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THE MAGNAGHI SEAMOUNT: A GRAVIMETRIC AND MAGNETIC COMBINED STUDY

Abstract. A study of the Magnaghi seamount from its magnetic and free-air gravity anomalies is presented. The first part of the study deals with the possibility of determining the density and magnetic contrast from their ratio, using Poisson's theorem. The second part concerns 3D inversion of the anomalies by constraining the inverted depths with the bathymetric limits of the volcano. The results indicate a fairly uniform distribution of density and a considerable complexity in the distribution of the magnetization.

INTRODUCTION

The Magnaghi seamount is a large volcano rising from the Thyrrenian Sea on the western border of the Tyrrenian abyssal plain. This volcano, more than 1500 meters high, is elongated toward the N-S, but has a prominence to the W at the centre of its western side. From radiometric data (Selli et al., 1977) a Pliocene age was determined for its products (about 3.0 Ma). Like the other big volcanoes of the Thyrrenian Sea, Magnaghi S. mt is basaltic-tholeiitic in composition. At first sight, the morphology of the volcano appears responsible for both gravity and aeromagnetic anomalies.

The free-air gravity anomalies in the area of Magnaghi S.mt were computed by Morelli (1970) from shipborn measurement data. A 50 mGal positive anomaly is centered on Magnaghi S.mt, whose shape is strongly related to the seamount morphology (Fig. 1). The computed Bouguer anomalies in the same area (Morelli, 1970; Fig. 2), for a density of 2.67 g/cm^3, are almost completely smooth: in fact, the anomalies are no longer correlated to the seamount and the values of the field constantly increase toward the centre of the basin, following the Thyrrenian Sea long period trend. This evidence shows that a typical oceanic volcanite density (about 2.7 g/cm^3) is a good approximation to the true rock density in this region.

The total aeromagnetic field anomalies in the Magnaghi S.mt area (AGIP, 1981) are shown in Fig. 3. The main feature is an intense anomaly with maximum centered on the western part of the volcano, and minimum north-west of the maximum; the amplitude is more than 200 nT. This magnetic anomaly shows a non-normal shape (Fedi and Rapolla, 1988): in fact, the peak-to-trough axis is not along the local magnetic meridian (in this region oriented almost in the direction of geographic north), but forms a —50° angle with it.

The free air gravity anomaly is very well correlated with the volcanic structure; the magnetic anomaly appears somewhat displaced. Part of this is certainly due to the local magnetic inclination of the inducing field (about 56°) and to the non-normal direction of the total magnetization

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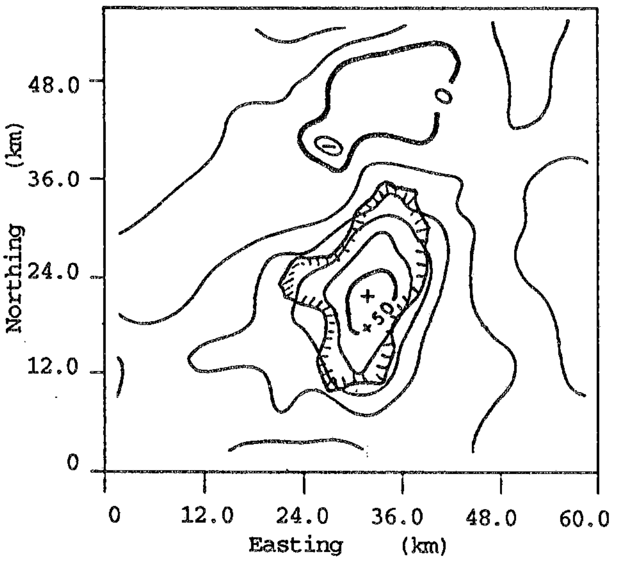

Fig. 1 — Free-air gravity anomalies in the area of the Magnaghi seamount (contour interval: 10 mGal). In this and following figures, the —3000 isobath, roughly corresponding to the base of the Magnaghi, is also indicated.

vector; however, it could also be related to a complex distribution of the total magnetization intensity.

POISSON ANALYSIS

Poisson's theorem:

$$U(x,\ y)=\frac{1}{4\pi}\ \frac{\Delta J}{\gamma\Delta\varrho}\ \frac{\partial V(x,\ y)}{\partial t} \tag{1}$$

is a useful tool (Cordell and Taylor, 1971) for a combined study of magnetic and gravity anomalies.

In eqn. (1), U and V are respectively the magnetic and gravity potential; ΔJ is the magnetization contrast, $\Delta\varrho$ is the density contrast, γ is the gravitational constant, and t indicates the direction of the total magnetization vector.

The theorem is valid for the directional derivatives of the two potentials, i.e., even for the gravity and magnetic field components taken along the same direction. For example, taking the vertical direction, we consider the magnetic field reduced to pole ($\mathrm{AT}_{\mathrm{pole}}$) and the vertical derivative of the gravity field G:

$$\Delta T\ (x,\ y)_{pole}=\frac{1}{4\pi}\ \frac{\Delta J}{\gamma\Delta\varrho}\ \frac{\partial}{\partial z}G\ (x,\ y). \tag{2}$$

Obviously, the theorem is only applicable when the gravity and magnetic sources can be reasonably considered as having the same shape and volume, and if the density and magnetization contrast are constant.

When these circumstances are only partially fulfilled, a new definition of Poisson's theorem can be used (Chandler et al., 1981):

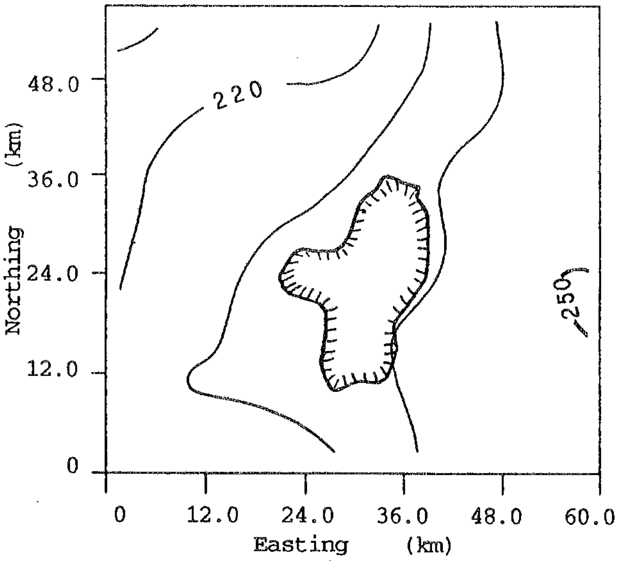

Fig. 2 — Bouguer anomalies in the area of the Magnaghi seamount (contour interval: 10 mGal).

$$U\,(x,\,y)=\frac{1}{4\pi\gamma}\,S\,(x,\,y)\,\frac{\partial V\,(x,\,y)}{\partial t}+A\,(x,\,y), \tag{3}$$

where the intercept A (x, y) and the Poisson ratio S (x, y) given by

$$S\,(x,\,y)=\frac{\Delta J\,(x,\,y)}{\Delta \varrho\,(x,\,y)}$$

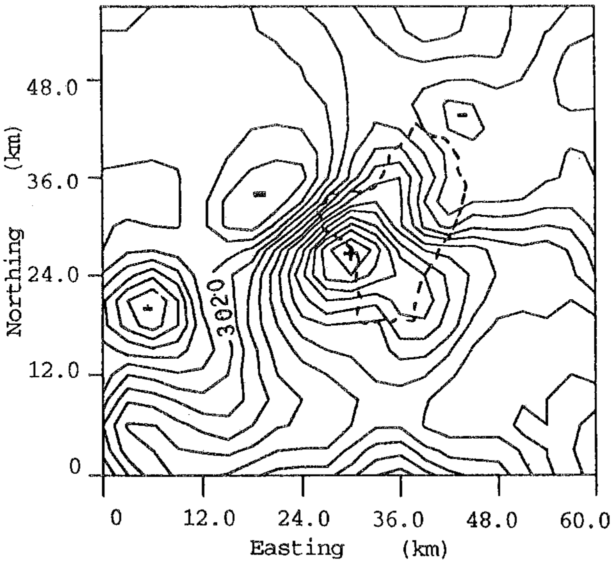

Fig. 3 — Total magnetic field in the area of the Magnaghi seamount (contour range from 2900 to 3220, int. 15).

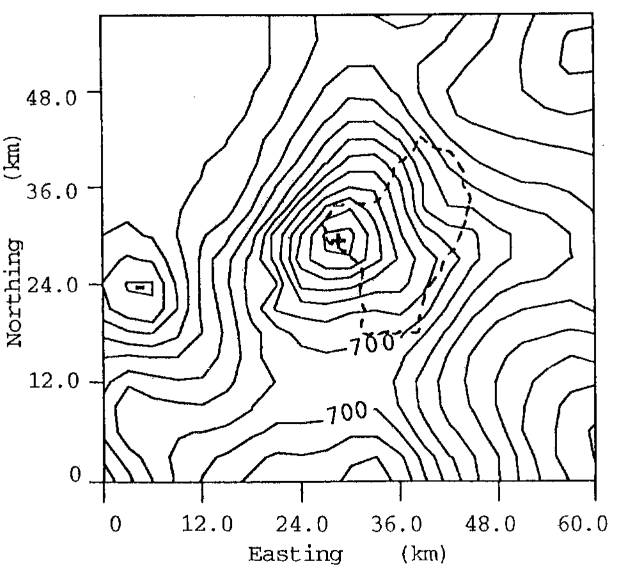

Fig. 4 — Pseudo gravimetric anomalies in the area of the Magnaghi seamount (contour range from 300 to 1000, int. 50). The direction of the total magnetization vector used to perform this transformation of the magnetic data is declination=—50°; inclination=56°.

account for extra-source effects, and for local variations in density and magnetization contrasts. By considering a moving window over the data set, a linear regression analysis is done for each position of the window, from which the stability of S and A can be checked. Poisson's theorem is obviously satisfied only in the region where A and S are approximately constant.

Using Poisson's theorem in the form of eqn. (2), we can correlate the vertical derivative of the gravity field and the magnetic field reduced to the pole. However, by performing the Poisson analysis with eqn. (3), the smoother anomalies can be better compared, because the reduction of the noise and the very local effects gives a more stable response. Thus, we will use pseudo-gravity anomalies (Fedi, 1989) and Poisson's theorem in the form:

$$U_{P.G.}(x, y)= \frac{1}{4\pi\gamma} S(x, y)\, G(x, y)+A(x, y), \tag{4}$$

where $U_{P.G.}$ is the pseudo-gravity field.

Poisson's theorem has been successfully used to study the gravity (free-air) and magnetic fields of sea-mounts (Cordell and Taylor, 1971). This is due to the fact that the majority of the anomaly effects, for both free-air and magnetic anomalies, can be related to the shape of the seamount. Thus, if density and magnetization are constant, eqn. (2) can be used to evaluate the Poisson ratio very precisely.

However, if density and magnetization vary, i.e., if there are anomaly sources in the volcano itself, we should use eqn. (4) and statistically identify the areas of stable A and S, i.e., the regions where Poisson's theorem can be applied.

THE AVERAGE MAGNETIZATION CONTRAST OF THE MAGNAGHI SEAMOUNT

It is easy to observe that the Poisson analysis is very relevant when one of ΔJ or $\Delta\varrho$ is known, either from direct or indirect estimation.

As we have seen, by simply comparing the free-air and the Bouguer anomalies of Magnaghi,

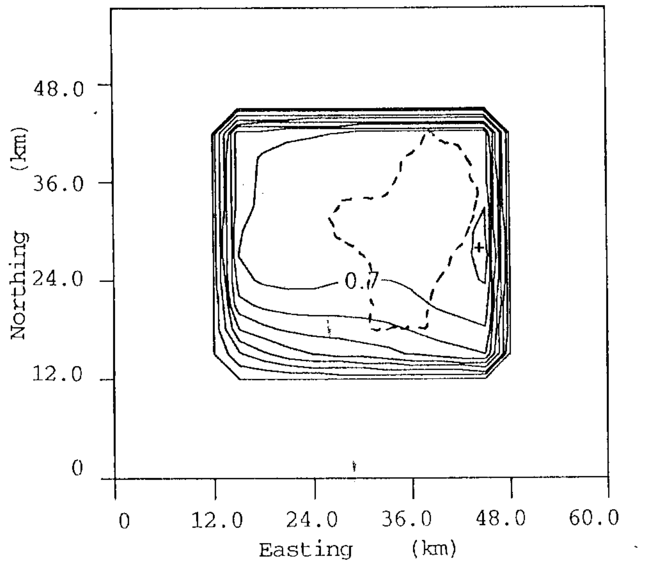

Fig. 5 — Map of the correlation (contour range from 0 to 0.9, int. 0.1).

we can deduce that the free-air gravity effect is well accounted for by a constant density distribution of about 2.7 g/cm^3. On the other hand, the imperfect correlation between the magnetic anomaly and the Magnaghi topography seems to indicate that a very complex magnetization distribution characterizes the source.

In order to use Poisson's theorem in the form of eqn. (4), we need to make a linear transformation from magnetic to pseudo-gravimetric anomalies. To this end the direction of both induced field and total magnetization must be known. While the former can be easily inferred from the I. G. R. F. model, the last, in the case of the Magnaghi seamount, can only be estimated in a indirect way by using the technique indicated by Fedi and Rapolla (1988), from which we get:

$$D_t=-50°;\ D_f=0°,\ I_t=I_f=56°,$$

where the index $_f$ indicates the induced field direction. The estimated total magnetization direction suggests that the remanent magnetization must play a significant role in the rock magnetization. In fact, by means of a relation between induced and total magnetization vectors (Cordell and Taylor, 1971), a quite high value (0.44) can be computed for the minimum Koenigsberger ratio, i.e., for the minimum of the possible ratio between remanent and induced magnetization intensities compatible with the above directions.

The Magnaghi pseudo-gravity anomaly spreads widely over the volcano's area. Moreover, this anomaly is not centered on the volcano, but on its western prominence. So, even in this pseudo-gravimetric form, the magnetic data do not seem to correlate perfectly with the volcanic structure.

The moving-window Poisson analysis (eqn. (4)) was done on the free-air gravity anomaly (upward continued to the same altitude as the magnetic data, i.e., 1.463 km) and the pseudo-gravity anomalies. The window used was a square with side length of 11 points (33 km). This dimension was a good compromise between the need to have both statistically meaningful and precise results. The three maps in Figs. 5, 6 and 7 show the results of the Poisson's analysis.

The first is a map of the correlation between the two data sets. In the area of Magnaghi S.mt, the correlation shows values greater than +0.7. This correlation value is not very large,

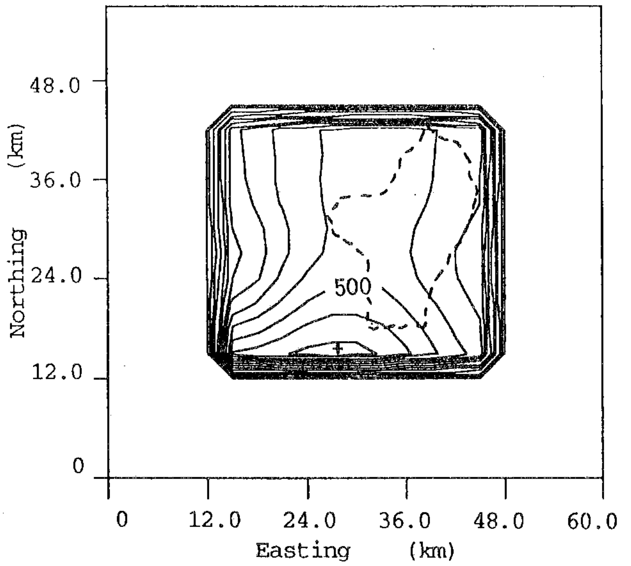

Fig. 6 — Map of the intercept (contour range from 0 to 700, int. 50).

but it is sufficient to make the analysis consistent.

The values of the intercept show that in the area of the volcano there is a relatively stable zone, thus respecting the applicability conditions of the Poisson analysis.

The last map concerns the Poisson ratio. The average value in the Magnaghi area is about 0.85×10^{-3}. By assigning a density of about 2.7 g/cm^3 as a realistic value for this volcano, a density contrast with respect to sea water of about 1.7 g/cm^3 results. The corresponding magnetization contrast is about 1.45 A/m. It is important to note that even if we consider a density contrast significantly different (i.e. 1.5 or 1.8 g/cm^3) a very stable magnetization

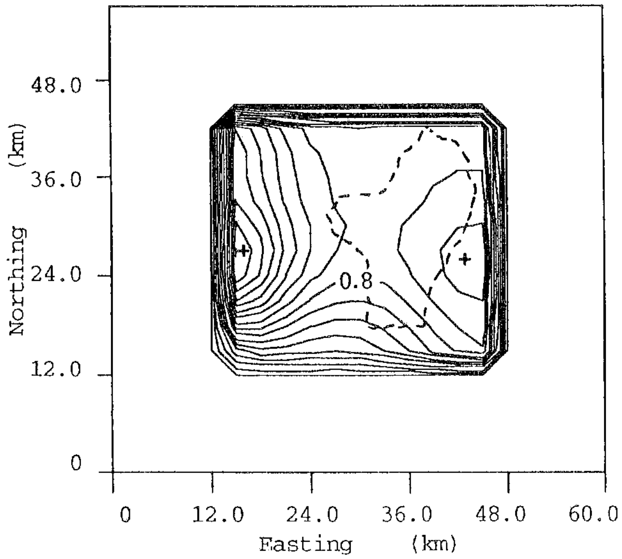

Fig. 7 — Map of the Poisson's ratio (×1000 S.I.; contour range from 0 to 1.6, int. 0.1).

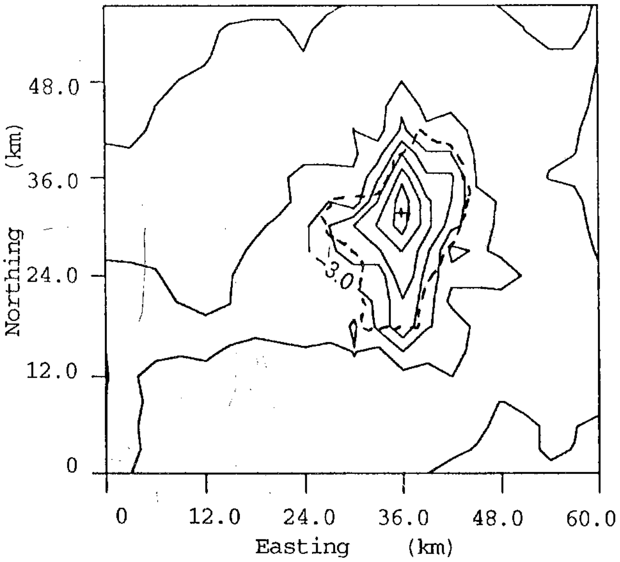

Fig. 8 — Gravimetric bathymetry as computed by the 3D inverse method (contour range from —1.5 to —3.5, int. 0.3).

contrast results (respectively about 1.3 and 1.5 A/m).

3D INVERSION OF MAGNETIC AND GRAVITY ANOMALIES IN THE MAGNAGHI REGION

We have already discussed, from a qualitative point of view, the fact that both magnetic and free-air gravity anomalies are probably, at least partially, caused by the topographic effect of the Magnaghi seamount itself.

In order to quantitatively test this hypothesis, we can estimate the depth of the sources

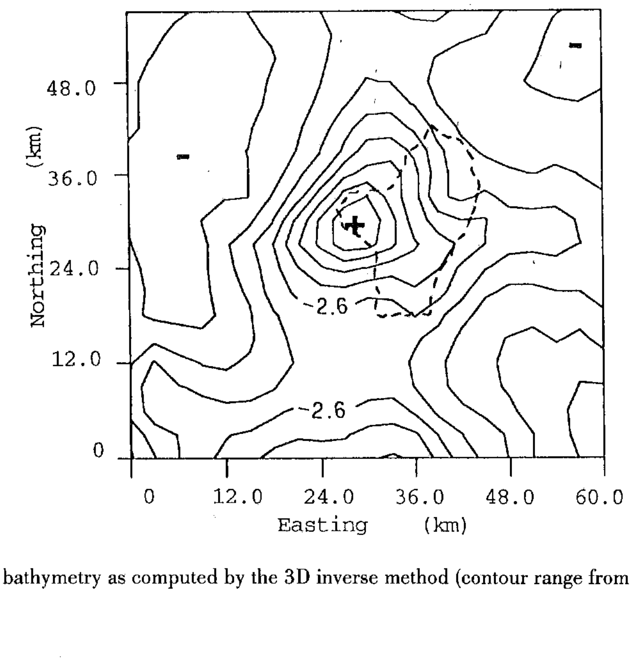

Fig. 9 — Magnetic bathymetry as computed by the 3D inverse method (contour range from —1.6 to 3.5, int. 0.2).

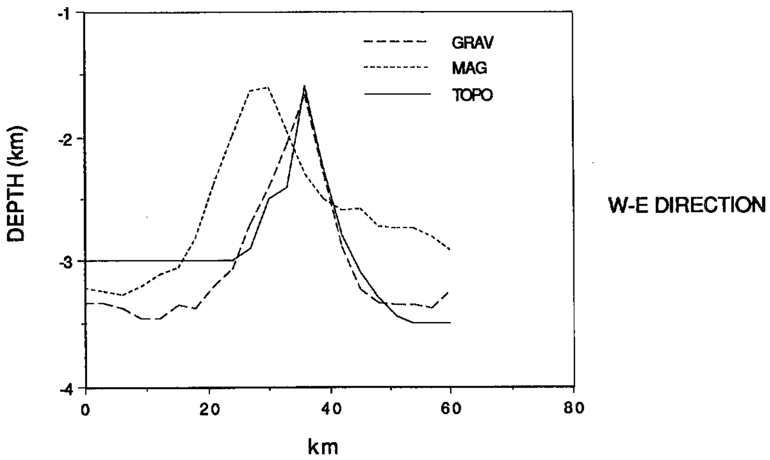

Fig. 10 — W-E gravity, magnetic and true topography profiles passing through volcano top.

of the two anomalies and compare them to the actual bathymetric depths of the volcano. For brevity, we will refer to such depths as "gravity bathymetry" and "magnetic bathymetric", respectively.

To this end, we inverted the two fields assuming as constraints the two bathymetric limits of the seamount, i.e., about 1.5 and 3.5 km (below sea level) respectively. Constant density and magnetization were also assumed. A 3D method of inversion recently proposed by Fedi (1993) was used.

The so obtained gravity and magnetic bathymetries (Figs. 8, 9) indicate a very good correlation between the gravity bathymetry and the actual one, while the magnetic case appears more complex. This is clearer in Fig. 10, where the various bathymetries are compared along the W-E direction. In the gravity case, we observe a perfect matching, except for the westernmost border of the volcano, where the gravity estimate is lower. Since a constant density was assumed, the above result confirms that the seamount is a uniformly dense structure. The mismatch at the western border is probably due to the presence of sediments which cause a lateral variation in density. This is in agreement with the current geodynamic models of the Thyrrenian Sea region, for which the western parts of the Tyrrhenian Sea have an older age than the eastern.

On the other hand, in the magnetic case, we note that the hypothesis of constant magnetization is not verified at all. Lateral magnetization variation appears as important as vertical. Even if more constraints are thus needed, we can conclude that the western prominence appears the more magnetized part of the volcano.

CONCLUSIONS

When magnetic and gravity anomalies of a given common source are correlated and the density is approximately known, a Poisson analysis can be used to infer the average value of the magnetization in some areas. A constrained inversion can also be useful to test the hypothesis that the density or the magnetization intensity are uniformly distributed in the source, the constraints being the bathymetric depths of the source. We attempted such a study for the Magnaghi seamount (Thyrrenian Sea). The constrained inversion indicated that the free-air gravity is almost entirely due to the topographic effect of the seamount, with a uniform density distribution of about 2.7 g/cm^3. A different result arises for the magnetic anomalies, whose inversion reveals great complexity in the distribution of the magnetization intensity. In particular, the western prominence of the volcano appears more magnetic than the rest.

The above complexity is responsible for some of the difficulties in estimating the average magnetization intensity of the volcano from a Poisson analysis. In fact, the imperfect correlation between gravity and magnetic anomalies (about 0.7) results in an only approximate evaluation of the parameter, i.e., less than 2 A/m.

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