GRAVITY INTERPRETATION OF MT. AMIATA GEOTHERMAL AREA (CENTRAL ITALY)

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ABSTRACT

A detailed gravity survey of the Mt Amiata geothermal area is re-interpreted in order to reconstruct the deep structure of the area. The study has the aim to interpret the gravity low (-24 mgal) centered on Mt Amiata. The interpretation, based on the stripping off technique using a 3D model, shows a residual anomaly attributable to previously unidentified bodies. The presence of an anomalous body at a depth of 6 km, referable to an intrusive mass responsible for most of the negative anomaly is assumed, on the basis of the geothermal gradient in the area. Two local negative residual anomalies of -4 and -6 mgal have also been identified at Piancastagnaio and Vallerona, which are interpreted as due to density variations owing to an increase in porosity within the Tuscan carbonate formation. Those anomalieshave been associated to the geothermal field.

1. INTRODUCTION

The Mt Amiata area (south Tuscany, Italy) has since ever attracted attention both because of the presence of quicksilver ores and, recently, of the geothermal power exploitation. Various geological and geophysical studies have been carried out in the area, which have explained its surface geological structure; but have not yet clarified the in-depth actual situations. In order to improve our knowledge a previous gravimetric survey carried out in the Mt. Amiata area has been re-inteipreted.

The Bouguer anomaly, calculated with a constant density of 2.6 g/cm^3 (Fig. 1) shows a gravity low already detected by previous studies (Giannelli *et al.*, 1988; Orlando *et al.*, 1991), having values as low as -24 ÷ -26 mgal in the Mt. Amiata area. Orlando *et al.* (1991) conclude that this low can only in part be associated with the

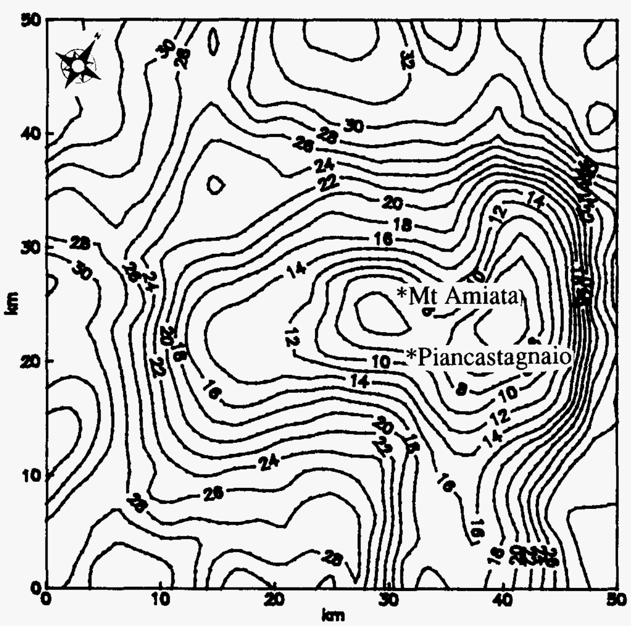

Fig. 1. Bouguer anomaly as computed using the constant density of 2.6 g/cm^3. The map is rotated 26° clockwise with respect to the geographic north.

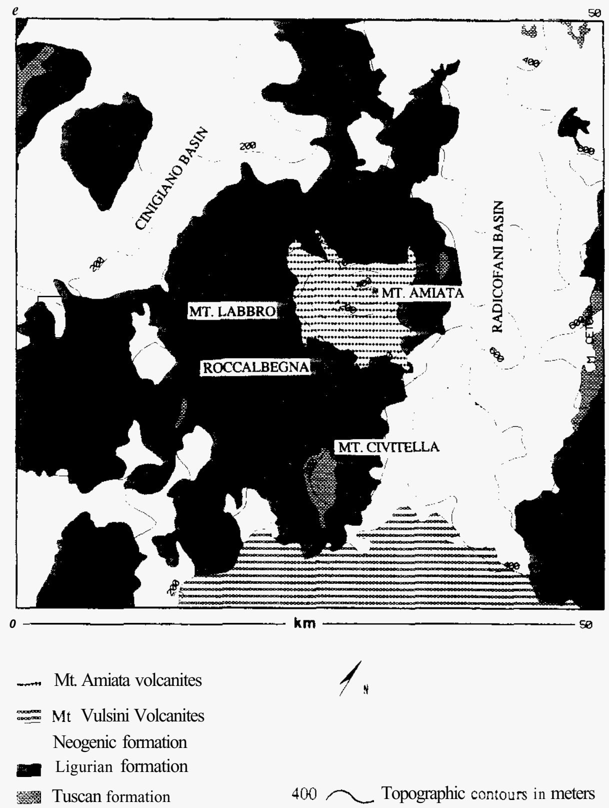

Fig. 2 Geological skech map of the Mt. Amiata surveyed area.The map is rotated 26° clockwise with respect to the geographic north.

lightest formations outcropping in the area, such as Mt Amiata volcanites and Neogenic deposits. The rest of the mass deficiency may be due to buried lighter formations.

A preliminary interpretation (Orlando *et al.,* 1993/4) suggests that the negative anomaly can be attributed only in part to a deep body.

In this study, a partially melted intrusive body is hypothesized on the basis of the geothermal gradient in the area, of the degree of thermometamorphism and of the hydrothermal water circulation in the bedrock metamorphic rocks. The gravity interpretation shows rather superficial negative residual anomalies in areas of potential geothermal fields.

2. GEOLOGICAL AND STRUCTURAL OUTLINE

The Mt Amiata area (Calamai *et al.,* 1970) is characterized (fig.2) by a N-S ridge made up by the Ligurian allochthonous complex and formations of the Tuscan nappe, on which the 0.3-0.2 My old rhyodacitic to mafic-latitic Mt Amiata volcano is located (Bigazzi *et al.*, 1981). This structure is bordered by the Radicofani neogenic depression on the East and by the Cinigiano one on the West.

Deep geothermal soundings — some of them spanning to depths of about 4000 m — indicate a sequence of metamorphic formations (phyllite, quaitz-iich metasandstone, and limestone) in age ranging from Devonian to Upper Permian under the Ligurian formation and

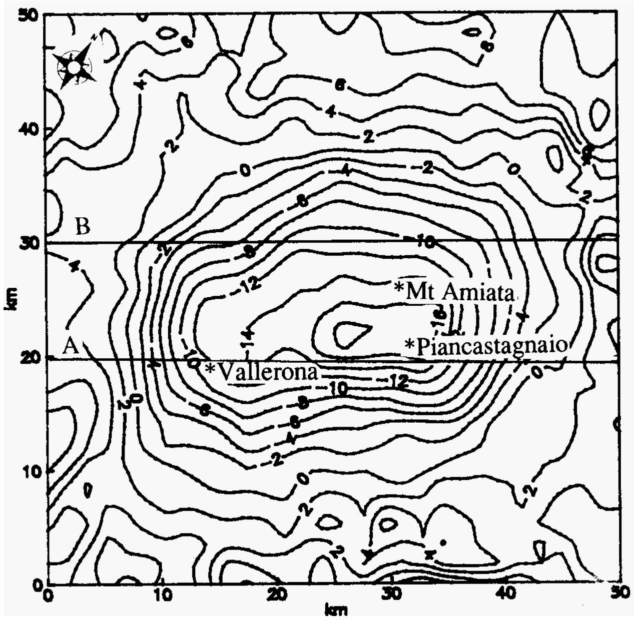

Fig. 3. Residual anomaly after the stripping off of the effects of the Mt. Amiata volcanites and neogenic deposits from the Bouguer anomaly of fig. 1.

the Tuscan nappe. Xenoliths in the Mt. Amiata volcanites (Van Bergen, 1984) indicate the presence of older metamorphic formations. The maximum temperature measured at depth is about 450°C, at -3,800 m below the sea level.

The Mt. Amiata area is characterized by the general uplift of neogenic formations (Upper Miocene - Lower Pliocene) up to the average height of 600-800 m, with a maximum at Mt. Labbro, on the South-West of Mt. Amiata, where there are neogenic outcrops at an elevation of about 1000 m (Gianelli *et al.,* 1988).

Uplifting began in Middle Pliocene and probably reached its climax during Quaternary with the emplacement of the acid magmatic body, which governs the Amiata volcanic activity and may be connected with the gravimetric low.

Measurements of thermal parameters, carried out on flysch-like sediments during a geothermal survey (Calamai *et ai.,*1970), confirm that geothermal gradients higher than 1.0°C/10 m (Baldi *et al.,* this volume) are present on the entire volcanic area, the highest values (up to 4°C/10 m) being clustered were productive geothermal fields are (Calamai *et al.,* 1970).

The Roccalbegna gradient anomaly (SE of Mt Amiata) reaching values up to 1÷1.5 °C/10 m, seems to be separated from the Mt Amiata one because of the hydrogeological effect of the Mt Labbro carbonate ridge. However, the area falls in the zone of maximum crustal uplift and it may be assumed that the magmatic body could be extended up to the Roccalbegna area.

A reflection seismic prospecting carried out by ENEL in the Mt Amiata territory allowed the identification (Batini et al., 1985) of the attitude of neogenic and Ligurian formations and the reconstruction of the underlying Tuscan nappe and of the roof of the metamorphic bedrock, which is not always marked by a seismic horizon. A very marked reflector ("K" horizon), which has not yet been clearly and univocally correlated with any geological evidence, is present within the bedrock at depths between **4** and 6 km.

3. INTERPRETATION OF GRAVITY DATA

The studied area is 50x50 km wide and, because of model requirements, was rotated 26° clockwise with respect to the geographic north.

The original gravity data had measurement stations with an average density of 1 station/km^2. The data used for the present study were interpolated on a grid, the side of which was 1.7 km long. Bouguer anomalies were calculated at the constant density of 2.6 g/cm^3. The stripping off technique, used in interpreting data, is based on the subtraction, from the Bouguer anomalies, of the gravimetric contribution of all the formations having known shape and density, this latter being different from 2.6 g/cm^3, which is the density used for the Bouguer anomaly correction (Bernabini et al., 1990; Bernabini et al., 1994). In the present case, the stripping off technique, starting from the ground surface, eliminates the effect of the Mt. Amiata volcanites and neogenic deposits.

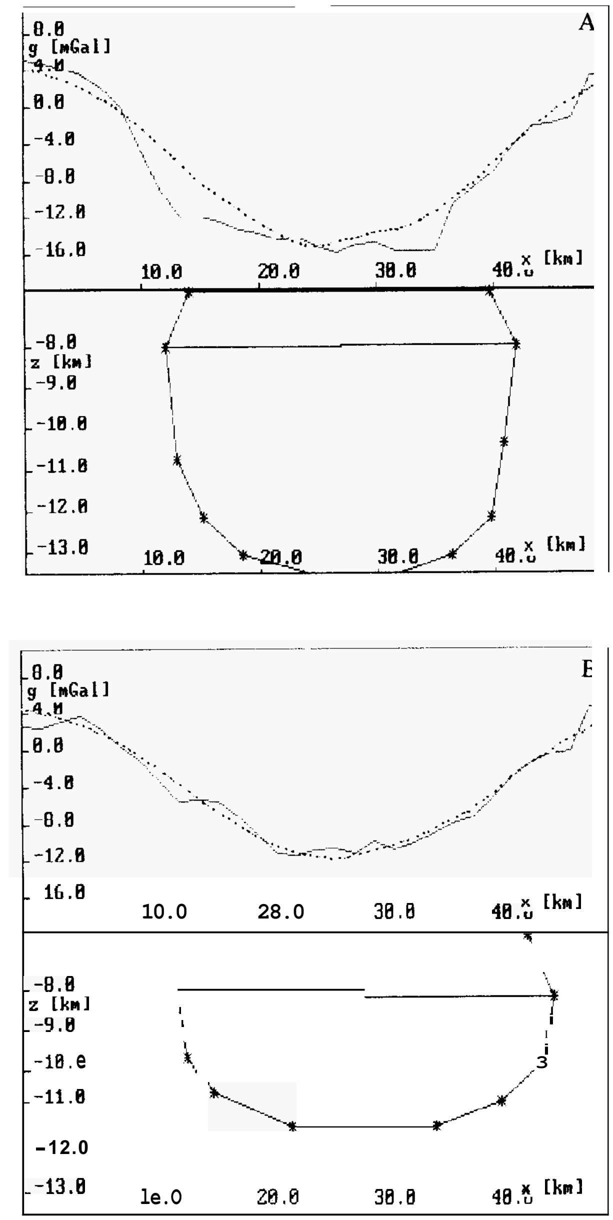

Fig. **4.** A 3D Talwani type models of sections A and B of the batholith. The lower window of each section shows the geometry of the batholith; its density is assumed as -0.15 g/cm^3 for the more superficial portion and -0.35 g/cm^3 for the deeper part. The upper part of the figure shows the calculated (dotted line) and the residual anomaly (solid line) of fig. 3. The respective positions of the sections A and B are shown in fig.3.

When the residual anomaly (Fig. 3) - obtained after the stripping off— and the Bouguer anomaly (Fig. 1) are compared, it can be seen that the portion of the gravity low located on the neogenic NW-**SE** stretching complex disappears, whereas a wide residual low with its minimun value on the south of Mt. Amiata is observable. This is less articulated and is well delineated with prevailing ENE-WSW trend; its differential values are in the order of -24 mgal.

The geological reconstruction based on borehole data and seismic surveys, evidences stratigraphical sequence — at least up to the "K" horizon — which does not explain the identified gravimetric low because: i) stripping off has eliminated the effects of the superficial light formations, ii) the remaining formations have rather high densities as indicated by the litology and by the lack of correlation between residual anomalies and topography and iii) no intrusive bodies are identified. Thus, the gravimetric low must be due to a mass deficiency caused by a formation (or a body) deeper than or as deep as the "K" horizon.

In order to interpret the gravity anomaly, it was preliminarily attributed (Orlando *et al..,* 1991) to a single intrusive magmatic body with constant differential density, the top of which is coincident with

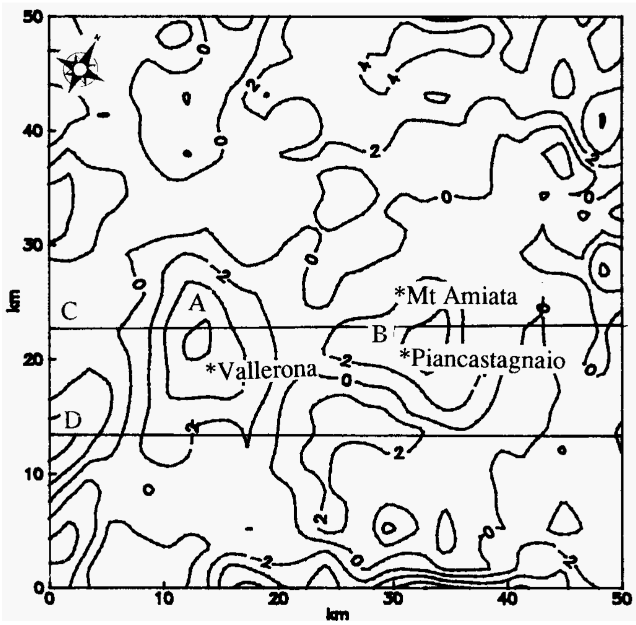

Fig. 5. Residual anomaly after the stripping off of the effect of the batholyth from the residual anomaly of fig. 3.

the "K" horizon. The supposed magnetic body might justify the principal part of the anomaly, but not some higher frequency features in the southern part of the anomaly.

On the basis of these preliminary results, the present study also takes into account the geothermal gradient as measured in deep wells. Temperatures measured on the bedrock metamorphic rocks give a gradient of about 0.85°/10 m, with a maximum temperature of 450' at -3800 m.

By extrapolating such gradient, temperatures of 600-650" at -6000 m and of 800-850' at -8000 m can be assumed. Such temperatures suggest the presence of a partially melted acid batholith. Melting is greater as depth is greater and, therefore, the batholith density decreases downwards. The density can be assumed equal to 2.55 g/cm^3 for temperatures of 600-800' and of 2.35 g/cm^3 for temperatures of about 800-850° (Murace and McBirney, 1973; Soula, 1982).

If the density of the embedding rocks is taken equal to 2.7 g/cm^3, the differential density in the upper part of the body is -0.15 g/cm^3 and that in the deeper part is -0.35 g/cm^3.

A model of a partially melted body at depths ranging between 6 and 15 km has been hypothesized and the gravimetric effects of this body have been calculatedby by the 3D programme (Gotze and Lahmeyer, 1988) already used in the previous studies (Bemabini *et al.*, 1990).

Figs. 4A and 4B show two representative sections of the model located as shown in fig. 3. The lower part of each window shows the geometry of the model; the upper part shows the calculated anomaly (dotted line) and the residual anomaly of fig. 3 (solid line).

A new residual anomaly (fig. 5) was calculated by eliminating the anomalous body's effect from the anomaly of fig. 3. The proposed model eliminates a large part of the anomaly, although short period residual anomalies are still present, such as those marked as A and B in fig. **5.** Anomaly A (about -6 mgal) is located in Vallerona. Anomaly B (about -4 mgal) is located at Piancastagnaio. The shape of the anomalies suggests a rather superficial origin; superficial geology does not justify the anomalies: effects of light formation are stripped off and the two lows are situated on geological structural highs which account for gravimetric highs. At present, the most likely cause is a decrease in density due to an increased porosity owing to the geothermal activity of the area. Considering the type of formations in the area, a density variation within the Tuscan carbonate formation may be hypothesized.

In order to evaluate this mass deficiency, it is presented a schematic model, considering two anomalous bodies which geometrical limits at depth are those of the Tuscan formation: for the Vallerona and Piancastagnaio areas the anomalous bodies are at depths ranging from 0 to -1000 m and from +100 to -600 m, respectively. The assumed differential density is of -0.2 g/cm^3. Figures 6 C and D show two profiles of the considered 3D models, located as shown in fig. **5.** Figure 7 shows the residual anomaly as obtained by subtracting the model anomaly from the values of fig. **5.**

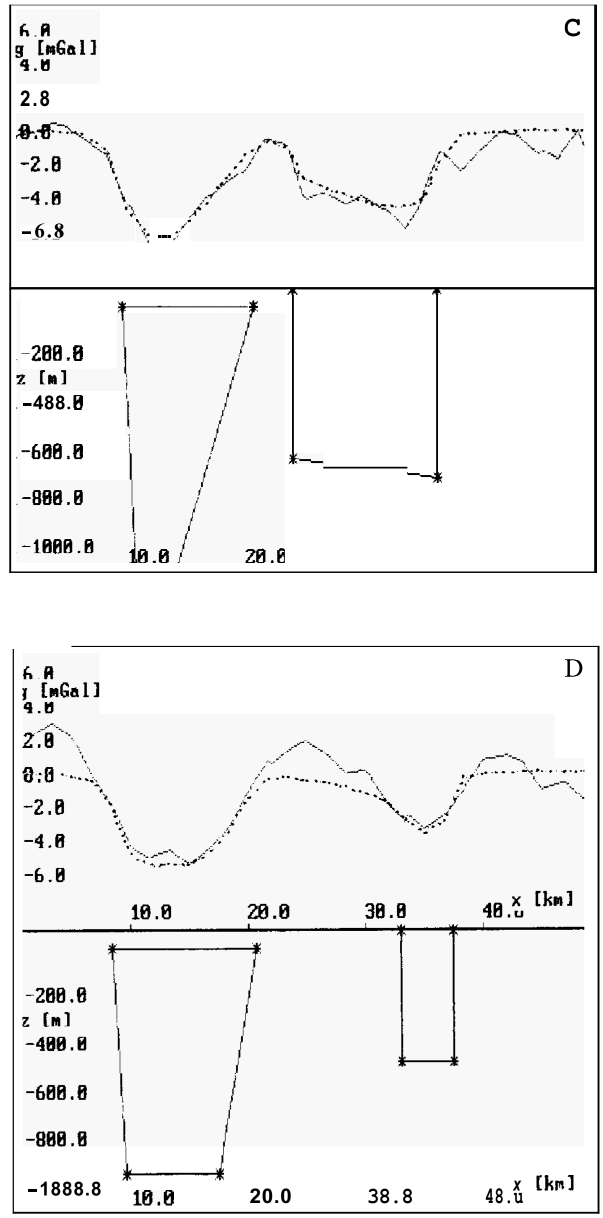

Fig. 6. Sections *C* and D of the low density-high porosity model within the Tuscan carbonate formation anomalies A and **B** in fig. 4. The lower part of each section shows the geometrical features of the models; the upper part shows the calculated anomaly of the models (dotted line) and the residual anomaly (solid line) of fig. 5. The respective position of the section C and D is shown in fig.5.

Negative anomalies disappear and only a relative maximum in corrispondence of the Mt. Civitella structural high is still present.

4. CONCLUSIONS

An extensive and strong gravimetric low, which is not justified by outcropping rocks (volcanites, neogenic sediments and flysh-like deposits) neither by buried ones (anhydritic and metamorphic carbonate formations), and an increase in heat flow can be explained if the presence at depth of a young intrusive body, which is still partially melted, is assumed. This deep body may explain the thermal anomaly and part of the gravimetric low in the area, but the remaining lows cannot be attributed to it. The residual anomalous zones correspond to structural highs, which usually imply zones of relative gravimetric maximum. A local increase of rocks porosity may better account for these residual gravimetric lows. **A** preliminary computation of the area of decreased porosity has been carried out assuming an anomalous density zone within the Tuscan carbonate formation.This hypothesis is in good agreement with the residual

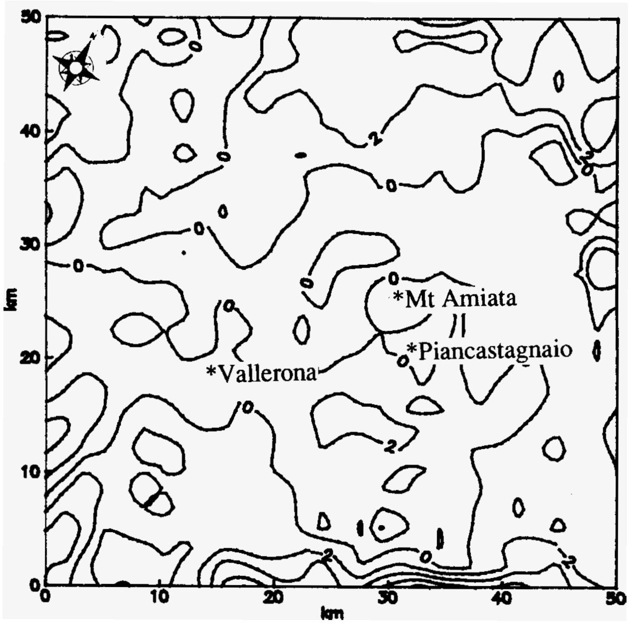

Fig. 7. Residual anomaly after the stripping off of the effect of the high porosity zones within Tuscan carbonate formation from the residual anomaly of fig. 5.

anomaly data and indicates that a residual anomaly — that of Piancastagnaio — corresponds with a well known geothermal field, and the other falls in a zone recommended for geothermal research, surveys. This result indicates that the gravimetric method can give direct evidence of a geothermal field.

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