A Gravity Study of the Island of Vulcano, Tyrrhenian Sea, Italy

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ABSTRACT

A detailed gravity survey was carried out on the island of Vulcano, Aeolian Islands, Italy. Gravity was measured on 107 stations and the Bouguer anomalies were computed by assuming geological densities.

Aim of this survey was to complete the island structural pattern relatively to the shallower structures.

Separation of the gravity anomaly field was carried out by means of data filtering, and two main components were discerned. The $\lambda > 2.2$ km wavelength component, filtered out of the longer wavelength components, was interpreted quantitatively along a NW profile. The best fitting model consists of an upper layer of recent pyroclastic products ($\rho = 2.1$ g/cm^3) lying upon a highly compacted pyroclastic series or lavas ($\rho = 2.4$ g/cm^3).

The shorter wavelength residual gravity field ($\lambda < 2.2$ km) is characterized by two anomalies, located on Vulcanello and the «Fossa di Vulcano» crater. Vulcanello anomaly could be interpreted, given the geothermal state of the area, as due to an increase of the rock density consequent to propylization processes by high temperature fluids ($T > 200°C$). «Fossa di Vulcano» anomaly is instead attributable to the local volcanic chimney.

A schematic comprehensive model of Vulcano is also presented, which accounts for the available main geological and geophysical data.

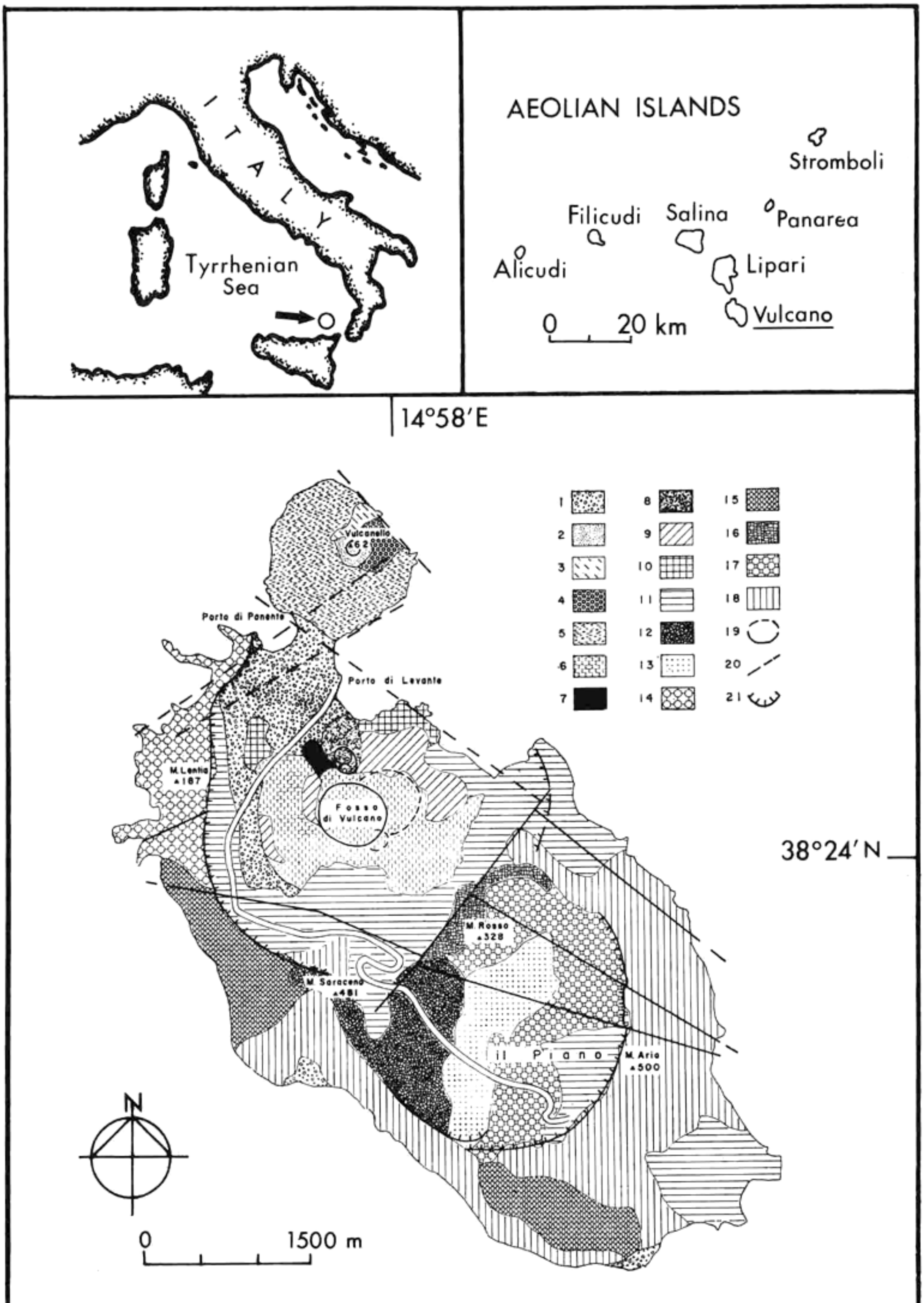
INTRODUCTION

The island of Vulcano is a quaternary active volcanic island, located in the southern Tyrrhenian sea (Fig. 1). It covers an area of 22 Km^2 and rises from a depth of about 1000 m up to a maximum elevation of 500 m a.s.l. It is the southernmost island of the so-called Aeolian Islands volcanic group. These islands rise at the margin of the abyssal plain and form (BARBERI *et al.*, 1973) an island arc related to the northward subduction of a part of the African plate under the European one.

The general volcanological, structural and geodynamic setting of the islands is, at present, quite well understood; a knowledge of the structures characterizing the shallower parts of the volcano, is, on the contrary, far from being reached. A detailed gravity survey of Vulcano island was thus planned by the CNR Energetic Special Programme and this paper is primarly concerned with the presentation and discussion of it.

GEOLOGICAL AND GEOPHYSICAL SETTING

The schematic geological map of the Vulcano island after KELLER (1980) is shown in Fig. 1: volcanic activity began during upper Pleistocene in the southern part of the island with the formation of a primordial strato-volcano, characterized by trachybasalts and trachyandesites. This volcano collapsed and the consequently formed caldera («Il Piano»), was later


ITALY
Tyrrhenian Sea
AEOLIAN ISLANDS
Stromboli
Filicudi
Salina
Panarea
Alicudi
Lipari
Vulcano
0 20 km
14°58′E
38°24′N
Vulcanello ▲62
Porto di Ponente
Porto di Levante
M. Lentia ▲187
Fossa di Vulcano
M. Rosso ▲328
M. Saraceno ▲481
il Piano
M. Aria ▲500
N
0 1500 m
1
2
3
4
5
6
7
8
9
10
11
12
13
14
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21

filled by pyroclastic products and lava flows of intracalderic activity, in which shoshonitic basalts and leucite-bearing tephrites alternate. Later, the volcanic activity continued with the formation of the Lentia mountains group (rhyolites and alkali rhyolites) and, during early Holocene, with the collapse of the caldera in which the active cone of «Fossa di Vulcano» is located (trachytes). The last eruption of this cone occurred in 1888-90. During historical time (183 B.C. - 1550 A.D.) Vulcanello peninsula was also formed (leucitic tephrites and potassio trachytes).

An intense fumarolic activity occurs on the north-eastern rim of «Fossa di Vulcano» cone and along the coast north of it.

Geophysical studies and mainly the physiography of the sea floor in this area as well as in the whole Tyrrhenian bathyal plain marginal belt, clearly show that this margin is characterized by a number of normal faults which dissect the continental plateau giving rise a number of deep basins and representing the transition zone between the continental area and the oceanized bathyalplain.

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FIG. 1 — Geological sketch map of the island of Vulcano (after KELLER, 1980). 1) Alluvional and beach deposits. Vulcanello products; 2) Ash-tuffs; 3) Trachytic lava flow; 4) Scoriae and breccias; 5) Leucite-tephrite lava flows. Fossa di Vulcano products: 6) Pyroclastic deposits of the recent eruptions; 7) Rhyolitic obsidian lava flows; 8) Ash-tuffs; 9) Well-bedded ash-tuffs; 10) Trachytic lava flows; 11) Pyroclastic deposits of the earlier Fossa eruptions. Fossa di Vulcano caldera: 12) Scoriae deposits and hyaloclastic lapilli tuffs; 13) Brown tuffs deposits. Lentia mountains: 14) Rhyolitic lava domes and flows. Il Piano caldera: 15) Scoriae deposits and pyroclastic flow deposits of trachyandesitic composition; 16) Leucite-tephritic lava flows; 17) Scoriae and pyroclastic deposits. «Primordial» Vulcano: 18) Trachyandesitic and trachybasaltic lava flows with subordinate pyroclastic deposits; 19) Crater rims; 20) Faults; 21) Caldera rims.

The general crustal structure of the Tyrrhenian sea and of the surrounding areas was studied by means of deep seismic surveys (FINETTI *et al.*, 1970; COLOMBI *et al.*, 1971) and regional magnetic and gravity studies (MORELLI, 1970). The Moho discontinuity is found to lie at a depth of about 25 km, rapidly rising toward the bathyal plain, and the crystalline layer has its top at the depth of about 6 km (PINNA and RAPOLLA, 1979).

Finally, the interpretation of a gravity and of an aeromagnetic survey, which were carried out respectively by BONASIA *et al.* (1973) and by the Institute of the Lithosphere of the Italian National Research Council (CNR) (1970), show that the volcanic structure is underlain by a non-magnetic (sedimentary?, metamorphic?) basement at depths varying from 2 km to 6 km (IACOBUCCI *et al.*, 1977). LATTER (1971) and BLOT (1971) studied the seismicity of the islands and the former suggested a qualitative idealized model of the shallow and deep structures of Lipari and Vulcano islands.

THE GRAVITY SURVEY

Gravity was measured on 107 stations irregularly distributed on the island (Fig. 2), because of the extremely variable morphology. One third of the stations belong to the Vulcano vertical ground deformation surveillance network (CORRADO *et al.*, 1979); the heights of the other stations were determined by means of geodetic leveling. A Worden Master gravity meter was utilized. Circuit closure was made within less than an hour. An overall error less than 0.1 mgal can be attributed to the field data. Gravity values were referred to the Lipari island harbour gravity station ($\varphi = 38°28'33''$; $\lambda = 14°57'34''$; g = 980,152.75 mgal) (CIANI *et al.*, 1960). Variable ρ density values were assumed for the terrain corrections in the different areas according to the known geology (Fig. 2); *i.e.*: 1.9 g/cm^3 for the «Fossa di Vulcano» area; 2.1 g/cm^3 for

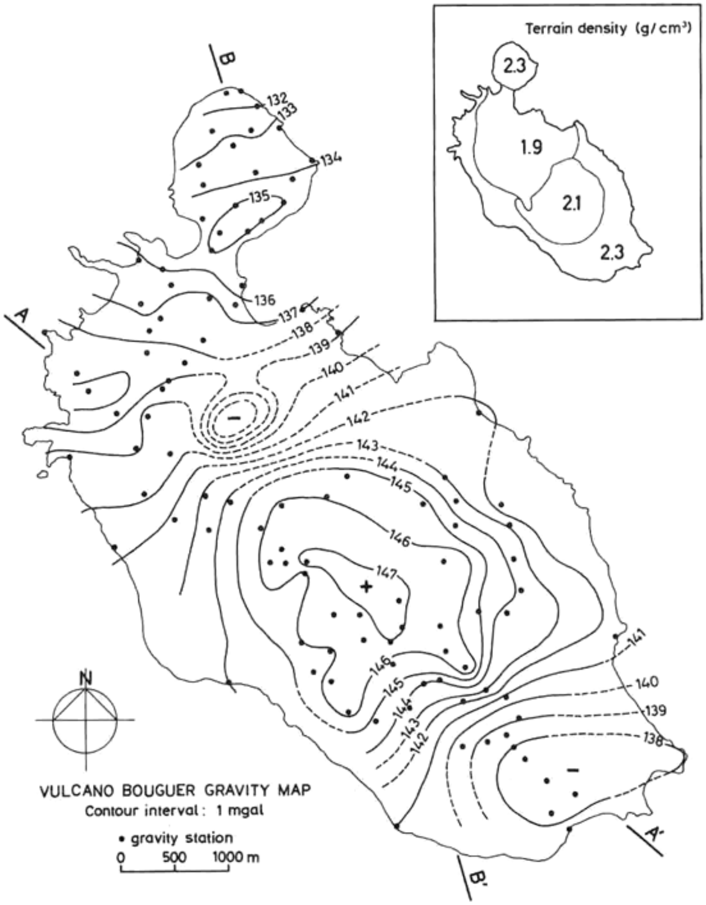

FIG. 2 — Bouguer gravity map of Vulcano. Geological density values are given in the inset.

the products of the so-called «Il Piano» caldera; 2.3 g/cm^3 for Vulcanello, Lentia and «Il Piano» caldera rim products. Observed values were then compared with the theoretical gravity values computed by the 1967 IUGG International formula, to which Free air, Bouguer and topographic (up to the M zone of the Hammer scheme) corrections were applied.

In the central part of the «Fossa di Vulcano» area some gravity values were taken from the wider but less detailed survey by BONASIA *et al.* (1973), relative to the whole Aeolian Islands area.

The obtained Vulcano Bounguer map is shown in Fig. 2.

The field in those areas where gravity station density is low and in the «Fossa di Vulcano» area where the few gravity values were taken from the survey by Bonasia et al. (1973) is represented by dotted lines.

The Bouguer map is characterized by a high in correspondence with the «Il Piano» caldera and by a slow decrease toward Vulcanello. A low is present on the «Fossa di Vulcano» crater and another one on the southernmost part of the island.

DATA ANALYSIS AND INTERPRETATION

Separation of the gravity anomaly field to single out the anomalies of interest is certainly the most difficult phase in the data analysis procedure and one where a strong ambiguity arises. The method we used is data filtering (BATH, 1974; KULHANEK, 1976) which has proved to be relatively simple to use and generally of a much higher effectiveness in complicated areas than most other methods.

As already said, we are interested in the shallower parts of the island structure and consequently in the evaluation of the shorter wavelength gravity components. On the contrary, in the past, other authors isolated and interpreted the longer wavelength components. In particular, the $\lambda > 100$ km components, deduced by a regional survey (MORELLI, 1970) were interpreted as deep crustal structures (PINNA and RAPOLLA, 1981) and those with wavelengths of about 10 km, which were deduced by means of a general survey of Aeolian Islands, were considered as pertaining to the relatively deep basement structures (IACOBUCCI *et al.*, 1977).

Therefore, in order to complete the structural model of the island, we had to analyse and interpret the components up to about ten kilometres. Spectral analysis carried out along selected profiles of our gravity survey (see Fig. 3) shows that a main gravity field component can be distinguished from a number of components having wavelengths ranging from a few hundred metres up to a few kilometres. However, the examination of the spectra relative to these profiles shows that these spectra do not correlate perfectly with each other and this prevented us to choose an unique cut-off to be used in the filtering procedure. Therefore we made a number of bidimensional filtering attempts by using different cut-off wavelengths within the range suggested by the spectral analysis. Figures 4a,b,c,d report the results obtained by filtering the Bouguer map which was digitized following a 0.1×0.1 km^2 square grid. It seems clear that the shorter wavelength gravity anomaly components completely disappear only when wavelengths less than 2.2 km are filtered out.

The $\lambda > 2.2$ km Component

The $\lambda > 2.2$ km filtered field is characterized by gravity anomaly about 6 mgal-high centred in the «Il Piano» area, slowly decreasing toward Vulcanello and showing a narrow low southward. Since this part of the field is still influenced by the much longer wavelength components, in order to interpret the part of this field of interest to us, we had first to filter out such longer wavelengths components. However, because of the limited extent of

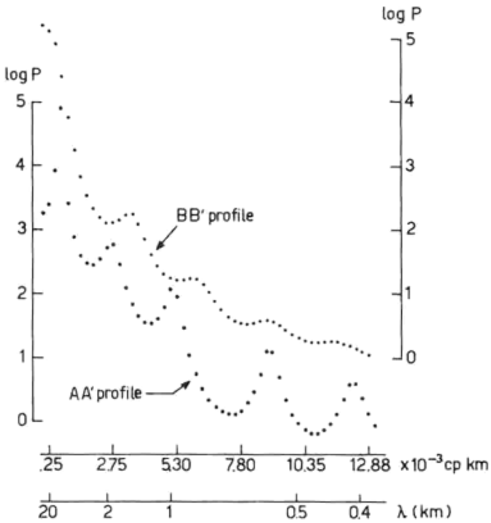

FIG. 3 — Maximum entropy power spectra of the Bounguer anomaly along the AA' and BB' profiles (see Fig. 2 for location).

our survey, the very left-hand part of the power spectra shown in Fig. 3 is not of help for choosing the cut-off value for filtering out the longer wavelengths. Actually, it was necessary to utilize the wider survey after BONASIA *et al.* (1973) and the spectral analysis of the data relative to this last survey let us select a cut-off at 8 km.

It can be noted, by the way, that the $\lambda > 8$km component practically corresponds to the gravity field interpreted by IACOBUCCI *et al.* (1977).

The obtained 2.2 km $< \lambda <$ 8 km gravity field, together with Bouguer anomaly, the $\lambda >$ 2.2 km and the $\lambda >$ 8 km components are shown in Fig. 5 along the AB profile (see Fig. 4d for location). This latter has quantitatively been interpreted in terms of best fitting bidimensional arbitrary shaped models (IACOBUCCI and RAPOLLA, 1972). It should be added that the computed effect to be compared with the observed one was referred to the actual morphology and not to a datum plane (the sea level), so that no erroneous

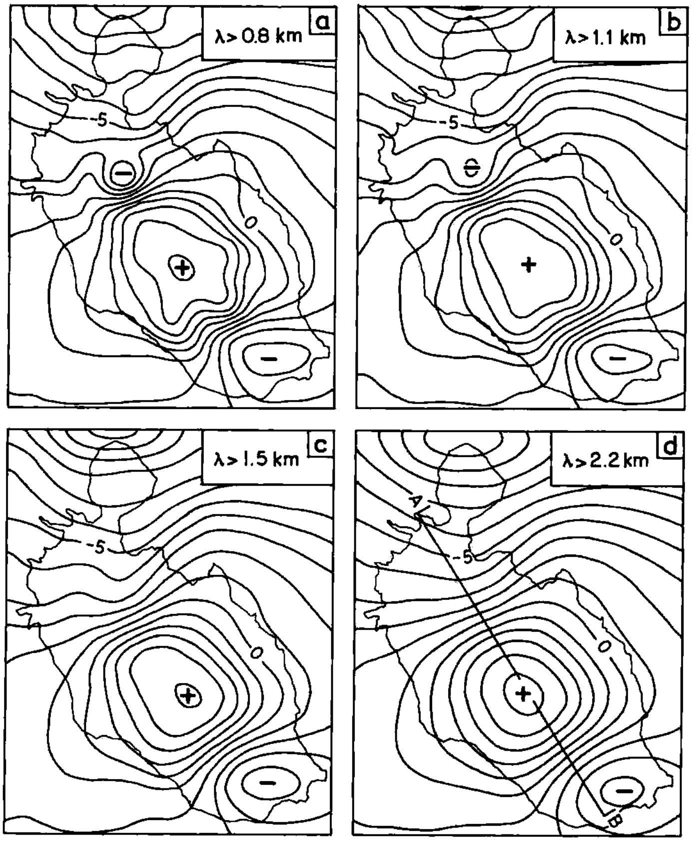

FIG. 4 — Filtered gravity anomalies (contour interval: 1 mgal): a) $\lambda >$ 0.8 km; b) $\lambda >$ 1.1 km; c) $\lambda >$ 1.5 km; d) $\lambda >$ 2.2 km.

influence results from the fact that the earth normal vertical gravity gradient (Free air) was utilized instead of, obviously, the unknown actual one (Faye correction) (RAPOLLA, 1981).

Only simple two-layers models were utilized, as more complicated models are lacking in significance, given the absence of other pertinent geophysical or drilling data to be used as constraints in the quantitative interpretation. The result of the interpretation is shown in Fig. 5. The best fitting model is composed of a lower (denser) layer ($\rho = 2.4$ g/cm^3) having its top in the central area. Its morphology reaches the depth of 1.8 km southward and of 0.9 km under «Fossa di Vulcano», to rise gently to 0.6 km under Vulcanello. For the upper layer an unique density was assumed (2.1 gr/cm^3). During computation the different geological densities above sea level as assumed for the different areas in the Bouguer correction, were obviously taken into account.

The $\lambda < 2.2$ km Component

Next, the shorter wavelength residual gravity field ($\lambda < 2.2$ km) has been examined. It is characterized by a number of anomalies. The very short wavelength anomalies cannot obviously be considered for interpretation due to the fact that they are strongly dependent on the contour drawing procedure. The most interesting anomalies are those located in the more recent parts of Vulcano, *i.e.* Vulcanello and «Fossa di Vulcano» crater (Fig. 6). The quantitative interpretation of the Vulcanello anomaly shows that it is compatible with the presence of a zone with a $+0.2$ g/cm^3 density contrast, having the top at the depth of 250 m and deepen-

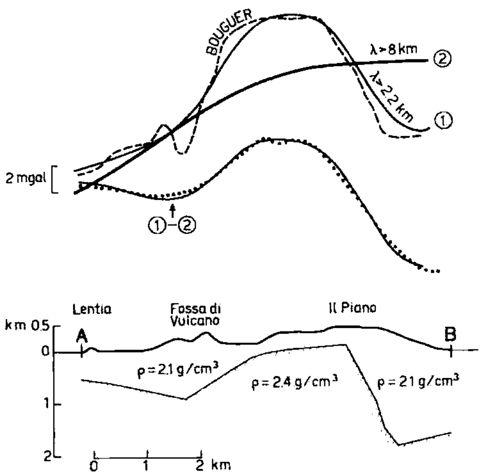

FIG. 5 — Interpretative model of the 2.2 km $< \lambda <$ 8 km gravity component (①-②) along the AB profile (see Fig. 4d for location):

---- Bouguer gravity field

① Filtered gravity component ($\lambda > 2.2$ km)

② Long wavelength gravity component ($\lambda > 8$ km)

.... Best fitting computed gravity anomaly ($\Delta\rho = 0.3$ g/cm^3)

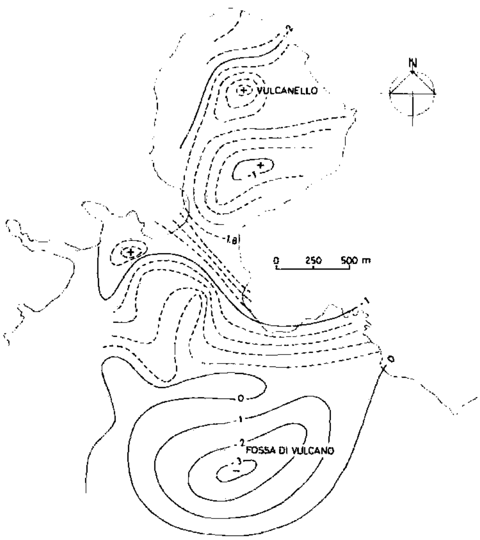

FIG. 6 — Residual gravity anomalies ($\lambda <$ 2.2 Km) in the northern part of Vulcano (Vulcanello and Fossa di Vulcano crater):

—— contour interval: 1 mgal

---- contour interval: 0.2 mgal

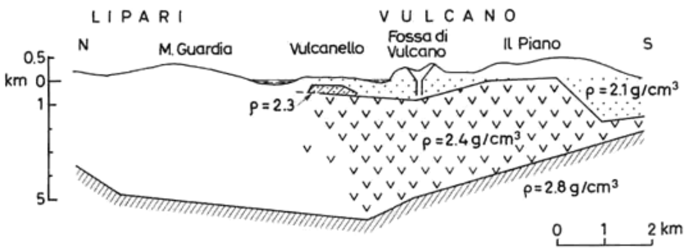

FIG. 7 — Comprehensive schematic model of Vulcano structural pattern along a N-S profile as deduced by the interpretation of gravity data (this paper and IACOBUCCI *et al.*, 1977).

ing on the two sides up to several hundred metres (Fig. 7). Given the geothermal state of the area (presence of high temperature fumaroles and of hot fluids in shallow wells) this discontinuity could be attributed to the vertical transition, within the same superficial layer, to a higher temperature environment ($T > 200°C$) where propylization processes could occur with a consequent increase of the rocks density (BARBERI *et al.*, 1980; LA TORRE and NANNINI, 1980; NUNZIATA and RAPOLLA, 1981). The «Fossa di Vulcano» anomaly seems to be compatible with the presence of a superficial less dense vertical body ($\Delta \rho = -0.4$ g/cm^3), a few hundred metres wide and about 1 km deep (Fig. 7). It can be seen as schematically corresponding to a volcanic chimney. It should be noted that recently BALLESTRACCI (1982) presented a model of the «Fossa di Vulcano» crater, based on MT soundings, where a vapor filled zone was hypothesized at very shallow depth. Such a zone indeed could also be compatible with a small amplitude local minimum.

DISCUSSION AND CONCLUSION

The obtained gravity results are presented as a schematic comprehensive model in Fig. 7. The deepest basement ($\rho = 2.8$ g/cm^3) morphology has been obtained by the interpretation of the gravity data along a Salina-Lipari-Vulcano profile (IACOBUCCI *et al.*, 1977). The upper discontinuity is that shown in Fig. 5, whereas the bodies under Vulcanello and Fossa di Vulcano represent the interpretation of the residual shorter wavelength components shown in Fig. 6.

This model should be examined by taking in mind that such results, both as far as the division of the field into a series of components and their quantitative interpretation are concerned, are relatively unchecked. Anyway, the obtained results seem to us of interest and reliable as they agree fairly well with the present knowledge. In fact GIRELLI (1981) in summarizing the geological and geophysical studies of the area, reports a general model of the island formed by a surface layer made up of loose pyroclastic materials lying over a lava basement. The volcanic complex was also divided into two main parts by LATTER (1971) who attributed a seismic velocity of 1 ÷ 3 km/sec to the uppermost layer and of 3.5 km/sec to the lower volcanic layer. Moreover, following IACOBUCCI *et al.* (1977), the whole volcanic sequence lies over a denser, non magnetic basement which is dissected by intense faulting. A deep basement was also recognized by LATTER (1971) who attributed a seismic velocity of 5.5 km/sec to this layer. The morphology we have deduced (Fig. 7) would represent the contact, inside the above mentioned volcanic sequence, between the upper slightly compacted recent pyroclastic products ($\rho = 2.1$ g/cm^3) and the highly compacted pyroclastic products or lavas (ρ=2.4 g/cm^3).

Finally, it is interesting to note that, from a geothermal exploration point of view, a density contrast of about 0.2 g/cm^3 may distinguish low temperature hydrothermally altered products from high temperature propylitic altered pyroclastic products ($T > 200$°C) (BARBERI *et al.*, 1980; LA TORRE and NANNINI, 1980; NUNZIATA and RAPOLLA, 1981). This interpretation may apply to the high frequency anomaly located in the northernmost area where high temperature springs and fumaroles occur and high temperature fluids ($T > 200$°C) were found in shallow drillings made several years ago by AGIP (pers. comm., 1982).

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