RELATIONSHIP BETWEEN GEOTHERMAL ACTIVITY AND GRAVITY ANOMALIES ON VULCANO ISLAND, ITALY

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SUMMARY – This study investigated the usefulness of gravity data in deducing information about the near-surface geological structures which may be controlling geothermal activity on the island of Vulcano. Gravity measurements were carried out along several profiles taken across and around the Fossa crater. A quantitative gravimetric interpretation was carried out along the profiles and a good fit model was obtained for a simple two layer model including a dense rectangular prism. The dense material beneath the crater may be the self-sealed volcanics under which geothermal fluids circulate, as inferred by other geophysical studies.

1. INTRODUCTION

A few gravimetric studies have been made of the Aeolian Islands including Vulcano (Bonasia *et al,* **1973;** Iacobucci *et al,* **1977;** Barberi *et al.,* **1994).** These studies were on a regional scale, and no features smaller than 1 km across were shown. A more detailed structural view of the Vulcano-Lipari complex using potential methods was substantially hindered by strong and short-wavelength lateral heterogeneities. None of these surveys could draw any inferences about the most relevant structural feature of Vulcano, first revealed by two deep geothermal wells in 1983-87 (Gioncada and Sbrana, **1991).** The drill-hole, located at the foot of the south-western flank of the Fossa crater, reached **2200** m bsl and an intrusion of monzogabbro was found at a depth of **1360** m. Obtaining a gravity signature of the intrusion is hindered by insufficient density variations between the lithotypes (Faraone et al., **1986).**

A two year project, using different airborne geophysical methods (magnetics, VLF and gamma ray mapping) and supplemented by detailed ground geophysical measurements (geoelectric and magnetic) was carried out to investigate the physical structure of the volcanic regions of southern Italy, including the Island of Vulcano (Supper et al., **2001).** In 2000, gravity measurements were carried out on the Island of Vulcano, particularly along the same profiles that were covered in **1999** by the geoelectric and magnetic ground geophysical survey.

This study aims to improve the extent of gravity data on the Island of Vulcano, and to see if gravity data can help to deduce information about near-surface geological structures which may be controlling geothermal activity as Hunt (1992) did in the Rotorua geothermal field.

2. GEOTHERMAL ACTIVITY

Vulcano Island belongs to the calc-alkaline Aeolian Islands arc. It has been a very active volcanic system during historical times. The last, typically *vulcanian,* eruption on Vulcano began at the Fossa crater in **1988** and continued until **1990.** Since then the volcano has remained in the fumarolic stage, with its main clusters on the northern margin of the crater, near Baia di Levante beach (Figure 1). The intensity of the activity has varied greatly with time and the two main zones of emission have very different characteristics. The most remarkable differences in the fluid chemistry of the two emission areas are the presence of volcanic components in the fumarolic fluids of the crater, and their absence in the beach fumaroles (Chiodini et al., **1991).**

Figure 1 - Simplified geological map of the island of Vulcano.

3. NEW GRAVITY MEASUREMENTS

The present gravimetric survey consists of **385** stations located on the island (Figure **2).** It was carried out using two Scintrex CG3M gravimeters **(S/N 352, 385).** The height of each station was measured by differential **GPS** using Magellan Promark **X-CM** receivers. The gravity network was connected to the absolute gravity station **VLC-g0** (Latitude: **38-22-42** N, Longitude: **14-59-**00 E, ht **417** m, **g 980029.693** mGal, ref.: Berrino, **1995).** The data, corrected for tidal and instrumental drift, were adjusted and then corrections for free air, Bouguer and terrain were made.

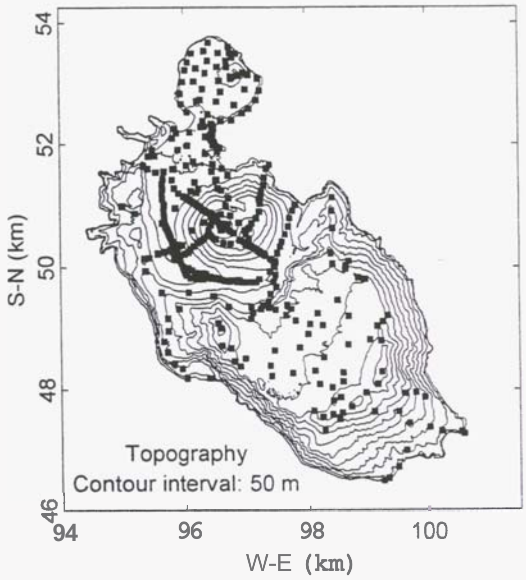

Figure 2 - Distribution of gravity stations. Topography was generated by combining DEM and multi-spectral ortho-images (Gwinner et al., 2000)

Barberi et al. **(1994)** computed the Bouguer gravity map of the Vulcano-Lipari complex assuming a baseline density of **2.4** g/cm^3, which represents the average value for the volcanic cover. We computed several Bouguer maps based on different arbitrary densities (Figure **3),** then selected the map which showed the least correlation with the topography and determined the optimum density to be 1.8 g/cm^3. This result is almost the same as the surface density of Ponza Island, about 400 km NW of Vulcano, that is considered to be composed of rhyolitic hyaloclastic deposits (Bellucci et al., 1997).

Because of access difficulties in some areas, the data coverage is quite uneven. Therefore, the contour map should be studied carefully in the zones where the density of measured points is low. In addition, the rough topography of this region can modify the shape of the anomalies even though topographic corrections have been performed.

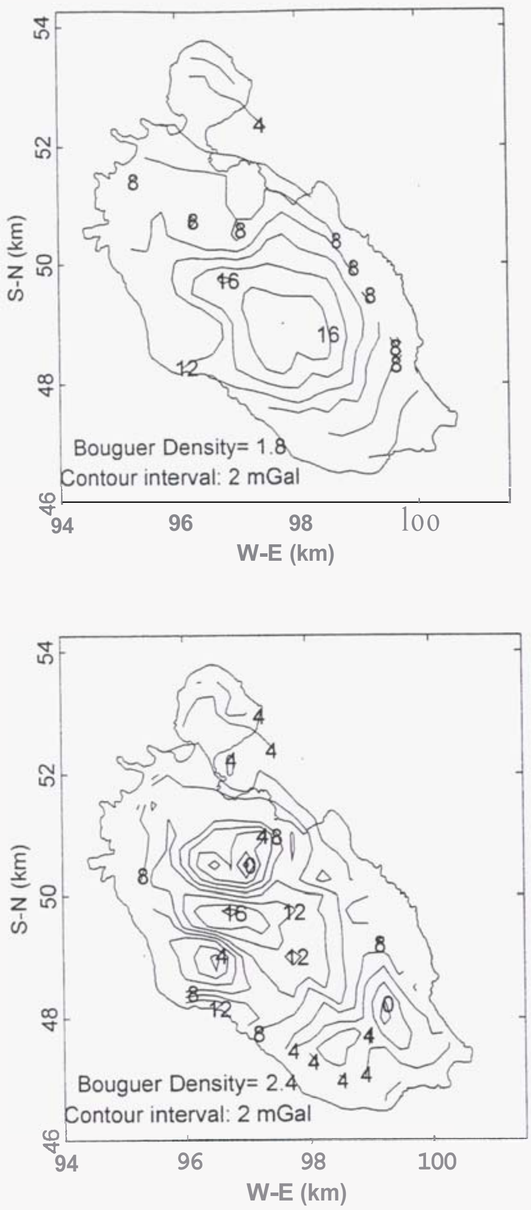

Figure **3** - Bouguer anomaly map for d= **1.8** g/cm^3 (upper) and map for d= 2.4 g/cm^3 (lower).

4. DISCUSSION AND CONCLUSION

Regional trends were removed, then anomaly maps of the two active geothermal fields were made, to identify any gravity features that are caused by the near-surface geological structures which may be controlling the geothermal activity.

4.1 Baia di Levante Beach

A geochemical study of the waters from wells in the plain of Vulcano Porto, between Fossa and Vulcanello, and geoelectric investigations showed the presence of a surface aquifer of a relatively simple geometry, sloping northwards and containing mainly sea water. Overlying this aquifer, in a limited area within the southern part of the plain, at the back of Fossa crater, there is a soft-water aquifer. Two further hot-water aquifers were found by drilling. These drillings clearly indicated a discontinuous permeability between the various levels. Therefore, circulation of fluids between the higher and lower levels is expected to be difficult (Carapezza et ai, 1981).

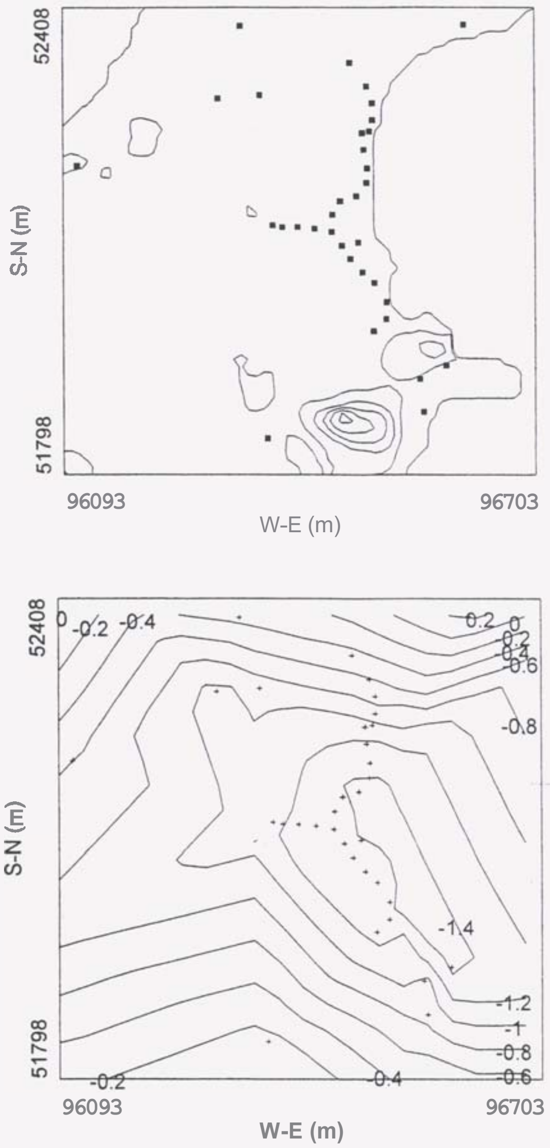

Figure 4 - Geothermally active area near Baia di Levante beach: Topographic (upper) and Bouguer anomalies (lower) maps. Contour intervals are 1Om (upper) and 0.2 mGal (lower).

Very detailed measurements were made at about 10 m intervals at the geothermally active area near Baia di Levante beach (Figure 4). The geothermal area is marked by a negative gravity anomaly. It **may** be caused by a hot-water aquifer in a limited area; however, the lack of data coverage in the sea area hindered a closer structural investigation of the anomaly.

4.2 Fossa Crater

The strict relationship between the carbon dioxide content of fumarolic fluids and local microseismic activity observed during the summer of 1988 suggests that they are caused by an increase in the fluid pressure at depth, beneath the Fossa crater (Chiodini et al., 1992). In August, high values of carbon dioxide were observed, accompanied by a sharp increase in the occurrence of monochromatic events a week after a swarm of high-frequency events. The foci of the monochromatic events are apparently clustered at depth between 400 and 1000 m beneath the Fossa crater, where the mechanical strength of the rocks is likely to be controlled by the thermal effects produced by ascending hot fluids and also the chemical corrosion induced by circulation of geothermal brines (Montalto, **1994).**

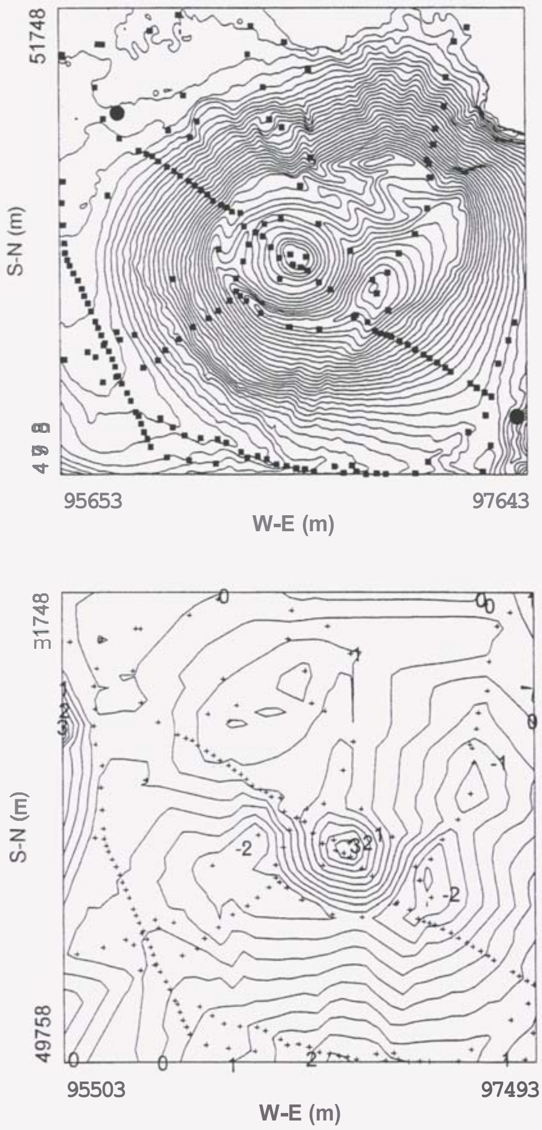

Figure 5 - Geothermally active area near Fossa crater: Topographic (upper) and Bouguer anomalies (lower) maps. Contour intervals are **10** m (upper) and 0.5 mGal (lower). Solid circles indicate the end points of the profile shown in Figure 6.

Since 1982, high precision relative gravity measurements have been periodically carried out at Vulcano. The most significant changes are generally recorded at the base of the present active crater, where most of the fumarolic activity is concentrated. The absence of ground movements and the localized nature of the gravity changes suggest that fluid migration through shallow levels of the crust (500-1000 m) may be the causative mechanism. The migrating fluids may belong partly to an active geothermal system and partly to a hydrological system which controls the local level of the water table (Berrino, 2000).

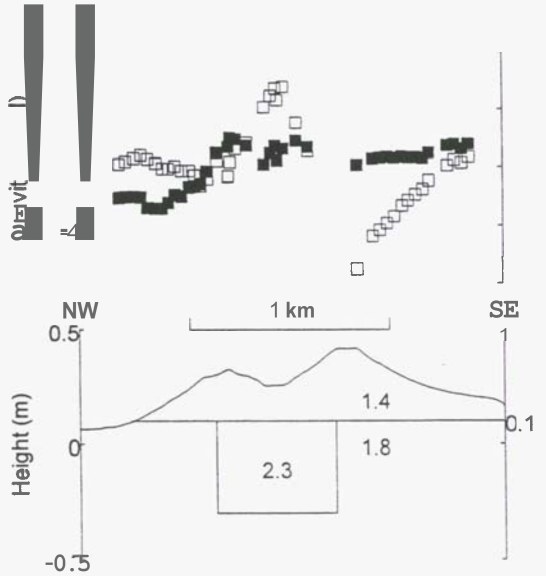

Figure 6 - A best fit model is shown on a NW-SE section (see Figure 5 for location). Gravity anomalies are shown by actual nearest values. Open squares indicate the local anomalies as shown in Figure 5 and solid squares show residuals as shown in Figure 7.

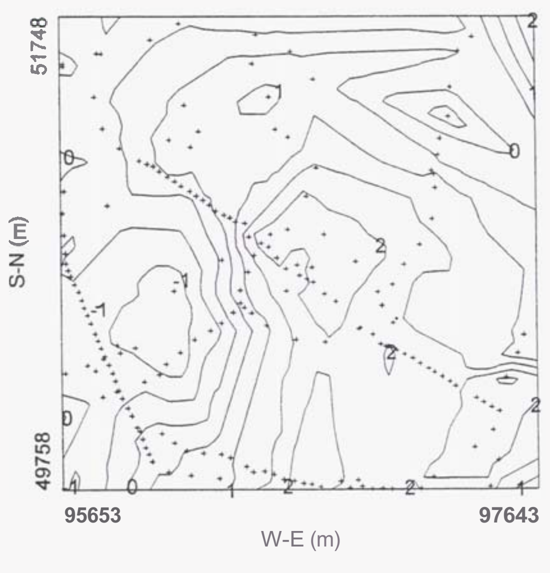

Figure 7 - Residuals distribution. Contour interval is 0.5 mGal.

Gravity measurements were carried out across and around the Fossa crater along the profiles shown in Figure 5, some of which are the same profiles covered in 1999 by geoelectrics and magnetics. Along the profiles, a quantitative gravimetric interpretation was carried out using rectangular prism modelling (Banerjee and Das Gupta, 1977) and taking into account the topographic pattern. Several models were set up, their gravity effects were calculated, and then the models were adjusted until a good fit was obtained between the observed anomalies and the calculated effects. Figure 6 shows a good fit model. It is a very simple model. Nevertheless, most of the anomalies shown in Figure 5 are reproduced and residuals are very small (Figure 7). The dense material beneath the crater may indicate the self-sealed volcanics under which geothermal fluids circulate, as inferred by the other geophysical studies mentioned above.

5. ACKNOWLEDGMENTS

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