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2D gravity modelling along the CROP11 seismic profile

M.M. TIBERTI[1] and L. ORLANDO[2]

[1] *Istituto Nazionale di Geofisica e Vulcanologia, Roma, Italy*
[2] *Dipartimento di Idraulica, Trasporti e Strade, Università "La Sapienza", Roma, Italy*

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ABSTRACT The purpose of this work is to present a gravity reconstruction of the deepest portion of the CROP 11 seismic line. The 2D gravity modelling is constrained by DSS data and by deep reflection seismic data obtained along the CROP 11 line. The role of the regional gravity anomaly trend of Central Italy as an independent constraint for the geological interpretation of the seismic line is also highlighted. The main gravity low (Fucino Plain) in the area is compensated by the combined effect of a regional deepening of both the Moho and the top of the crystalline basement, while the gravity low, located east towards the Maiella Mt., seems to originate between a 4 and 10 km depth. A lower density can be assigned to the western portion of the mantle with respect to the eastern side. The westernmost part of the upper crust in the model also shows a slightly lower density. The crystalline basement is not likely to be heavily involved in the deformation of the chain; ramp-and-flat deformations are present down to a depth of 20 km, i.e. the "highly reflective body" on the western side of the profile, which does not have a marked gravity imprint and should be due to relatively "light" sedimentary units.

1. Introduction

This work aims at discussing and refining the work-in-progress interpretation of the CROP11 seismic profile by specifically constraining the structural setting of this area with gravity data properly processed for this purpose.

The applied methodology consists in a 2D trial-and-error forward gravity modelling of the deep structures, based on the regional component of the gravity anomaly. This anomaly has been obtained removing surficial gravity anomalies from Bouguer anomalies, over central-southern Italy (Bernabini *et al.*, 2002; Tiberti *et al.*, 2005) by means of the "stripping off" technique. With this technique the effects of the surficial structures, that heavily affect the Bouguer anomaly trend, were removed, as a consequence of their complex geometry (see Hammer, 1963; Bernabini *et al.*, 2000; Orlando and Bernabini, 2003). Data sources are fully described in Tiberti *et al.* (2005).

The gravity modelling is constrained by DSS data [Cassinis *et al.*, (2003), and references therein] and by deep reflection seismic data obtained along the CROP 11 line (Parotto *et al.*, 2004).

A previous 2D gravity model, along the trace of the CROP 11 (Bernabini *et al.*, 1996b), was realized before the seismic data acquisition, when only geological and DSS data were available. Given these constraints, the most conservative solution suggested the presence of a "light" portion of the upper mantle on the western side of the profile; moreover, the gravity low observed in the middle of the section was correlated to a crust wedge plunging into the mantle.

Now new 3D gravity (regional data) and seismic (CROP 11 partial interpretation) constraints allowed us to realize a more refined 2D model.

2. Central Apennines geological setting

The Apennine Chain is a fold-and-thrust belt with associated foredeep/thrust-top basin sedimentation [e.g. Patacca *et al.*, (1990); Cipollari and Cosentino, (1995), and references therein].

In particular, the central Apennines (Fig. 1) consist mainly of the superposition of tectonic units derived from pelagic basins (Ligurides, Sicilides, Tuscan, Umbria-Marche, Molise) and carbonate platforms (Laziale-Abruzzese and Apulia Platforms). From the Tortonian to Pliocene time span these units thrust toward the foreland represented by the Apulia Platform [Butler *et al.*, (2004) and references therein], which lies on the Triassic formation known as Anidriti di Burano.

Siliciclastic foredeep and thrust-top-basin sediments were deposited from the Tortonian to the Early Pleistocene [among others: Patacca *et al.*, (1990), Cipollari and Cosentino, (1995)]. The most recent foredeep consists of Plio-Pleistocene deposits lying upon the buried Apulia Platform and partially overlain by the external thrust front [Mostardini and Merlini, (1986), Patacca *et al.*, (1990), Casnedi, (1991), and references therein].

Plio-Pleistocene extensional basins developed along the Tyrrhenian side after the Tyrrhenian opening [starting from Late Tortonian: Patacca *et al.*, (1990), and references therein], whereas Quaternary extensional basins affected the core of the central Apennines (Cavinato and De Celles, 1999). Moreover, after Pliocene, the Tyrrhenian margin of central Italy was affected by magmatic effusions (Peccerillo, 2003).

The available geological data give a precise picture of the shallowest upper crust; on the other hand, there are not enough data on the deep structure of the chain to define the deformation style [thin-skinned or thick-skinned; see Butler *et al.*, (2004)].

3. Geophysical constraints

3.1. Seismic constraints

The deep seismic data available for this area are the CROP11 profile (Parotto *et al.*, 2004) and the DSS (Deep Seismic Soundings) data, interpreted by Cassinis *et al.* (2003), who focuses on the main velocity discontinuities.

The Latina-Pescara profile [Cassinis *et al.*, (2003) and references therein] suggests the presence of two distinct crust-mantle discontinuities: the Moho of the Peri-Tyrrhenian thinned crust, and the Moho of the Afro-Adriatic plate. For the sake of simplicity, we will respectively refer to them as Tyrrhenian and Adriatic Moho. The Tyrrhenian Moho is located at a depth of about 25 km and gently dips to the east, while the Adriatic Moho is located at a depth of about 30-32 km and characterised by a slightly convex shape. How these two segments of the Moho are related is still a matter of debate. The lack of information is localised in correspon-

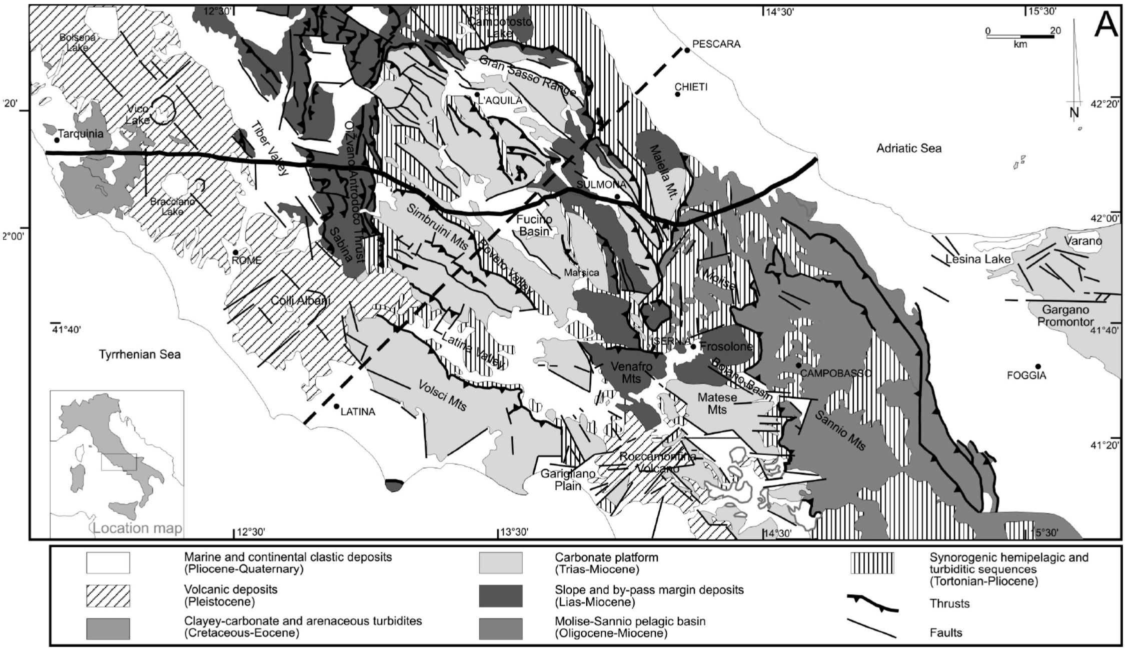

Fig. 1 - Geological sketch-map of Central Apennines with the trace of the CROP 11 seismic profile (solid line) and of the DSS profile Latina-Pescara (dashed line).

dence of the core of the chain.

The CROP 11 crosses the central Apennines from Marina di Tarquinia (W) to Vasto (E). Its work-in-progress interpretation (Parotto *et al.*, 2004) has so far shown the structure of the shallowest portion of the crust between the Fucino plain and the Adriatic coast (Fig. 2).

The stratigraphy of the Adriatic foreland consists mainly of ~6 km of a Meso-Cenozoic carbonate succession (Apulia Platform) overlain by ~2 km of Plio-Pleistocene foredeep deposits. A succession correlated to the Permo-Triassic terrigenous deposits drilled by Puglia 1 and Gargano 1 wells lies at the bottom of the Apulia Platform. The top of the underlying crystalline basement is detected at a depth of about 12 km. The base of the lower crust is likely located at 31 km, a depth consistent with the results of DSS seismic investigation.

The backbone of the Apennine belt in the eastern part of the CROP11 seismic lines consists of a first-order duplex structure involving both the Apulian carbonates and the Permo-Triassic terrigenous deposits. The main detachment level of the Apennine chain seems to be the base of the Permo-Triassic terrigenous deposits.

Both the top of the crystalline basement and the Moho discontinuity were suggested to progressively deepen westward, to a depth of about 50 km (Parotto *et al.*, 2004).

The westernmost part of the seismic line is characterised by the presence of a highly reflective duplex structure recognized beneath the Simbruini Mts. at a depth ranging from 10 to more than 20 km in the area where the transition between the Tyrrhenian Moho and the Adriatic one is reported by DSS data interpretation to occur.

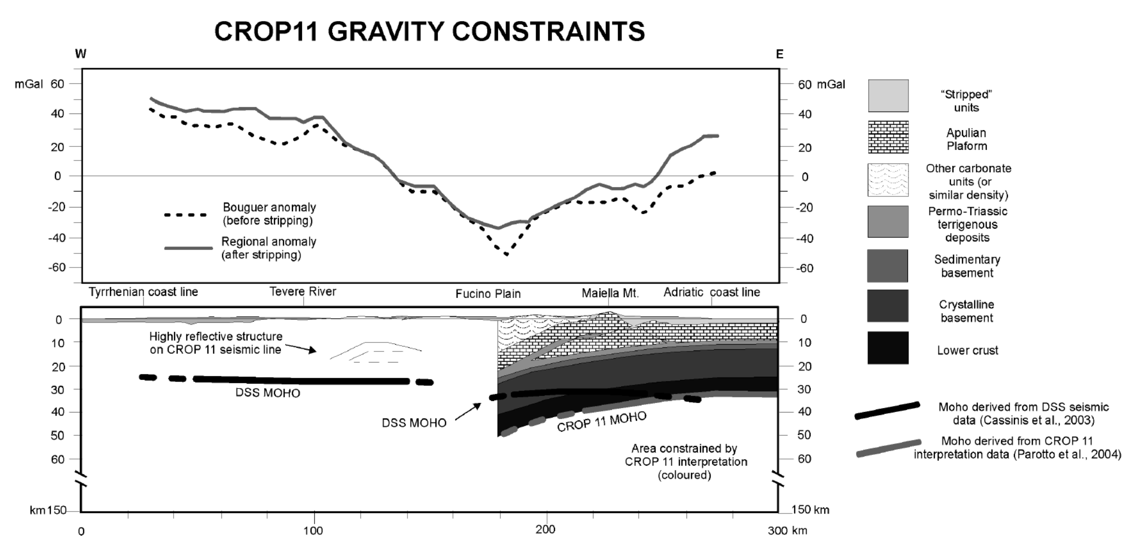

Fig. 2 – On the top, Bouguer Anomaly (dashed line) and stripped data (solid line). On the bottom, principal seismic constraints for the 2D model along CROP 11.

3.2. Gravity data

The gravity data interpretation is based on the deep-sourced gravity anomaly map obtained by the stripping procedure and starting from the Bouguer anomalies (Bernabini *et al.*, 2002; Tiberti *et al.*, 2005). The stripping consists in computing and subtracting the gravity effect of all the surficial bodies whose geometry and density are known in sufficient detail and has been done on the base of a 3D lithological model of the surficial Apennine units (Bernabini *et al.*, 1996a, 2000).

Such a map allows the individualization of the principal gravity patterns of the deep crust in central-southern Italy, which indicate marked differences between the anomalies of the central and southern Apennines, suggesting a lack of cylindrism for the deep structures of the whole Apennine chain. In the central Apennines a regional gravity low is quite evident, suggesting the presence of crustal sources below the bodies considered in the stripping. Moreover, the stripped data revealed that the regional gravity lows are shifted westward in comparison with the Bouguer data [see profiles in Tiberti *et al.*, (2005)].

Regional gravity anomaly values were picked up along a regional cross-section (Fig. 2) coincident with a rectified trace along CROP11. A comparison between the anomaly trends before and after the stripping along this section highlights some significant differences.

As the backbone of the chain along CROP11 is mainly made up of carbonate rocks, the differences between the regional gravity trend and the Bouguer anomaly trend are located mainly on the Tyrrhenian and Adriatic coast areas.

The stripped data revealed that the source of most of the gravity lows in the Bouguer anomalies of the study area is located in the upper portion of the crust, at a depth not exceeding 6-8km. In particular, along the Marche-Abruzzo coastal area the Bouguer low originates from the thick cover (more than 5km) of Plio-Quaternary deposits that fill the Adriatic foredeep.

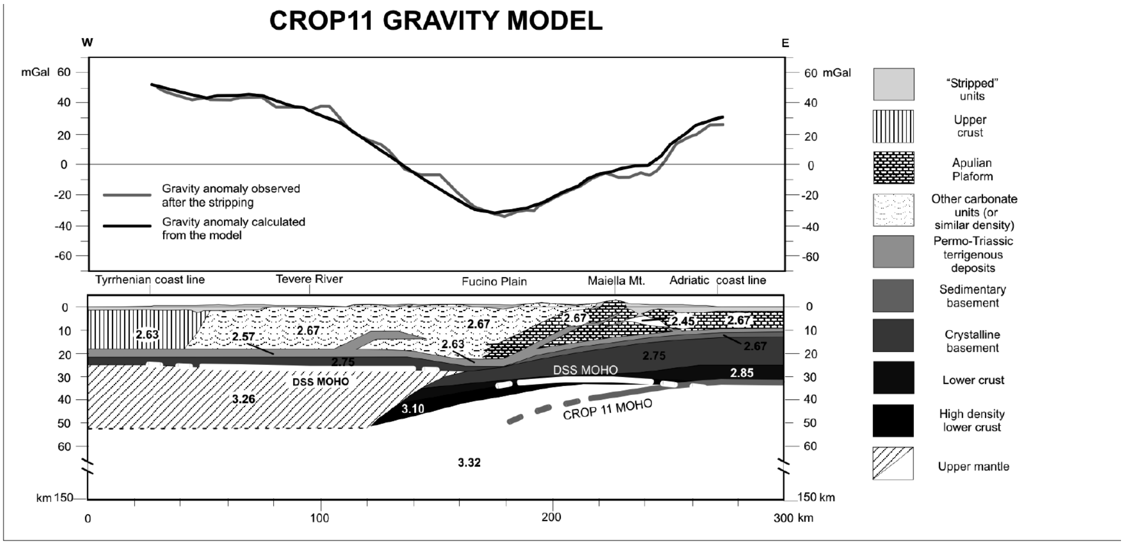

Fig. 3 – On the top theoretical (black line) and actual data (grey line) of 2D gravity model along CROP 11 profile. Density values are expressed in g/cm^3. On the bottom, the gravity distribution which produces the minimum gap between the two curves, given the main seismic constraints (where possible). These last are also highlighted (white and grey lines).

4. 2D gravity model along the CROP11 profile

The 2D gravity modelling was carried out to a depth of 150 km by means of a software based on the algorithm of Won and Bevis (1987) and on the method of Talwani *et al.* (1959).

The model takes into account constraints provided by seismic data and the deep-sourced gravity anomalies only (continuous line in Fig. 2), as the 3D effect of the surficial bodies have already been stripped off.

Density values have been assigned to the non-investigated portion of the crust and the upper mantle according to literature data (e.g., Pasquale *et al.*, 1997; Gualteri and Zappone, 1998) and then the density distribution was progressively changed by means of a trial-and-error procedure in order to reach the best fit between the observed gravity and the calculated gravity.

The lower part of Fig. 2 shows the seismic constraints available for the gravity model.

Note the discrepancy between the position of the Moho detected by DSS investigations and the position of the Moho inferred from a proposed interpretation of the CROP 11 seismic line (Parotto *et al.*, 2004).

Fig. 3 shows the best fitting gravity model. As the gravity problem has a non-unique solution, the most conservative has been chosen.

Given the main constraints, the best fit between calculated anomalies and the observed ones is obtained by assigning a slightly lower density to the western portion of the crust and mantle [where high values of heat flow are observed; Della Vedova *et al.*, (2001)]. About the shape of this mantle wedge, the most conservative solution implies a simplified flat geometry for the bottom of the wedge at 50 or more kilometres depth.

On the western side of the profile, the seismic reflectors are arranged in a duplex structure (“highly reflective body”), which constitutes the most evident and also intriguing feature of the entire seismic line. The “highly reflective body” does not have a marked gravity imprint and should be due to relatively “light” sedimentary units.

The gravity low located east, towards the Maiella Mt., given its relatively short wavelength, seems to originate between 4 and 10 km depth, but no such body (white in the figure) is known there, except for the Apulian Basin hypothesised by Mostardini and Merlini (1986). Part of the anomaly can be compensated by shifting downwards (about 2 km) the top of the Apulia Platform, as shown.

Finally, the gravity low in the Fucino area can be compensated with the combined effect of a regional deepening of both the main density (and velocity) discontinuities (such as the Moho and the top of the crystalline basement). The crust wedge below the Apennines shows an increasing density to a depth of 50 km. This agrees with the density distribution calculated in the thermal models of Goffé *et al.* (2003). Nevertheless, the Moho depth provided by the CROP11 seismic data (Parotto *et al.*, 2004) seems to be excessive, unless the lower crust is given the same density as that assigned to the mantle. Even the deepening of the crystalline basement top seems to be too steep. Below 50 km, no density contrast is expected. At greater depths (100-150 km), density contrast of about ±0.1 g/cm^3 is possible without a significant effect on the gravity trend and so they are never detected.

5. Discussion

The present 2D gravity model substantially confirms the general outline of the previous known model (Bernabini *et al.*, 1996b). Density values of the upper mantle, smaller on the western side of the profile, and a crust wedge plunging into the mantle are recognized into both models. However, the new model attempts to solve the discrepancy between the position of the Moho detected by the DSS experiments and the position of the Moho from the proposed interpretation of the CROP11 seismic line by Parotto *et al.* (2004). The latter seems to be too deep, even if an increasing density for the crust wedge (while the previous model considered a constant density) is considered. The increase of density is reliable according to Goffé *et al.* (2003). On the contrary, the geometry of the Moho suggested by the interpretation of the DSS profile seems to be too flat to compensate the gravity low.

The present study on the CROP 11 profile confirms that the crystalline basement is not likely to be heavily involved in the deformation of the chain in the eastern portion of the profile. In the westernmost part of the seismic line, small density contrast and poor resolution of the seismic line did not allow a precise definition of structures at present. Ramp-and-flat deformations are present to a depth of 20 km with relatively low densities, which have been assigned to sedimentary or slightly metamorphosed units.

Finally, as far as it concerns the shallowest portion of the crust, the gravity model suggests revising the depth of the top of the Apulian carbonates in the area east of the Maiella Mt., and to carefully check the geometry of the thrust structures. In fact, the gravity low observed there could be ascribed to the presence of a widely extended body of terrigenous deposits near the top of the Apulian platform.

6. Conclusions

The 2D gravity model carried out along the CROP11 profile allows us to focus on some characteristics of the area.

A lower density can be assigned to the western portion of the mantle with respect to the eastern side. The westernmost part of the upper crust in the model also shows a slightly lower density.

The gravity low in the central part of the profile can be compensated with the combined effect of a regional deepening of both the main density (and velocity) discontinuities (such as the Moho and the top of the crystalline basement). The depth of the Moho figured out considering also the gravity constraints results in an intermediate position between the one derived from the CROP11 seismic line and the one detected by DSS experiments.

The crystalline basement is not likely to be heavily involved in the deformation of the chain in the eastern portion of the profile.

Summing up, the gravity model provides constraints on the density of the crust and the upper mantle in the peri-Tyrrhenian region and suggests the need for a careful check on the depth of the Moho in the central part of the profile.

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Corresponding author: Mara M. Tiberti
Istituto Nazionale di Geofisica e Vulcanologia
Sezione di Sismologia e Tettonofisica
Via di Vigna Murata 605, 00143 Roma, Italy
phone: ++39 06 51860443; fax: ++39 06 5041181; e-mail: tiberti@ingv.it