

## Structural setting of the Trieste area from gravity modelling

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**ABSTRACT** An extensive onshore gravity survey, with a nominal density of 1 station/km<sup>2</sup> comprehending 177 stations, has been carried out to improve the existing low-resolution data set in the area surrounding Trieste (Italy). The survey has been processed and the Bouguer anomaly computed over the entire area and then interpreted. The Bouguer anomalies show a negative gravity trend going from south to north probably associated with the regional direction of the main geological structures. According the gravity model computed along six profiles, the regional gravity trend and the minimum negative Bouguer anomaly are related to folding phenomena of the flysch units in the Panzano Gulf and thrusting of limestones over flysch rocks along a fault that outcrops in the “Costa dei Barbari” and runs near the coast southwards. Intraformational deformation cannot be excluded and should be taken into consideration to explain the increase of thickness of flysch northwards.

### 1. Introduction

The structural setting of an area is usually investigated through geological surveys by field work and mapping. This approach gives just a picture of the near-surface geologic units and structures. Sometimes the deeper crustal setting can be extrapolated if the deformation is well known and spatially restricted. In deformed terrains geology needs to retrieve information from geophysical surveys that can indirectly sample and draw pictures (ie. from deep seismic reflection and refraction surveys) of the deep crust. Then, seismic sections 2D and 3D gravity modelling, among many, are coupled with geology to better constraint the geologic structure and evolution of an area.

Even if the geological literature of the area surrounding the Gulf of Trieste (Fig. 1) is comprehensive of a lot of field work, the known geophysical data are restricted to some few offshore seismic surveys that are quite outdated (Finetti, 1967; Morelli and Mosetti, 1968). To get round this lack of geophysical data a new gravity survey has been undertaken and the new measurements have been merged with the few and sparse pre-existing gravity data. The Bouguer anomalies were then analysed through a forward inversion model along six profiles taking into account the local geological data (D’Ambrosi, 1961, 1976; Carulli and Carobene, 1981; Placer, 1981; Carulli and Cucchi, 1991) as a constraint. This research has been part of the PRIN 2002 project “Analysis and interpretation of crustal deformation through high resolution spatial and/or temporal observational methods”.

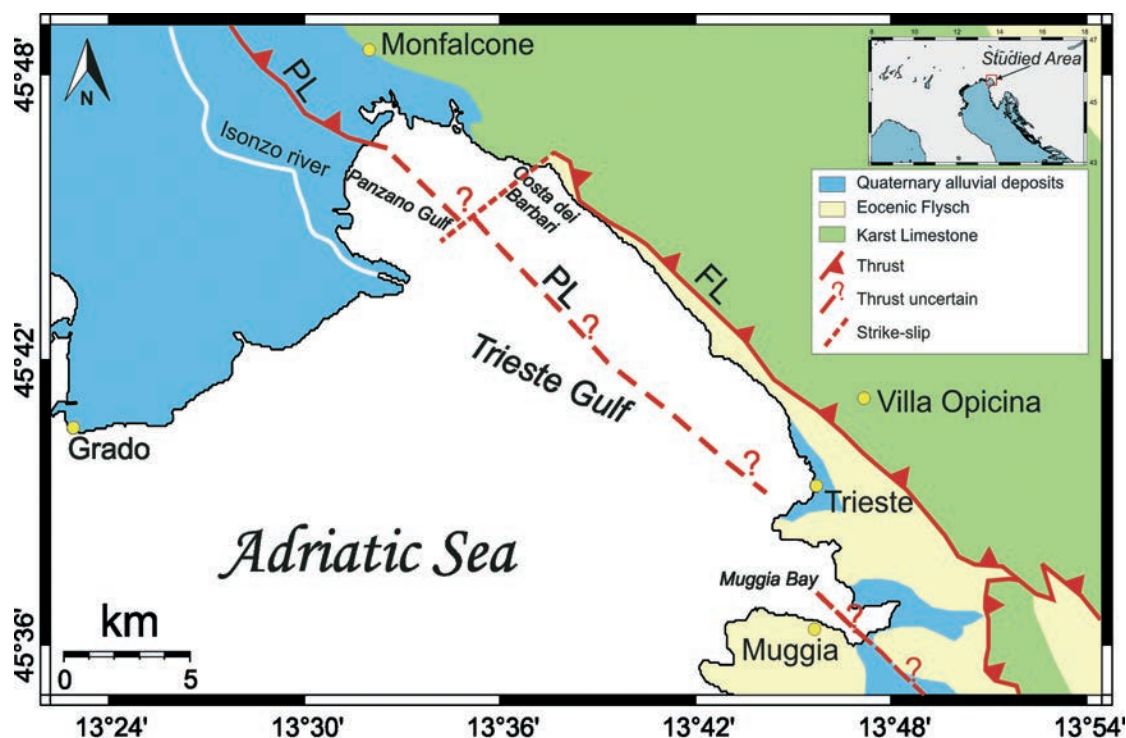


Fig. 1 - Location map and geo-structural map of the Gulf of Trieste area (modified from Carulli and Cucchi, 1991). PL = Palmanova Line; FL = Flysch-Limestone Line

## 2. Geological setting

The deformation that took place in the Eastern Alps and Dinarides deeply affect this area. From the Late Jurassic-Early Cretaceous some of the basins that formed the Mesogea started to closed. The carbonate platform that accreted during the rifting phase was disrupted and involved in the deformation of the Dinarides (Mauritsch *et al.*, 1995). Later, between the Paleocene and the Eocene a new compressive push was coupled with the making of a deep flexural basin. Flysch sediments from the near Dinarides filled this basin and formed the so-called Dinaric foredeep. At the end of the Eocene the deformation shifted to the west of the Dinaric orogenic building and affected the portion of the Dinaric foredeep and the flysch units previously undeformed. The Karst anticline started to rise in the Oligocene. The Gulf of Trieste lowered towards NE while the Karst Units overthrust the Flysch Units along NW-SE structures.

At present, the Gulf of Trieste area is characterized by three main units (Fig. 1): 1) Cretaceous-Paleocene Karst Limestone; 2) Eocene Flysch; 3) Quaternary alluvial deposits. The whole structure is an anticline with a Dinaric NW-SE axis trend. The contact between Flysch and Karst Limestone Units is rarely stratigraphic. Only in a few small and isolated zones is there a vertical continuity between the units. In fact, deformation affects the Gulf of Trieste and it is possible to outline two main tectonic lineaments (Fig. 1)(Carulli and Carobene, 1981; Placer, 1981; Carulli

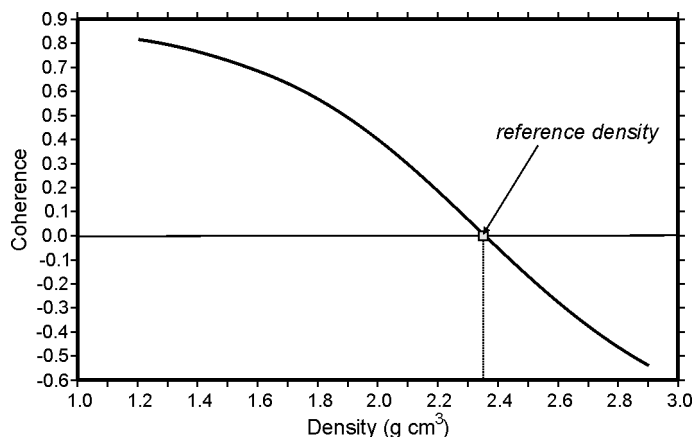


Fig. 2 - Nettleton method. The coherence between the measured gravity anomaly and the observed topography is calculated as a function of different possible reduced densities. The best density for the gravity data set is around  $2350 \text{ kg/m}^3$ .

and Cucchi, 1991): 1) the Palmanova Line (PL); 2) the Flysch-Limestone line (FL). The PL cross-cuts the Gulf of Panzano which could be linked to the faults that outcrop in the Bay of Muggia (Carulli and Cucchi, 1991) to the south. Drilling holes on the two sides of the PL, in the northern portion, out of the studied area, shows that to the west the stratigraphy is characterized by 190 m of alluvial sediments and then flysch while to the eastern, at the same depth, there are limestones. There is no clear evidence that PL crosses the whole Gulf of Trieste offshore. It has been interpreted as one of the normal faults of a hypothetical graben structure according to an outdated seismic survey (Finetti, 1967). Clearly, this interpretation is not corrected since the whole area has been affected by compression since the Paleocene-Eocene. The PL should deform only Flysch Units and this southern prosecution could be interrupted by left-lateral strike slip faults (Carulli and Cucchi, 1991). FL outcrops near the coast (Costa dei Barbari) and is a low-angle, with a Dinaric trend, reverse fault where the Karst Limestone overthrusts the Flysch Units. Onland evidence of this fault is masked by vegetation, anthropization and some small likely left lateral NE-SW faults that break the southern continuity of the FL (Carulli and Cucchi, 1991).

Nowadays the area is stable and active deformation is restricted to the easternmost sector of the Dinarides.

### 3. Gravity survey

The field work was conducted in the period between June and October 2002. 177 gravity stations, spatially distributed with a nominal density of 1 station/ $\text{km}^2$ , were measured in the Trieste area. The gravity data were collected using a LaCoste-Romberg mod D-018 gravimeter provided by a feedback to avoid the periodic errors due to the gear system. Each gravity station was chosen, based on a regional technical map of 1:10000, on points of known altitude.

In the surveyed area a first order gravity net was established and linked to the absolute gravity station located at the "Osservatorio Astronomico di Basovizza". Every gravity loop followed the

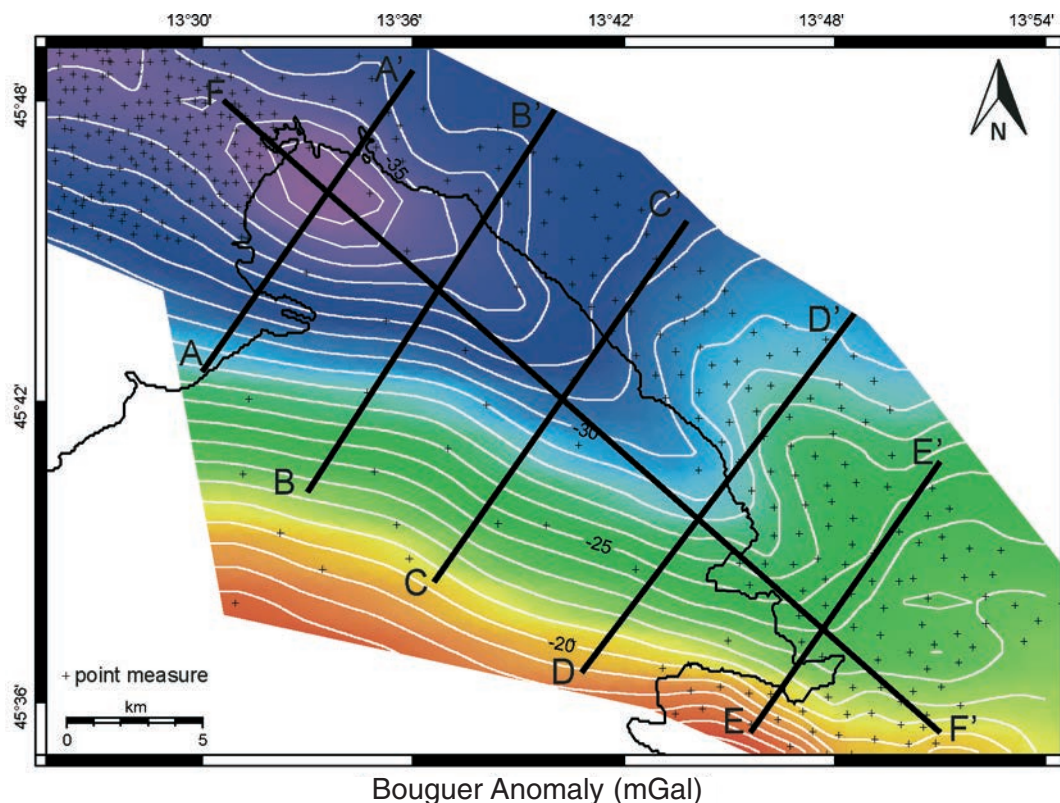


Fig. 3 - Bouguer anomaly map of the studied area with the location of the surveyed points and the traces of the profiles that have been modelled.

scheme A,b,c,d,...,F, A where A and F are points belonging to the first order gravity net and b, c..., are the detailed gravity stations. In this way, it was possible to verify the instrumental drift, that shows a range between  $\pm 0.002$  mGal/h, and the loops error closure, that spans from -0.003 to 0.006 mGal.

Standard Bouguer corrections (La Fehr, 1991) were applied to the field measurements: the Bouguer correction was calculated considering the Bullard A and B terms (Bullard, 1936) and the Banerjee-Das Gupta (1977) algorithm was used for the terrain corrections (Bullard C term). For the inner-zone topography, from 0.020 to 0.250 km, a Digital Terrain Model (DTM), provided by the Regione Friuli-Venezia Giulia, with a grid space of 0.040 km was utilized; for the outer-zone topography, from 0.250 to 167 km, the national DTM, with a grid space of 10" in longitude and 7.5" in latitude, was used. According to the results of the Nettleton method (Fig. 2) a density of  $2350 \text{ kg/m}^3$  was chosen. To get a wider spatial coverage the existing gravity data (Costa, 1983; Prodan, 2002) was re-processed with the same reduction procedures: so several data sets have been merged in order obtain the gravity anomaly map that is presented in Fig. 3.

### 3.1. Gravity anomalies

The gravity anomaly map depicts a NW-SE trend according to the direction of the Dinaric

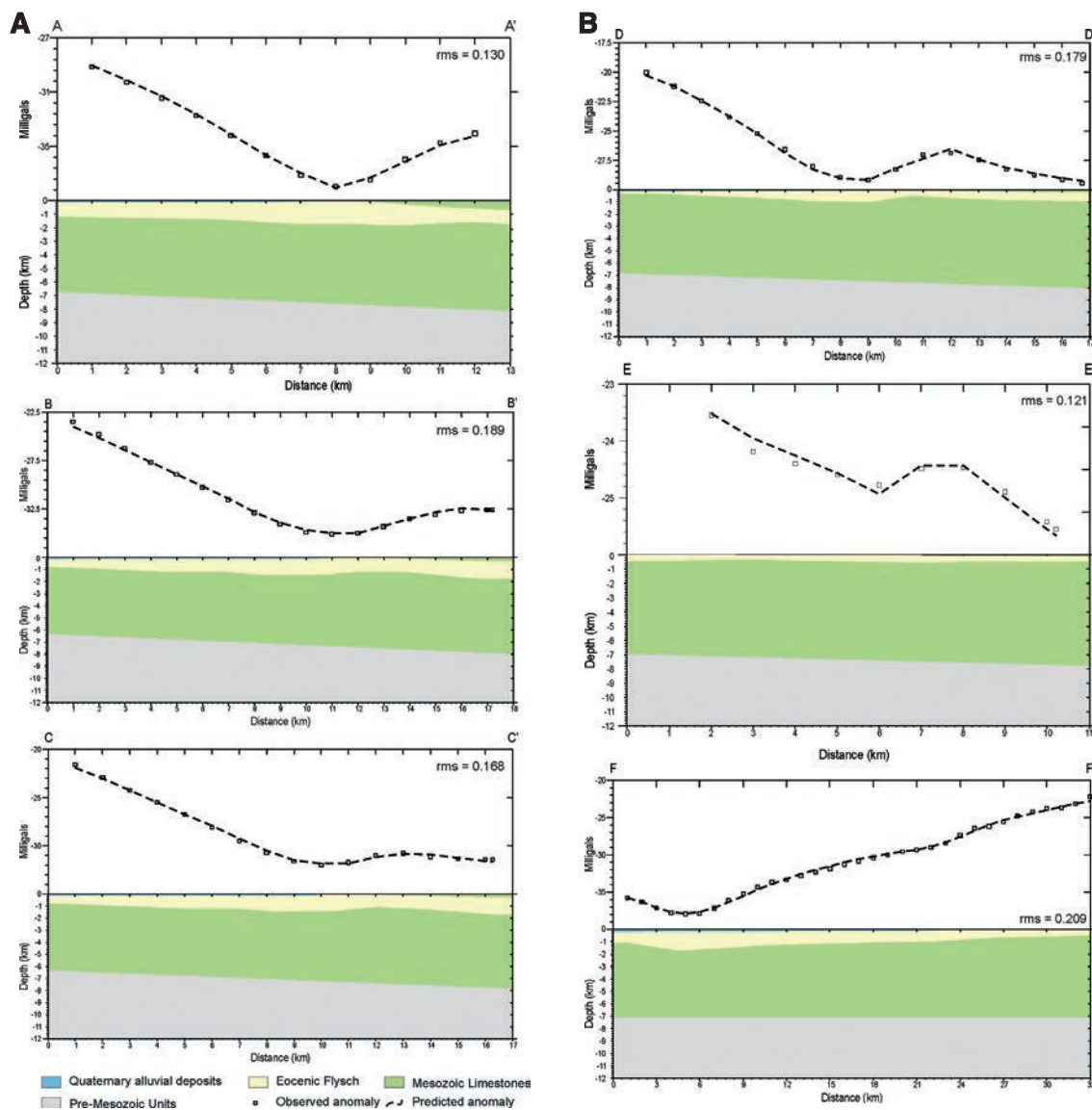


Fig. 4 - Modelled profiles. Trace of the sections is reported in Fig. 3.

structures that characterize the area (Fig. 3). A striking feature is the negative gravity trend from south to north that clearly reflects the Dinaric tectonic phases that took place in the past and formed synclines, anticlines and thrusts. In fact, the localized negative gravity anomaly near the mouth of the Isonzo River should be ascribed to a downward flexure whose axis has a Dinaric direction (NNW-SSE) while the rise of the anomaly toward Istria and the Adriatic Sea should instead reflect the small deep of the “basement” in that area.



#### 4. Gravity modelling

The gravity anomalies have been interpreted using a forward inversion method through the analysis of five profiles with a SW-NE trend and one nearly perpendicular to them with a NW-SE trend (Figs. 3a and 4). According to the previous geophysical studies, quite outdated (Finetti, 1967; Morelli and Mosetti, 1968), the Quaternary Units and the Flysch Units have a thickness of 200-250 m and 1000 m respectively. The depth of the “basement” can be estimated only through considerations on the magnetic survey (Cati *et al.*, 1987). The “basement” should be around 6.5 km deep near Grado and increases its depth towards E-SE.

The densities of the rocks have been adopted according to the seismic velocity recorded by Finetti (1967) and to the velocity-density regression parameter of Christensen and Mooney (1995). The gravity model is composed of a maximum of four layers: “basement”, limestone, flysch and alluvial deposits of density 3000 kg/m<sup>3</sup>, 2670 kg/m<sup>3</sup>, 2400 kg/m<sup>3</sup>, and 1900 kg/m<sup>3</sup>, respectively.

The highest negative anomaly seems to be associated to a folding of the Flysch Units that is clearly evident in sections A-A' and E-E' (Fig. 4). We cannot exclude that this increase in the flysch thickness could be due to the deformation carried on by the PL. The Flysch Units reach a thickness of 1500 m and gently decrease southwards due to a rise of the limestone and “basement”. The FL is clearly evident in the modelled profiles as a low-angle thrust fault that lets the limestones overlap flysch. The overthrusting of the Karst Units over the Flysch one has the effect of driving a rise of the gravity anomaly. We are not able to calculate the amount of offset along the fault. The “basement” is at the depth of around 6.5 km to the north and in the Adriatic Sea and deepens inland, eastwards.

#### 5. Conclusions

The Gulf of Trieste zone is characterized by an elongated negative gravity trend that reflects both the overthrusting of the Flysch Units over the Karst Limestone Units and the offshore folding of the Flysch Units. The gravity field modelling indicates that the area is dominated by a gentle folding of the flysch units near the coast. The folding phenomenon reaches its maximum near the Gulf of Panzano and decreases southwards. The FL appears as a flat low angle thrust whose gravity signature decreases from north to south as the contact between limestone and flysch shallows. We cannot exclude that some deformation of the flysch (folding and thickening) was due to the activity of the PL in the proximity of the Gulf of Panzano. Since this structure deforms only the Flysch Units there is no density contrast that can be traced in the gravity field. This survey cannot resolve the geometry of the faults neither their prosecution in the basement. PL, FL and left lateral strike-slip faults should be the distal and outermost portion of the bigger eastern thrust system that deforms the whole Dinarides complex.

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