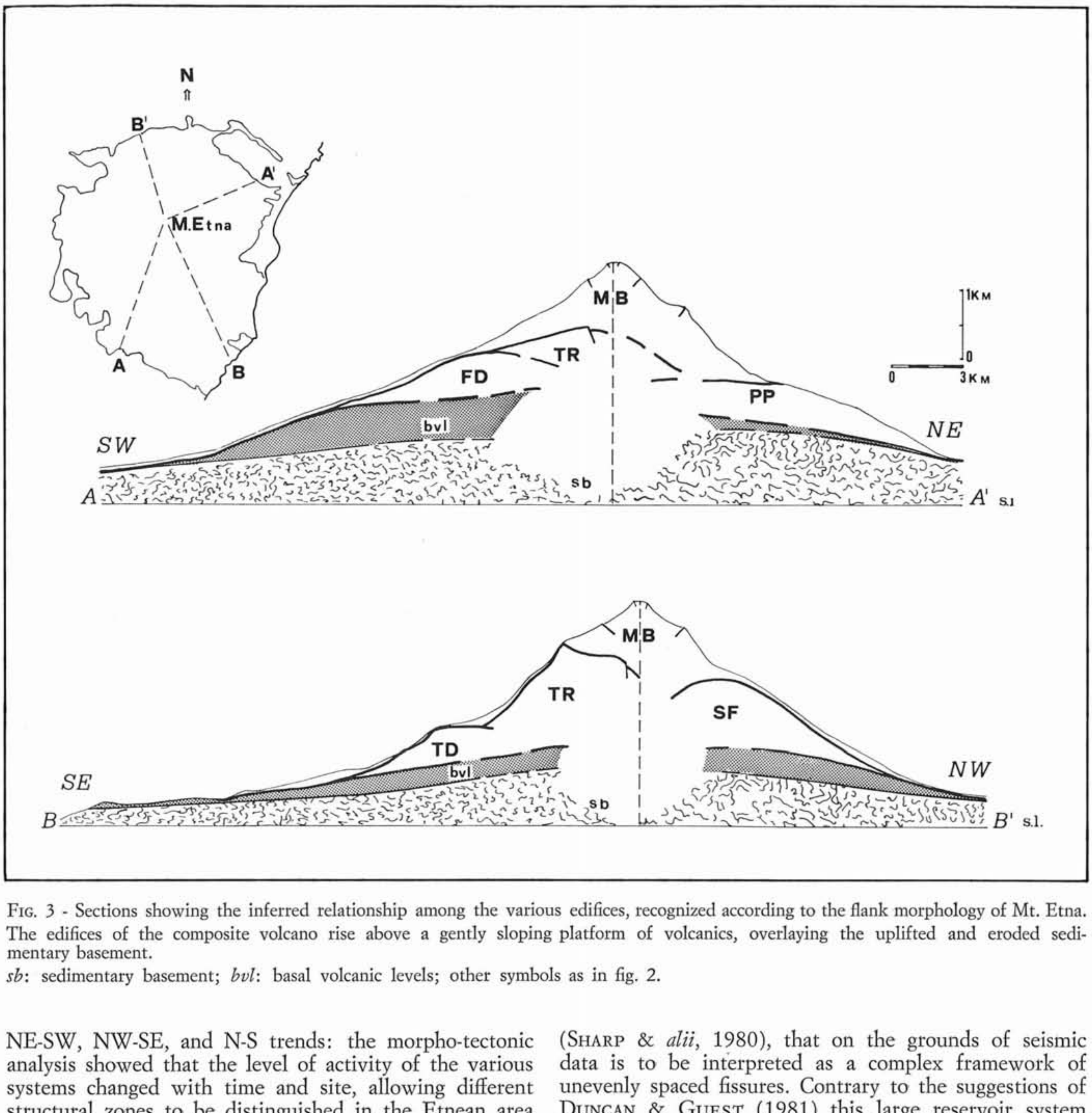

FIG. 3 - Sections showing the inferred relationship among the various edifices, recognized according to the flank morphology of Mt. Etna. The edifices of the composite volcano rise above a gently sloping platform of volcanics, overlaying the uplifted and eroded sedimentary basement.
sb: sedimentary basement; *bvl*: basal volcanic levels; other symbols as in fig. 2.

NE-SW, NW-SE, and N-S trends: the morpho-tectonic analysis showed that the level of activity of the various systems changed with time and site, allowing different structural zones to be distinguished in the Etnean area (CRISTOFOLINI & *alii*, 1978; 1979; 1980a; LO GIUDICE, 1978; GHISETTI & VEZZANI, 1979). Another important structural alignment, trending E-W, is given by fold axes, parallel to the northern Chain, and associated faults (BARBANO & *alii*, 1978), which generates an important negative structure at the western side of the volcano between Adrano and Bronte. Given the presence of the above mentioned well developed framework of tensional fractures and faults, it can be suggested that the different centres, probably originated at their intersections, have been fed from the complicated magma storage system, intermediate between the source region and the surface, shown by the geophysical evidence at a depth of 15-20 km (SHARP & *alii*, 1980), that on the grounds of seismic data is to be interpreted as a complex framework of unevenly spaced fissures. Contrary to the suggestions of DUNCAN & GUEST (1981) this large reservoir system should be an originary feature of the Etnean volcanic structure, as indicated also by petrologic data on ancient lavas (CRISTOFOLINI & *alii*, 1981; CRISTOFOLINI & TRANCHINA, 1980), showing evidence for crystallization stages at pressures up to about 5 kb (as inferred from augite compositions).

Comparing figs. 2 and 4, the surface, over which the suggested volcanic centres are scattered, matches fairly well the projection of the storage system over the horizontal plane (SHARP & *alii*, 1980). The same also occurs with the distribution of the recent parasitic vents, many of which can be defined excentric (i.e. fed through fissures independent from the present-day axial system;

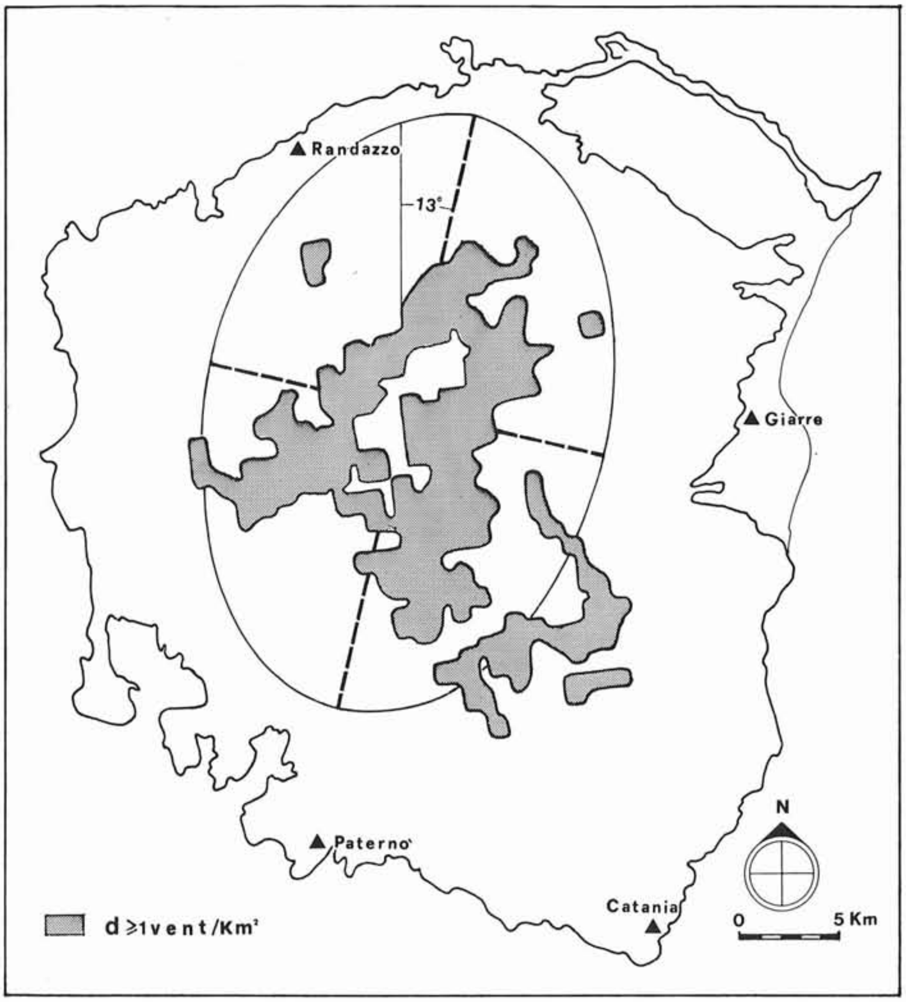

FIG. 4 - Density distribution of the parasitic vents at Mt. Etna (shaded area: d ≥ 1 vent/km²) and projection onto the horizontal surface of the magma reservoir according to SHARP & *alii* (1980).

RITTMANN, 1963; 1973). The distribution of the ancient volcanic centres and of the recent parasitic vents in the Etnean area looks then to be controlled by the geophysically shown deep-seated reservoir, intersected by the pattern of regional tensional fractures, through which the volcanic activity has been being fed since its start.

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