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Remanent and induced magnetization in the volcanites of Lipari and Vulcano (Aeolian Islands)

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Abstract
The role of remanent and induced magnetization as sources of magnetic anomalies in the Lipari and Vulcano islands has been studied by systematic sampling. Remanent magnetization is higher than induced magnetization in almost all lithotypes. Its polarity is normal, and the mean directions are close to the present magnetic field. A slight thermal enhancement of the magnetic susceptibility occurs up to 450-500 °C, followed by a fall up to the Curie point, which is comprised in the range 550 ± 30 °C. This points to titanomagnetite as the main carrier of magnetization. The blocking temperature spectrum of the remanence ranges between the Curie point and 400 °C in most lithotypes, and falls to 150-200 °C in the pyroclastic deposits. The results as a whole yield an outline of the areal distribution of the total magnetization intensity within the two islands.

Key words *magnetization – susceptibility – blocking temperature – volcanites*

1. Introduction

Magnetic surveying is one of the most widely employed geophysical methods for the structural study of volcanic edifices. Quantitative modeling and geological interpretation of the anomalies are greatly facilitated if the magnetic characteristics of their sources are known a priori. The main problems in volcanic areas are:

a) the roles of induced ($\bar{J}_i$) and remanent ($\bar{J}_r$) magnetization. The latter is almost always preponderant, and its direction may be very different from the present magnetic field;

b) the sometimes very pronounced variations in the magnetic properties of individual lithotypes;

c) the effect of temperature. The stability of $\bar{J}_r$, in fact, depends on the spectrum of its blocking temperature, while the magnetization of a geological body disappears at temperatures higher than the Curie point of its ferromagnetic minerals. In areas with a high geothermal gradient, therefore, the temperature distribution at depth heavily affects the sources of magnetic anomalies.

This paper examines these three questions with regard to the volcanic islands of Lipari and Vulcano, which have recently been the subject of magnetic surveys (Budetta and Del Negro, 1989; Barberi *et al.*, 1994), while an ongoing research programme is exploring their palaeomagnetism (Lanza and Zanella, 1991).

2. Geological setting

Lipari and Vulcano are the southernmost islands of the Aeolian archipelago. They lie along an axis whose direction is parallel to the Tindari-Letojanni transform fault, which was active during the Pliocene (Barberi *et al.*, 1994). They are mainly composed of Pleis-

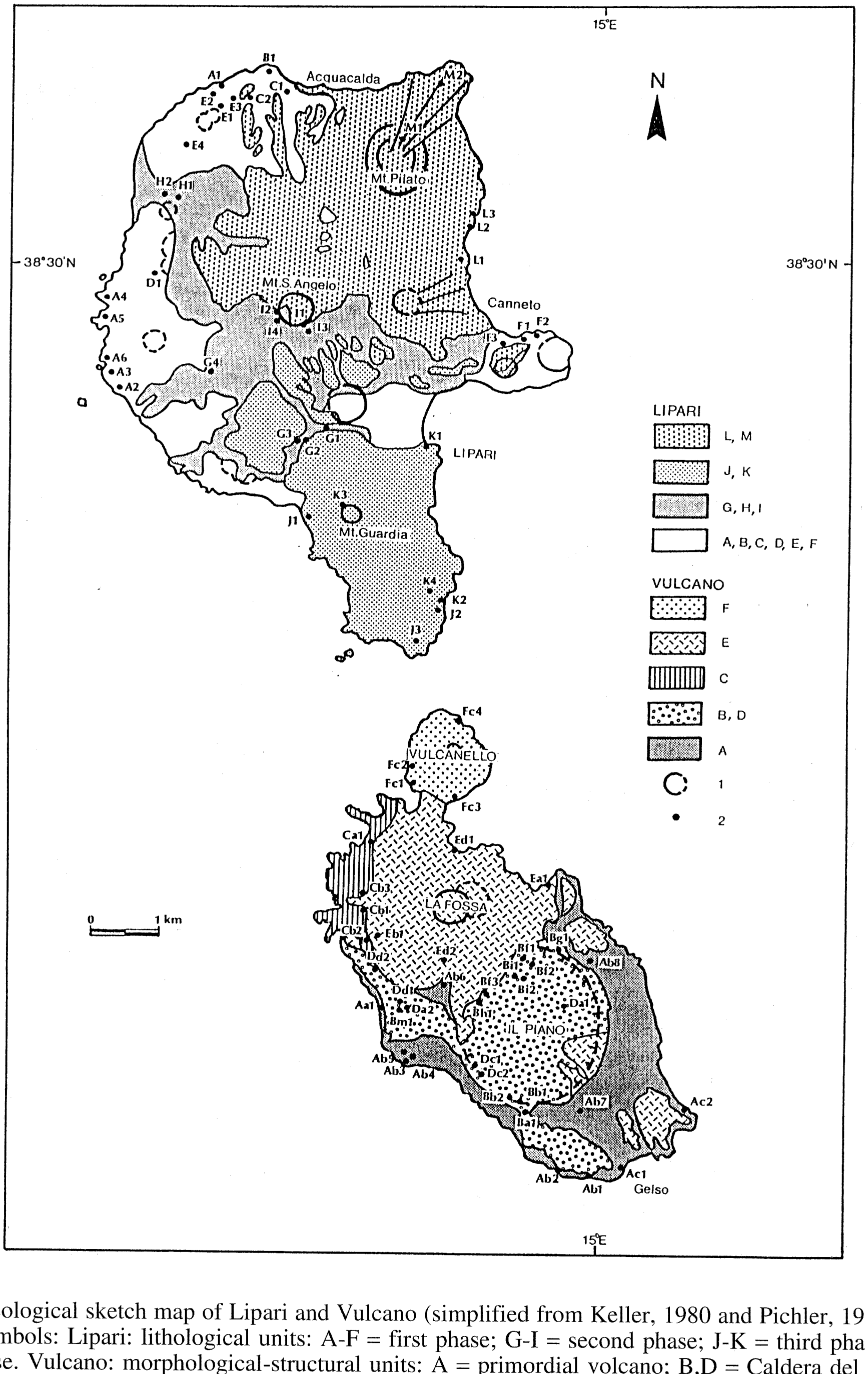


Fig. 1. Geological sketch map of Lipari and Vulcano (simplified from Keller, 1980 and Pichler, 1980 respectively). Symbols: Lipari: lithological units: A-F = first phase; G-I = second phase; J-K = third phase; L-M = fourth phase. Vulcano: morphological-structural units: A = primordial volcano; B,D = Caldera del Piano and its subsequent filling; C = Lentia complex; E = Caldera della Fossa; F = Vulcanello. 1 = crater rims, 2 = sampling localities.

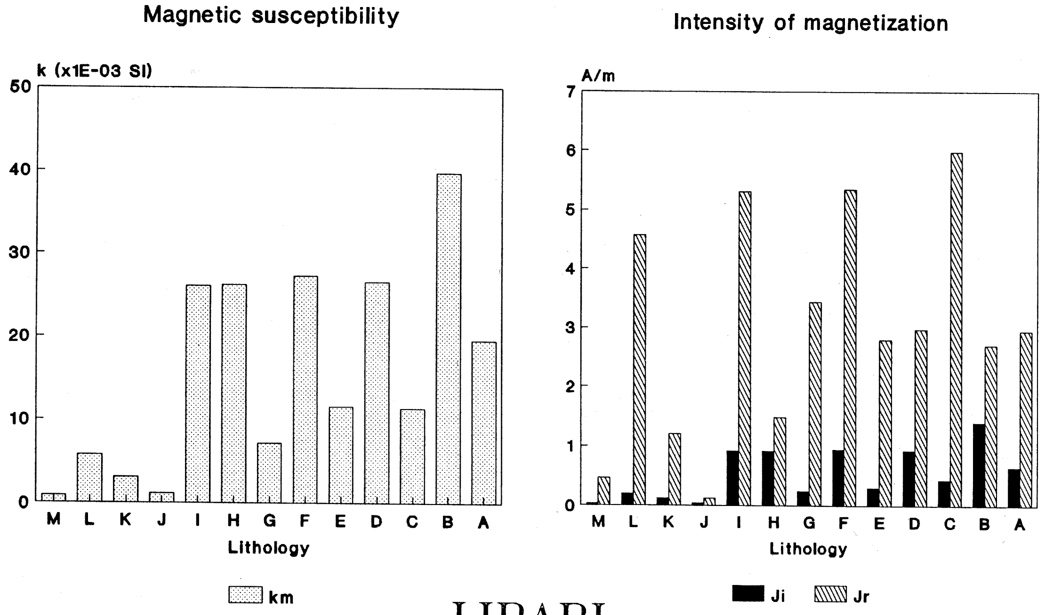
tocene calcalkaline and shoshonitic products. Four distinct magmatic phases have been described for Lipari (fig. 1) by Pichler (1980). The first two are basaltic-andesitic and primarily crop out along the cliffs and in the northwestern part of the island. The other two are rhyolitic and appear both as endogenous domes in the southern part, and as obsidianoid lava flows and thick pumice deposits in the northeastern part. Five morphological-structural units have been identified on Vulcano (Keller, 1980): the primordial volcano, the Caldera del Piano and its filling products following the collapse of the original cone, the Lentia complex, the lava flows of the Vulcanello platform, and the Caldera della Fossa, which constitutes the still-active part of the island. K-Ar dating (Capaldi *et al.*, 1985; Frazzetta *et al.*, 1985; Crisci *et al.*, 1991) has disclosed a period of discontinuous magmatic activity from about 230 ka to the Present.

Samples for magnetic measurements were collected so as to include, as far as the outcrops would allow, several localities for each lithological unit. They were obtained from nearly all the lava units, and from some pyroclastic and scoriae deposits (Keller, 1980; Pichler, 1980), making a total of 39 localities on Lipari and 40 on Vulcano. From 4 to 12 oriented cores from each locality were used to cut about 900 cylindrical specimens of standard size (∅ = 25 mm, h = 22 mm).

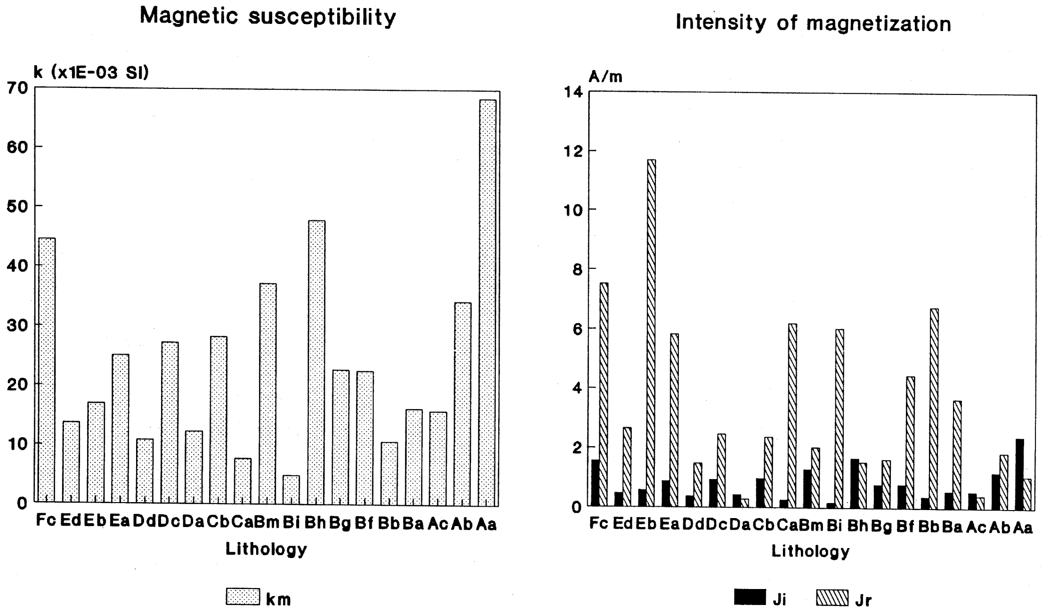
3. Magnetization intensity

A magnetic anomaly source is characterized by a total magnetization given by the resultant of $\bar{J}_i$ and $\bar{J}_r$. The intensity of $\bar{J}_i$ is expressed by $k * |\bar{F}|$, where k is the magnetic susceptibility value (measured with a KLY-2 bridge), and $|\bar{F}|$ is the regional mean value of the earth's magnetic field (35 A/m: Meloni *et al.*, 1988). $\bar{J}_r$ was measured with a JR-4 spinner magnetometer. The susceptibility and magnetization intensity values reported here are means per lithotype. On Lipari, k is clearly correlated with the type of rock (fig. 2): higher values ($10\text{-}25 \times 10^{-3}$ SI units) were found in the basalts and andesites of the first two magmatic stages, lower values ($1\text{-}5 \times 10^{-3}$ SI) in the two rhyolitic stages. The same is true for the intensity of $\bar{J}_r$: 3-6 A/m in the first two phases, and equal to or less than 1 A/m in the other two, with the exception of the oldest obsidianoid lava flows. No such systematic distinction can be drawn between the magnetic properties of the Vulcano lithotypes, and the values themselves often overlap owing to the wide variations displayed by those for an individual lithotype. Generally speaking, k lies between 5×10^{-3} and 70×10^{-3} SI (fig. 2), while the intensity of $\bar{J}_r$ is of the order of 1-4 A/m (range 0.3-12 A/m). The lowest values for both parameters were obtained from the pyroclastites and scoriae. An exception, on the other hand, was provided by the unconsolidated deposits within the Caldera della Fossa, where the maximum $|\bar{J}_r|$ was 12 A/m, whereas the k value was only 17×10^{-3} SI. Values of this kind can be referred to the minute size (< 20 μ) of the titanomagnetite grains (Dunlop, 1981). Other characteristics, mainly associated with mineralogical differences, can be extended to both islands: low susceptibility values are common in the rhyolites, whereas higher values are a distinguishing feature of the older trachybasaltic units.

Comparison between the $|\bar{J}_r|$ and $|\bar{J}_i|$ values (fig. 2) shows that the former prevails in all lithotypes, with the exception of two pyroclastic deposits and two lava flows. The Koenigsberger ratio $Q = |\bar{J}_r| \,/\, |\bar{J}_r|$ is only close to 1 in these last cases, whereas in the others it is of the order of 7 to 20. This means that the magnetic characteristics of the anomaly sources primarily depend on those of the remanent magnetization, and hence its direction. The mean directions of the individual localities (fig. 3) are concentrated around the present field. The scatter is small and becomes even smaller when the means for each lithological unit are considered. The mean magnetization direction of the two islands is statistically indistinguishable from that of the axial dipole ($D = 0°$, $I = 57°$): for Lipari $D = 1.9°$, $I = 54.4°$ with $\alpha_{95} = 6.2°$; for Vulcano, $D = 3.9°$, $I = 55.5°$ with $\alpha_{95} = 6.5°$. These results are consistent with the age of emplacement of the rocks, which occurred during the Brunhes nor-



LIPARI



VULCANO

Fig. 2. Mean values per lithotypes of magnetic susceptibility (k_m) and intensity of induced (J_i) and remanent (J_r) magnetization. Symbols as in fig. 1.

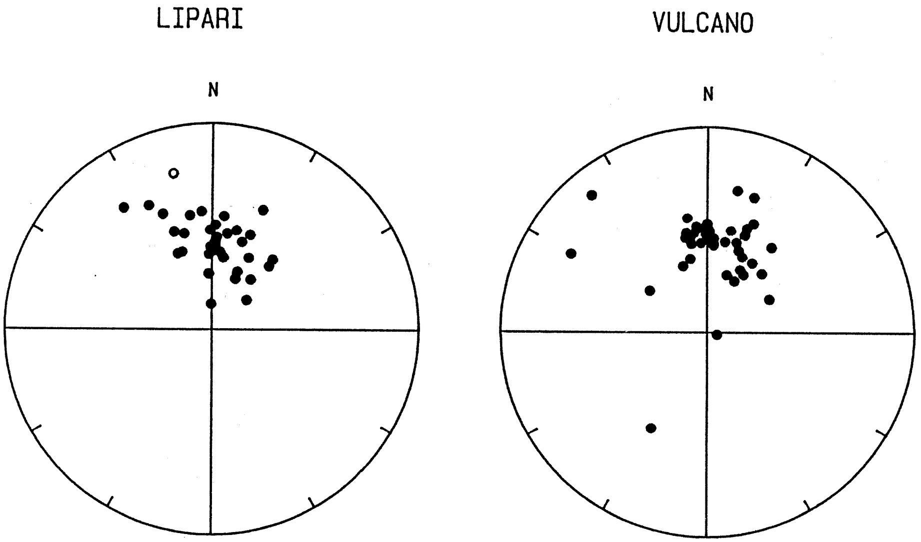


Fig. 3. Equal-area projection of mean directions per site of the natural remanent magnetization (NRM). Full/open circle = positive/negative inclination.

mal polarity chron (Mankinen and Dalrymple, 1979; Cande and Kent, 1992). Directions certainly referable to the more recent reverse polarity subchrons (Lascahmp, Blake, ...) have not yet been detected.

In conclusion, a good approximation is obtained if $\bar{J}_r$ in an anomaly model is assumed to be parallel to the present field. This is also the direction of the total magnetization, whose intensity is equal to the algebraic sum $|\bar{J}_t| = |\bar{J}_r| + |\bar{J}_i|$.

4. The effects of the temperature

Persistent fumarolic activity, especially on Vulcano, shows that very high temperatures are present not far from the surface. Downward extrapolation of magnetic properties measured on outcrops must thus take account of the influence of temperature on rock magnetization. Measurements of susceptibility as a function of temperature (fig. 4) show that k increases slightly up to 400-500 °C, and then falls sharply just before the Curie point (520-580 °C). These last values were confirmed by tests run with a Curie balance (fig. 5). They show that low-Ti titanomagnetite is the main ferromagnetic mineral of the Lipari and Vulcano rocks.

Thermal demagnetization processes allow the stability of $\bar{J}_r$ as a function of temperature

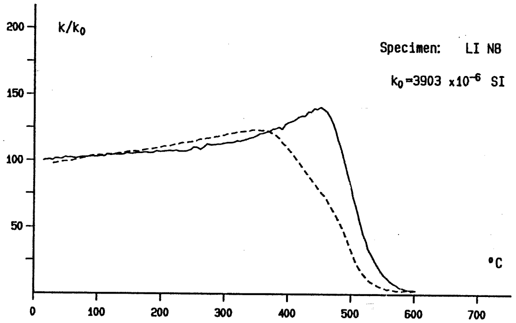


Fig. 4. Normalized susceptibility versus temperature curve. Full/dashed line = heating/cooling cycle; k_0 = initial susceptibility.

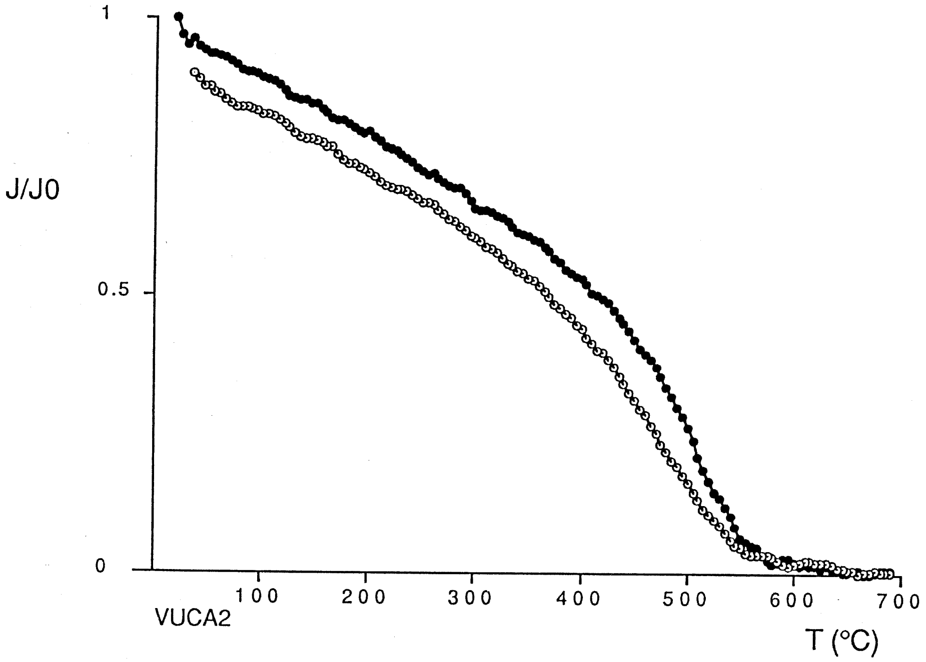


Fig. 5. Normalized saturation magnetization versus temperature curve. Full/open symbols = heating/cooling cycle.

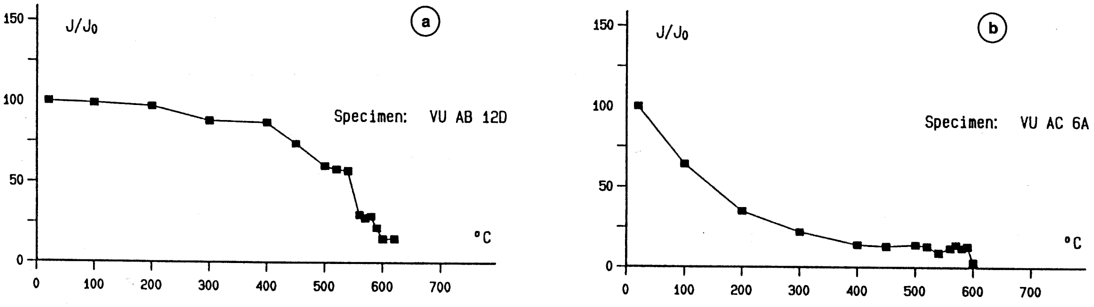


Fig. 6a,b. Normalized intensity decay curve during thermal demagnetization: a) andesitic lava; b) pyroclastite.

to be determined. The $\bar{J}_r$ or both islands is virtually unchanged up to about 400 °C (fig. 6a), followed by a rapid fall. In a few cases only, especially the pyroclastic products, the blocking temperature spectrum is much wider, and 50% of the initial magnetization is already lost at 200 °C (fig. 6b).

It may thus be deduced that in most cases magnetization intensities measured on outcrops do not change appreciably down to depths corresponding to the 400 °C isotherm. At greater depths and temperatures, $\bar{J}_i$ falls and the natural Thermal Remanent Magnetization (TRM) is gradually replaced by Viscous Remanent Mag-

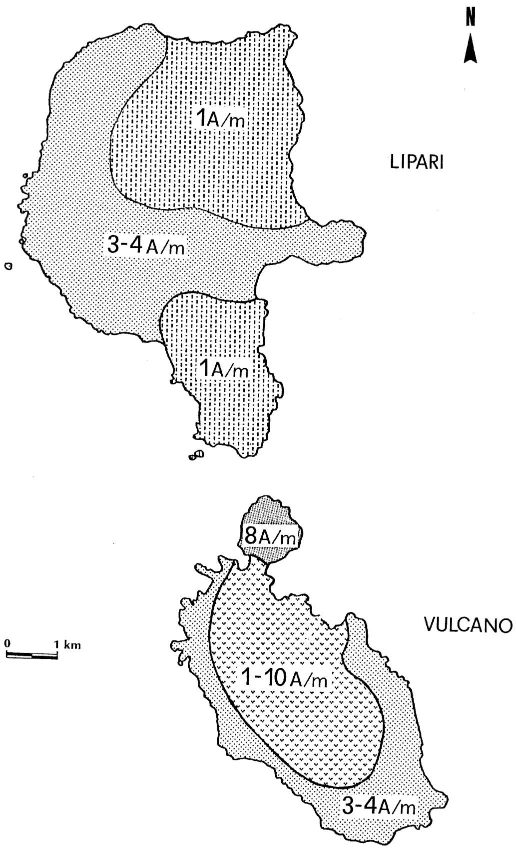


Fig. 7. Areal distribution of total magnetization intensity on Lipari and Vulcano.

netization (VRM), whose contribution to the total magnetization is hard to assess. The direction is still parallel to the present field, though no experimental data or theoretical models from which to determine its intensity in quantitative terms are as yet available.

5. Conclusions

The data presented in this paper were obtained from some 900 specimens from nearly all the lithotypes cropping out on Lipari and Vulcano. Some magnetic characteristics are similar in these lithotypes, whereas others display a greater variability. Even so, three general conclusions can be drawn for use in the more realistic definition of the magnetization of sources of anomalies:

a) the magnetization direction is parallel to the present field;

b) the intensity of magnetization varies greatly from one lithotype to another. It was nonetheless possible to divide each island into regions displaying similar values (fig. 7). If account is taken of both $\bar{J}_r$ and $\bar{J}_i$, the mean intensity for both islands is 3-4 A/m. This value falls to 1 A/m in the southern and northeastern part of Lipari, where rhyolites predominate. On Vulcano, the Vulcanello edifice displays a very high value (8 A/m), whereas the Caldera del Piano filling zone and the Caldera della Fossa values embrace a wide range (1-10 A/m), that reflects the complex areal distribution of their products;

c) rock magnetization does not vary with temperature up to about 400 °C, after which there is a gradual fall up to the Curie point of the titanomagnetite (550 ± 30 °C), though the additional contribution of the VRM to the total magnetization is not known.

These general features can be taken as the starting points for interpretation of the anomalies associated with these two volcanic edifices. As far as the more superficial part of the source bodies is concerned, magnetization can be determined on the strength of the results presented in this paper, whereas for the deeper parts our data must be supplemented by other geophysical methods, which provide a better definition of the shape of source bodies and above all a clearer picture of the real distribution of temperature values as a function of depth.

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