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## Bouguer gravity field of the Tuscan Archipelago (central Italy)

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### ABSTRACT

In this paper, we present a new Bouguer gravity map of the Northern Tuscan offshore (central Italy), based on original gravity data acquired on the islands of the Tuscan Archipelago. Our dataset integrates 274 unpublished gravity field measurements with 126 available marine gravity data of the northern Tyrrhenian Sea. The Bouguer anomaly map shows a westward and southward increase of the regional gravity field associated with the uplift of the Moho boundary from central Apennines towards the Tyrrhenian Sea. At a local scale, several Bouguer anomalies are well associated with the igneous plutons of the Elba, Montecristo and Capraia islands, as a result of a deep density contrast between the granitoid intrusive rocks and the embedding metamorphic basement. The presented Bouguer anomaly map represents a useful tool for future studies of the complex geological and geodynamical setting of the Tuscan Archipelago and of the buried and deep igneous structures.

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Tuscan Archipelago; Bouguer gravity map; magmatic intrusion; Tyrrhenian Sea

## 1. Introduction

The Tuscan Archipelago is located in the northern part of the Tyrrhenian Sea. Its geology derives from several geodynamic events, associated to the genesis of the Alps-Apennines orogenic system and of the Tyrrhenian Basin, that led to the formation of the intrusive and extrusive igneous products of the Tuscan magmatic province (e.g. Peccerillo, 2017). In this paper, we aim at contributing to the knowledge of this complex volcanic region by studying the relationship between the main geological features of the archipelago and the Bouguer gravity field.

In the last decades, gravity field surveys were carried out in continental Italy and its adjacent areas to produce gravity maps of the whole Italian territory (e.g. Carrozzo et al., 1981; Cassano, 1983; Makris, Morelli, & Zanolta, 1998; Morelli, 1970). In the Tuscan region, the geothermal setting and crustal deformation rate have been obtained from a joint gravity, seismic and petrological analysis (e.g. Accaino, Nicolich, & Tinivella, 2006; Della Vedova, Vecellio, Bellani, & Tinivella, 2008; Geri, Marson, Rossi, & Toro, 1982, 1985; Orlando, 2005).

In this paper, we give the first detailed study of the gravity field of the islands of the Tuscan Archipelago. More specifically, we aim at presenting the Bouguer gravity map obtained from an unpublished dataset of 274 gravity measurements collected on the Tuscan Archipelago islands between 1972 and 1974 and 126 marine gravity data (Ciani, Gantar, & Morelli, 1960).

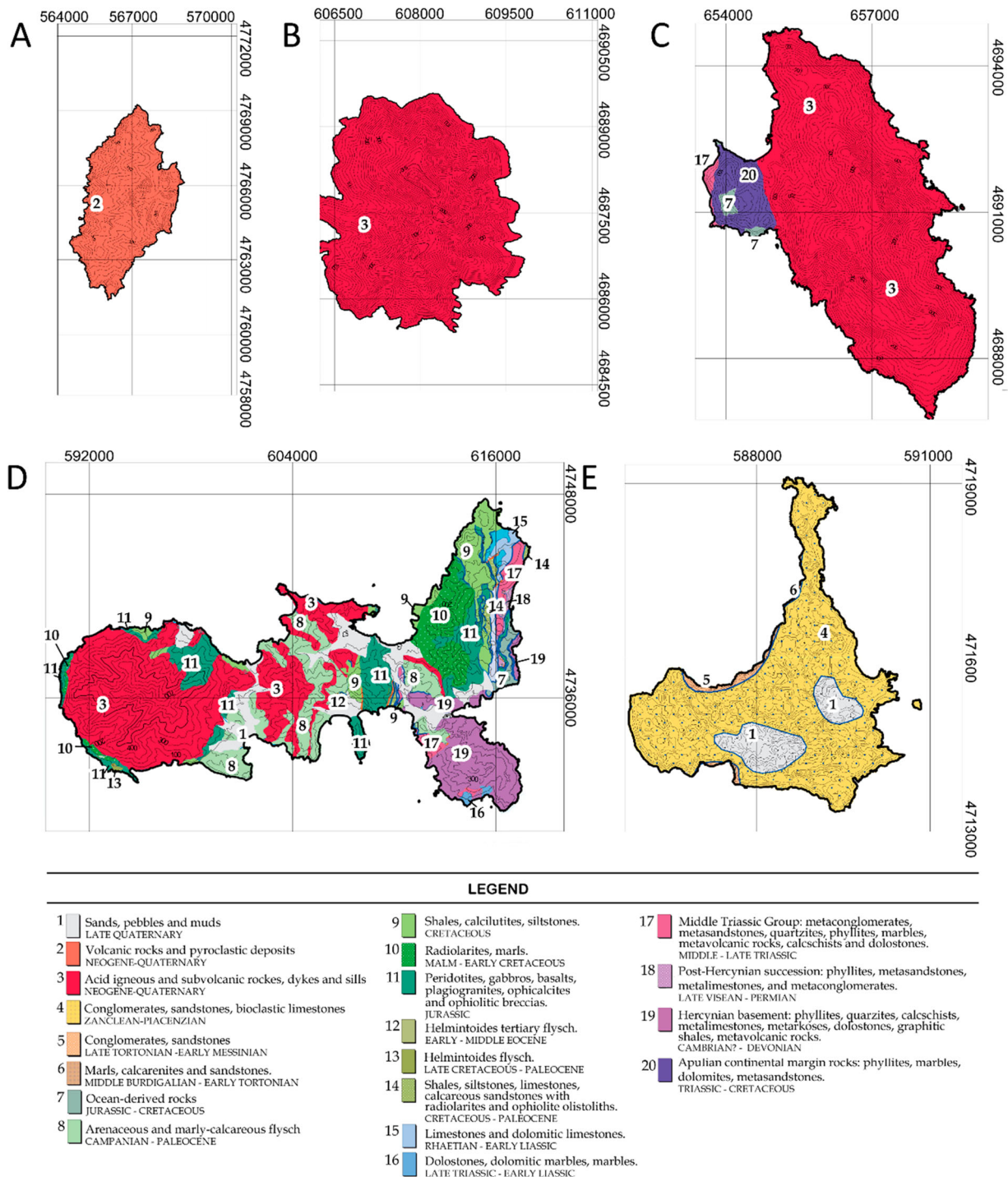
## 2. Geological setting

The geological and structural setting of the Tuscan Archipelago is associated to the complex geodynamical evolution of the Italian peninsula, which is the result of many geodynamical events spanning from Neogene to Quaternary, including the Apennines orogeny and the genesis of the Tyrrhenian Sea (e.g. Malinverno & Ryan, 1986; Rosenbaum & Lister, 2004). The archipelago consists of seven main islands mostly formed of acid plutonic and volcanic rocks produced by the Cenozoic volcanic activity developed during the convergence between Europe and Africa (e.g. Peccerillo, 2017; Serri, Innocenti, & Manetti, 1993; Wilson & Bianchini, 1999) (Figure 1). Several petrological and geochemical analysis were carried out in the Tuscan magmatic province in the last decades (e.g. Boccaletti, Gianelli, & Sani, 1997; Dini, Gianelli, Puxeddu, & Ruggieri, 2005; Poli, 1992), which provided detailed information about the main facies and composition on the igneous rocks, ranging from granodioritic to alkali-granitic. Seismic surveys have been also fundamental in the interpretation and imaging of the tectonic structures as well as for establishing the depth extent of the large magmatic intrusions within the northern Tyrrhenian Sea (e.g. Finetti et al., 2001; Mauffret, Contrucci, & Brunet, 1999).

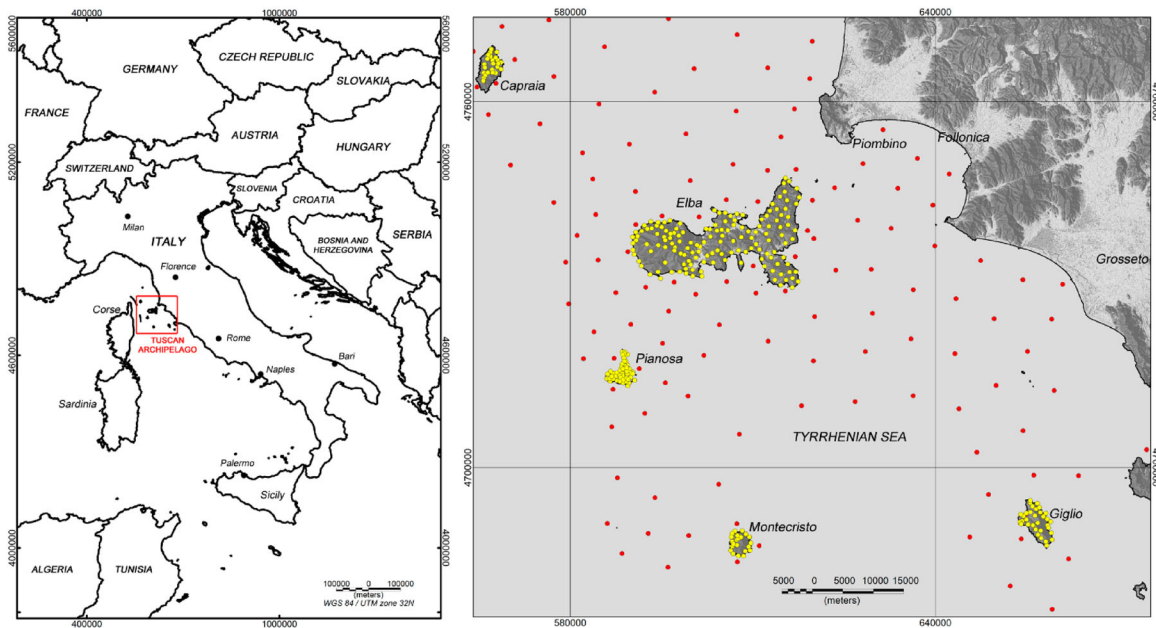
Elba is the main island of the Tuscan Archipelago, located between Corsica and Tuscany. It is considered as an extension of the Northern Apennines and the link

with the ‘Alpine’ Corsica (Bortolotti, Pandeli, & Principi, 2001). The complex structural framework of Elba (Figure 2(D)) divides the island into three main areas. The eastern side mainly formed of metamorphic rocks such as metavolcanic rocks, metaconglomerates, peridotites, gabbros, basalts, plagiogranites and ophiolitic breccias (Rocchi, Westerman, Dini, & Farina, 2010). The central part of the island is constituted by an igneous sequence of laccolith layers developed over a time-range of 1 Ma during Late Miocene (Rocchi, Westerman, Dini, Innocenti, & Tonarini, 2002). The western area is mostly characterized by monzogranitic plutonic complex

of Monte Capanne associated to the second magmatic cycle of around 7 Ma (Bortolotti et al., 2001; Carmignani, Conti, Cornamusini, & Pirro, 2013; Rocchi et al., 2010). Pluton similar to those of Monte Capanne crop up on the Montecristo Island (Figure 2(B)), located 40 km south of Elba, where those intrusions were placed inside a pile of Mesozoic ophiolite and argillaceous sedimentary rocks (Rocchi, Westerman, & Innocenti, 2003). Intrusive materials of the same volcanic activity are also found in the Giglio Island (Figure 2(C)) classified as the Giglio Monzogranite Intrusion and Scole Monzogranite Intrusion (Westerman, Innocenti, & Rocchi, 2003). A large



**Figure 1.** Geological maps of the Tuscan Archipelago islands: (A) Capraia; (B) Montecristo; (C) Giglio; (D) Elba; (E) Pianosa. Redrawn from Carmignani et al. (2013).



**Figure 2.** Location map of the study area (left); Map of the position of the land gravity stations (yellow dots) and submarine gravity stations (red dots) of the Tuscan Archipelago region (right).

part of the areal extent of Giglio is underlain by granitic rocks, while metamorphic rocks and ocean-derived rocks characterize the westernmost part of the island (Carmignani et al., 2013; Westerman et al., 2003).

The Capraia Island (Figure 2(A)), located about 30 km NW of Elba, is mostly constituted of two volcanic series erupted during two events (Messinian 6.9–6 Ma and Pliocene 3.7–3.5 Ma (e.g. Serri, 1997; Serri et al., 1993)) that, according to Gasparon, Rosenbaum, Wijbrans, and Manetti (2009), can be classified: series-1 representing the bulk of Capraia formed of high-K dacites to high-K andesitic and subvolcanic latites (Barberi et al., 1986), and series-2, representing high-K andesitic to rhyolitic products of the central-eastern area. Pianosa Island, situated about 11 km SW of the Elba Island (Figure 2(E)), is, instead, constituted of Middle Pliocene–Lower Pleistocene sedimentary rocks forming the so-called Pianosa Formation (Aldighieri, Gropelli, Norini, & Testa, 2004; Graciotti, Pantaloni, & Foresi, 2008) made of conglomerates, sandstones and bioclastic limestones.

### 3. Materials and method

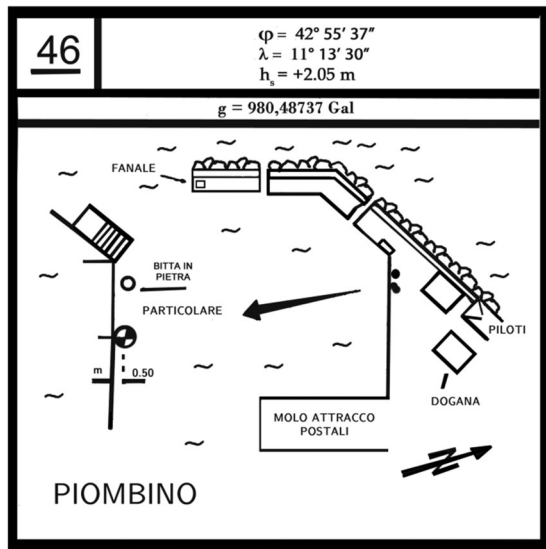
The Bouguer gravity field map of the Tuscan Archipelago has been produced by merging two different datasets of land and marine gravity measurements:

- *Onshore gravity data:* Between 1972 and 1974 gravity surveys were carried out on the main islands of the Tuscan Archipelago by University Federico II of Naples (Prof. Vito Bonasia), using a Worden gravity meter, mod. Prospector n. 606, collecting a total amount of 274 data. The elevations of the

measurements were obtained using a 1:10000 aerophotogrammetry map with 1 m contour-line. The gravity field anomalies were calculated with respect to the absolute value of 980487.37 mGal at the reference station of Piombino (Ciani et al., 1960, Figure 3).

- *Offshore gravity data:* In the region of the Tuscan Archipelago, 126 submarine measurements have been integrated with the onshore gravity dataset described in the previous section, to provide a more complete coverage to the gravity field map of the whole area. These data are part of a large data set collected between 1953 and 1960 by the CNR (Consiglio Nazionale delle Ricerche) and the ‘Osservatorio Geodetico di Trieste’ on behalf of the Italian Geodetic Commission, to provide a regular gravity survey of the Italian offshore (Ciani et al., 1960). The dataset consists of 3135 measurements with an average data density of around 1 station/100 km<sup>2</sup>, measured at a maximum depth of 222 m below the Adriatic Sea and 207 m in our area of study, using a Western remotely controlled gravity meter. The measurement precision can be considered around  $\pm 0.05$  mGal close to the coast or in short circuits, and around  $\pm 0.2/0.3$  mGal in long circuits or with rough sea (for more details see Ciani et al., 1960)

The free-air gravity reduction has been firstly applied to both land and submarine dataset using the Faye correction, always negative for submarine data, which is obtained by multiplying the altitude by the vertical gradient of the gravity field at latitude 42° (Monte Mario reference coordinate system), that is  $\delta g/\delta z = 0.30857$  mGal/m.



**Figure 3.** Sketch map of the Piombino reference station (V. Bonasia, personal communication. Redrawn).

The Bouguer correction  $B_{g\perp}$  is computed using the following formula for land data:

$$B_{g\perp} = 2\pi k d h_s \quad (1)$$

where  $h_s$  is the altitude of the station point;  $k = 6.67 \times 10^{-11} \text{ m}^3 \text{ kg}^{-1} \text{ s}^{-2}$  (gravitational constant);  $d$  is the density of the slab (in  $\text{g/cm}^3$ ).

For submarine measurements, the formula becomes:

$$B_{g\perp m} = -2\pi k (1.026 + d) h_s \quad (2)$$

where  $h_s$  is negative and 1.026 is the density of seawater (in  $\text{g/cm}^3$ ).

The standard density value ( $d$ ) of the Bouguer slab correction can be assumed, for the Italian peninsula, as  $2.4 \text{ g/cm}^3$  (Carrozzo et al., 1981) or, according to the standard processing methodology in APAT Geophysical Service (Moritz, 1980), as  $2.67 \text{ g/cm}^3$ . In the present study, we decided to use  $2.67 \text{ g/cm}^3$ , being it better in accordance with the average density values of the outcropping Tuscan Archipelago lithological units, spanning from granitic to monzogranitic in Elba, Montecristo and Giglio islands and from latitic to rhyolitic in Capraia.

Then, the terrain correction was also applied, by means of the Hayford-Bowie chart (e.g. Sandberg, 1959), out to 28.8 km ( $L$ -zone) from the point station, with the same density value used for the Bouguer correction. Therefore, the total Bouguer anomaly field (BA) is obtained by the following formula:

$$BA = G_o - (G_T + FA) - (B + T) \quad (3)$$

where  $G_o$  is the observed gravity;  $G_T$  is the theoretical gravity; FA is the free-air reduction;  $B$  is the Bouguer slab correction and  $T$  is the Terrain correction.

Finally, we merged the two gravity data sets and also produced a unique complete Bouguer anomaly map of

the Tuscan Archipelago. The reference coordinate system was transformed from the Monte Mario coordinate system to the UTM projection (zone 32N) with WGS84 datum. The grid map has been produced using the Grid-Knit<sup>TM</sup> package of the Geosoft Oasis-Montaj tool, to obtain a  $111 \times 98 \text{ km}$  map with the average step size of 1293 m, that is the average point distance estimated by the software using the default formula:

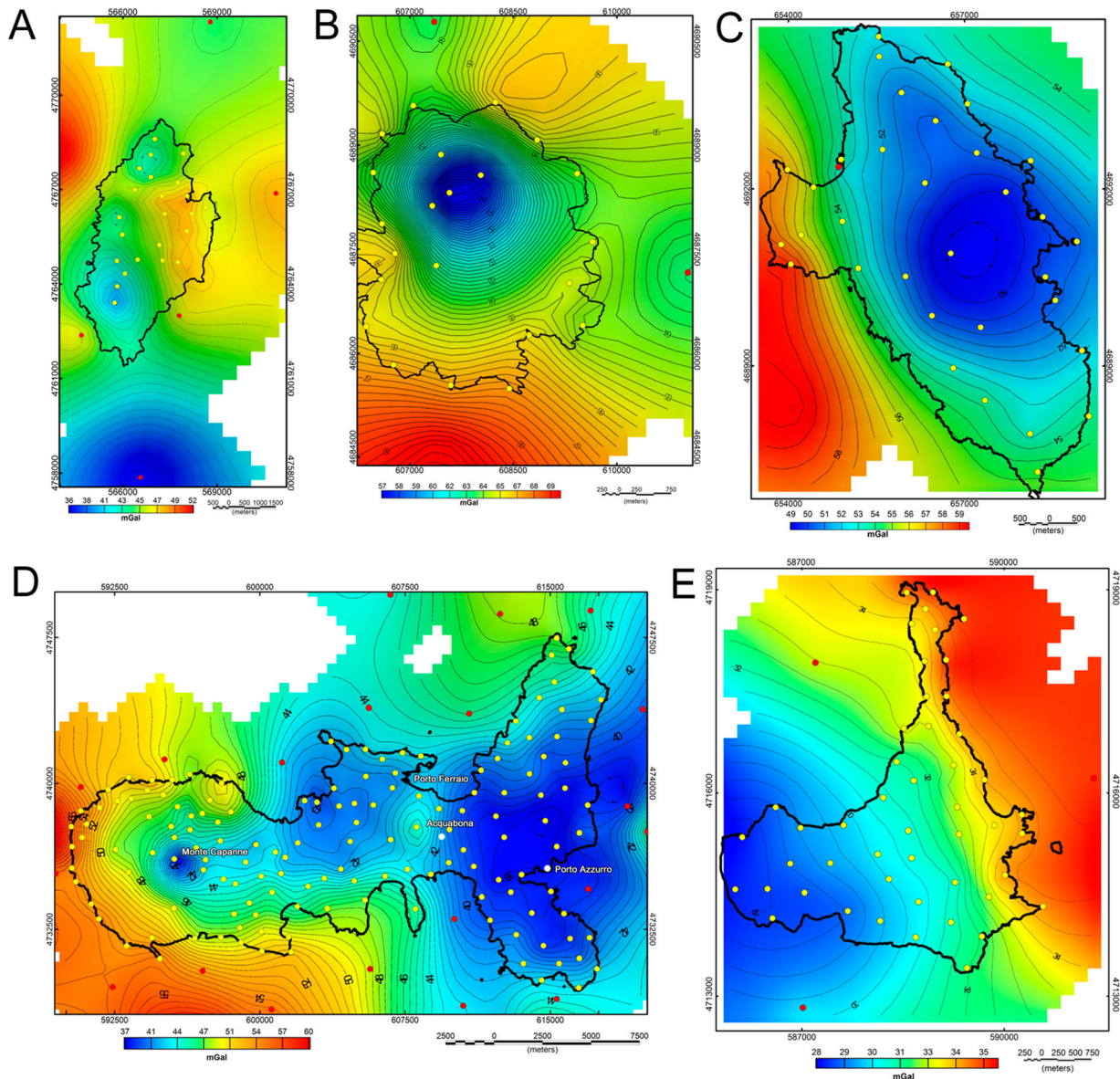
$$\text{stp} = \frac{1}{4} \sqrt{\frac{\text{grid area}}{\text{number of data}}} \quad (4)$$

#### 4. Results

The resulting Bouguer gravity map of the Tuscan Archipelago shows values ranging between 20 and 76 mGal with a broad trend of maxima in the central part and lower gravity values toward W–SW. Despite the not uniform data coverage in the area and the gap in short-wavelength signal, it is possible, however, to observe a good correlation between the main anomaly patterns and the complex geological setting.

Figure 4 shows the map of the Bouguer gravity field of the Tuscan Archipelago islands. We will provide now a qualitative description of the main Bouguer anomalies basing on their correlation with the shallow outcropping geology of the area. According to Morelli (1960), most of the positive anomalies can be interpreted with a high-density crystalline-metamorphic basement at shallow depth representing the root of the Elba Island and of the whole Tuscan Archipelago. We observe a general increase of the gravity field in this area, with respect to the onshore Tuscan and Corse domains, as well as an increase southward. These features can be associated to the significant decrease of the crustal thickness, with the Moho reaching a depth of about 20 km in this area and of about 10 km in the central Tyrrhenian Sea, as documented from seismic and seismological data (e.g. Di Stefano, Bianchi, Ciaccio, Carrara, & Kissling, 2011; Mauffret et al., 1999).

The main anomalies observed in the map of the Elba gravity field (Figure 4(D)), where 147 onshore measurements and 19 marine data well cover the whole area, are gravity lows located above the structures of Monte Capanne, in the western area, and above Porto Azzurro, on the eastern area. Both these structures are probably associated to post-orogenic Tertiary intrusions (Marinelli, 1959; Trevisan, 1951). In the western part of Elba island, we notice a ‘C’ shaped gravity high in correspondence to the coast (see the Main map), correlated with narrow outcrops of peridotites along the shoreline, and a central gravity low correlated to the acid intrusion. Thus, our interpretation is that the Tertiary acid intrusion has a negative density contrast with the peridotites and



**Figure 4.** Bouguer gravity maps of the Tuscan Archipelago islands: (A) Capraia; (B) Montecristo; (C) Giglio; (D) Elba; (E) Pianosa. Land and submarine gravity stations are shown, respectively, with yellow and red dots.

other basement units (see Table 1), which we assume are present in the offshore and at depth. High-density rocks (peridotites) outcrop in the eastern side of the island only along narrow belts, whereas the most diffuse units outcropping in this area exhibit lower densities. Examples of these units are sedimentary rocks (units 8, 9, 14, 15 – see legend in Figure 3) or metasedimentary rocks (units 17, 18, 19 – see legend in Figure 3). This could explain the presence of gravity lows in the eastern part of the island. The central part of the Elba island exhibits a gravity low corresponding to acid igneous rocks (unit 3 – see legend in Figure 3), while in central-eastern part of the island (near Acquabona) a gravity high is well correlated to a large outcrop of peridotites (unit 11 – see legend in Figure 3).

The Bouguer anomaly map of Montecristo, shown in Figure 4(B), is characterized by a low detail due to the limited number of gravity stations caused by the impossibility of reaching areas of the island

characterized by a too steep topography. Therefore, the dataset is composed of 21 land measurements and 3 marine data close to the Montecristo coast. As said before, the Montecristo island is made by a granitoid intrusion very similar to that of Monte Capanne and Porto Azzurro on Elba Island (Rocchi et al., 2003). According to this similar geology, as in the case of Elba Island also the Montecristo gravity field presents a relative low of 57 mGal, largely extended on the central-northern part of the island. We interpret the gravity low as due to the density contrast between the root of the igneous structure and the denser basement rocks, in agreement with the density values shown in Table 1. The lack of gravity stations in the southern part of the island and the influence of the regional field may explain why the gravity low is apparently localized in the northern part of the island.

Similar features are found also in the gravity field map of Giglio Island (Figure 4(C)), where the area is

**Table 1.** Density values of the geological units shown in Figure 2.

Lithologies	Density (g/cm <sup>3</sup> )	Units
Sand	1.60–2.00 <sup>B</sup>	1
Mud	1.60–1.67 <sup>A</sup>	1
Andesite	<b>2.66</b> <sup>A</sup>	2
Rhyolite	<b>2.49</b> <sup>A</sup>	2
Monzogranite	2.61–2.77 <sup>C</sup>	3
Conglomerate	2.31–2.72 <sup>D</sup>	4, 5
Sandstone	<b>2.22</b> <sup>A</sup>	4, 5, 6, 8, 12, 13
Clay	1.49–1.9 <sup>A</sup>	5
Marl	2.1–2.6 <sup>H</sup>	5, 6, 10, 12, 13
Siltstone	1.60–1.71 <sup>A</sup>	5, 8, 9, 14
Calcarenite	1.60–1.75 <sup>E</sup>	6
Metagabbro	2.61–3.1 <sup>A</sup>	7
Metabasite	2.51–2.93 <sup>A</sup>	7, 17, 19
Schist	2.73–3.19 <sup>A</sup>	7
Metalimestone	2.67–2.75 <sup>A</sup>	7, 18, 19
Metasandstone	2.64–2.93 <sup>A</sup>	7, 17, 18, 20
Phyllite	2.10–2.80 <sup>F</sup>	7, 17, 18, 19, 20
Shale	2.06–2.67 <sup>A</sup>	9, 12, 13, 14
Radiolarite	<b>2.20</b> <sup>G</sup>	10
Peridotite	3.15–3.28 <sup>A</sup>	11
Gabbro	<b>2.97</b> <sup>A</sup>	11
Basalt	<b>2.87</b> <sup>A</sup>	11
Limestone	1.83–2.51 <sup>D</sup>	12, 13, 14, 15
Dolostone	2.72–2.84 <sup>A</sup>	16, 19, 20
Marble	2.67–2.75 <sup>A</sup>	16, 17, 20
Quartzite	2.60–2.70 <sup>B</sup>	17, 19, 20

Notes: The densities are expressed as range of values; where single values in bold are present, they represent the median. A: Carmichael (1982); B: Sharma (1997); C: de Oliveira, Dall'Agnol, Correa da Silva, and Costa de Almeida (2008); D: Manger (1963); E: Rahmouni, Boulanouar, Boukalouch, and Géraud (2013); F: Ruotoistenmaki and Birungi (2015); G: Busch, Vanden Berg, and Masau (2006); H: Bourbié, Coussy, and Zinszner (1987).

covered by a total amount of 33 measurements on land and 2 marine data offshore the western coast. Similarly to Elba and Montecristo islands, we observe a large relative low elongated in a SE–NW direction along the granitoid intrusion, reaching values around 49 mGal. In the western side, gravity increases without forming a well-localized high in correspondence to a change of outcropping lithologies (Figure 1). The densities of the intrusion and of the outcropping lithologies in the western area of the Giglio Island are similar, thus our interpretation for the westward gravity increase is that it is at least partly determined by the regional field increasing in NE–SW direction, as it can be seen on the Main map.

The Pianosa Island gravity anomaly field ranges between 27 and 36 mGal with a westward decrease in agreement with the regional trend in this part of the Tuscan Archipelago area (Figure 4(E)). The density contrasts are not relevant and not evident gravity anomalies are observed, as a consequence of the uniform geology of the island, mostly formed of Quaternary conglomerates and sandstones.

Finally, we show in Figure 4(A), the Bouguer anomaly map of Capraia Island based on 24 land measurements and 5 offshore data covering well the areal extent of the island. Here, we observe small-amplitude gravity anomalies, ranging from 36 to 51 mGal presumably correlated to weak density contrasts among volcanic and subvolcanic products.

## 5. Conclusions

The gravity field of the Tuscan Archipelago shows regional and local anomalies. A general increase of the gravity field, with respect to the onshore Tuscan and Corse domains, occurs in this area as well as a southward increase due to the crustal thinning beneath the Tyrrhenian Sea. At a local scale, a good correlation was found between the main gravity anomalies and the geological and structural setting of the islands, with particular reference to the correspondences between extended gravity lows and the large magmatic intrusions of Elba, Montecristo and Giglio islands. According to Finetti et al. (2001) such igneous intrusions of the Tuscan Archipelago are widely extended into the upper crust and appear embedded within the metamorphic basement of the northern Tyrrhenian Sea. This information is useful for deducing a possible explanation to the large and intense gravity lows located above the granitic plutons. We can indeed suppose that the roots of the intrusive bodies produce a strong density contrast with the surrounding metamorphic basement. Such negative density contrast is possible if we assume the basement rock density higher than that of the igneous bodies outcropping in most islands of the archipelago (say 2.67 g/cm<sup>3</sup>). Previous studies have indeed pointed out that density value around 2.74 g/cm<sup>3</sup> can be reasonably associated to low-grade metamorphic rocks of crystalline basement (e.g. Bott, 1971; Hinze, 2003; Woollard, 1966). In the context of the Tuscan Archipelago the basement rocks may include also peridotites and other mafic metamorphic rocks ('Ophiolitic basement', e.g. Bortolotti et al., 2001b; Principi et al., 2015), so that we can infer a negative contrast of density of at least 0.1 g/cm<sup>3</sup> between the intrusive rock and the surrounding crust.

In conclusion, it is our opinion that the Bouguer anomaly map of the Tuscan Archipelago can contribute to improve the knowledge of the complex geology of this area, where the reconstruction of the deep magmatic and structural features still represents an open problem.

## Software

Geosoft Oasis-Montaj has been used to produce the Bouguer anomaly map.

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## Disclosure statement

No potential conflict of interest was reported by the authors.

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## References

- Accaino, F., Nicolich, R., & Tinivella, U. (2006). Highlighting the crustal structure of southern Tuscany by the reprocessing of the CROP03 NVR profile. *Bollettino di Geofisica Teorica e Applicata*, 47, 425–445.
- Aldighieri, B., Gropelli, G., Norini, G., & Testa, B. (2004). Capraia island: Morphology and geology of a complex volcanic activity during the Miocene and Pliocene. In D. Morini & P. Bruni (Eds.), *The 'Regione Toscana' project of geological mapping, case histories and data acquisition* (pp. 51–59). Firenze, Italy: Tipografia Martinelli.
- Barberi, F., Ferrara, G., Franchi, F., Serri, G., Tonarini, S., & Treuil, M. (1986). Geochemistry and geochronology of the Capraia island volcanic complex (North Tyrrhenian Sea, Italy). *Terra Cognita*, 6(2), 185.
- Boccaletti, M., Gianelli, G., & Sani, F. (1997). Tectonic regime, granite emplacement and crustal structure in the inner zone of the northern Apennines (Tuscany, Italy): A new hypothesis. *Tectonophysics*, 270(1), 127–143. doi:10.1016/S0040-1951(96)00177-1
- Bortolotti, V., Pandeli, E., & Principi, G. (2001b). The geology of the Elba island: A historical introduction. *Ofioliti*, 26(2a), 79–96.
- Bott, M. H. P. (1971). The mantle transition zone as possible source of global gravity anomalies. *Earth and Planetary Science Letters*, 11(1), 28–34. doi:10.1016/0012-821X(71)90137-3
- Bourbié, T., Coussy, O., & Zinszner, B. (1987). *Acoustics of porous media*. Institut Francais du petrole Publications. Paris: Editions Technip.
- Busch, W. H., Vanden Berg, M. D., & Masau, P. E. (2006). Velocity and density of Paleogene equatorial sediments: Variation with sediment composition. In P. A. Wilson, M. Lyle, & J. V. Firth (Eds.), *Proceedings of the Ocean Drilling Program: Scientific Results* (Vol. 199, pp. 1–31). College Station, TX (Ocean Drilling Program). doi:10.2973/odp.proc.sr.199.226.2006
- Carmichael, R. S. (1982). *Handbook of physical properties of rocks*. Boca Raton, FL: CRC Press.
- Carmignani, L., Conti, P., Cornamusini, G., & Pirro, A. (2013). Geological map of Tuscany (Italy). *Journal of Maps*, 9(4), 487–497. doi:10.1080/17445647.2013.820154
- Carrozzo, M. T., Chirenti, A., Giada, M., Luzio, D., Margiotta, C., Quarta, T., & Zuanni, F. (1981). *Carta Gravimetrica d'Italia: Tecniche automatiche per la sua realizzazione*. Atti del I Convegno GNGTS.
- Cassano, E. (1983). *Contributo AGIP alla carta gravimetrica d'Italia*. Atti del II convegno GNGTS.
- Ciani, A., Gantar, C., & Morelli, C. (1960). Rilievo gravimetrico sullo zoccolo epicontinentale dei mari italiani. *Bollettino di Geofisica Teorica e Applicata*, 2(6), 289–386.
- Cunietti, M., & Inghilleri, G. (1955). *La rete gravimetrica fondamentale italiana*. Milano: Stamperia Cesare Tamburini.
- de Oliveira, D. C., Dall'Agnol, R., Correa da Silva, J. B., & Costa de Almeida, J. A. (2008). Gravimetric, radiometric, and magnetic susceptibility study of the Paleoproterozoic Redencao and Bannach plutons, eastern Amazonian Craton, Brazil: Implications for architecture and zoning of A-type granites. *Journal of South American Earth Sciences*, 25, 100–115. doi:10.1016/j.jsames.2007.10.003
- Della Vedova, B., Vecellio, C., Bellani, S., & Tinivella, U. (2008). Thermal modelling of the Larderello geothermal field (Tuscany, Italy). *International Journal of Earth Sciences*, 97(2), 317–332. doi:10.1007/s00531-007-0249-0
- Di Stefano, R., Bianchi, I., Ciaccio, M. G., Carrara, G., & Kissling, E. (2011). Three-dimensional Moho topography in Italy: New constraints from receiver functions and controlled source seismology: New Moho map of Italy. *Geochemistry, Geophysics, Geosystems*, 12, 9. doi:10.1029/2011GC003649
- Dini, A., Gianelli, G., Puxeddu, M., & Ruggieri, G. (2005). Origin and evolution of Pliocene–Pleistocene granites from the Larderello geothermal field (Tuscan Magmatic Province, Italy). *Lithos*, 81(1), 1–31. doi:10.1016/j.lithos.2004.09.002
- Finetti, I. R., Boccaletti, M., Bonini, M., Del Ben, A., Geletti, R., Pipan, M., & Sani, F. (2001). Crustal section based on CROP seismic data across the North Tyrrhenian–Northern Apennines–Adriatic Sea. *Tectonophysics*, 343, 135–163. doi:10.1016/S0040-1951(01)00141-X
- Gasparon, M., Rosenbaum, G., Wijbrans, J., & Manetti, P. (2009). The transition from subduction arc to slab tearing: Evidence from Capraia island, northern Tyrrhenian Sea. *Journal of Geodynamics*, 47(1), 30–38. doi:10.1016/j.jog.2008.06.004
- Geri, G., Marson, I., Rossi, A., & Toro, B. (1982). Gravity and elevation changes in the Travale geothermal field (Tuscany) Italy. *Geothermics*, 11(3), 153–161. doi:10.1016/0375-6505(82)90024-4
- Geri, G., Marson, I., Rossi, A., & Toro, B. (1985). Crustal deformation and gravity changes during the first ten years of exploitation of the new travale—Radicondoli geothermal field, Italy. *Geothermics*, 14(2–3), 273–285. doi:10.1016/0375-6505(85)90067-7
- Graciotti, R., Pantaloni, M., & Foresi, L. (2008). Geomorphological map of the Pianosa island (Tuscan Archipelago, Italy). *Journal of Maps*, 4(1), 463–471. doi:10.4113/jom.2008.1025
- Hinze, W. J. (2003). Bouguer reduction density, why 2.67? *Geophysics*, 68, 1559–1560. doi:10.1190/1.1620629
- Makris, J., Morelli, C., & Zanolla, C. (1998). The Bouguer gravity map of the Mediterranean Sea (IBCM-G). *Bollettino di Geofisica Teorica ed Applicata*, 39(2), 79–98.
- Malinverno, A., & Ryan, W. B. F. (1986). Extension in the Tyrrhenian Sea and shortening in the Apennines as result of arc migration driven by sinking of the lithosphere. *Tectonics*, 5, 227–245. doi:10.1029/TC005i002p00227
- Manger, G. E. (1963). *Porosity and bulk density of sedimentary rocks*. Contributions to Geochemistry (Geological Survey Bulletin 1144-E).
- Marinelli, G. (1959). Le intrusioni terziarie. *Atti Società Toscana di Scienze Naturali, Memorie*, 66, 50–253.
- Mauffret, A., Contrucci, I., & Brunet, C. (1999). Structural evolution of the northern Tyrrhenian Sea from new seismic data. *Marine and Petroleum Geology*, 16(5), 381–407. doi:10.1016/S0264-8172(99)00004-5
- Morelli, C. (1960). Gravità assoluta: stato attuale e necessità metrologiche. *Boll. Geod. Sc. Add., Firenze*, 19, 4.



- Morelli, C. (1970). Physiography, gravity and magnetism of the Tyrrhenian Sea. *Bollettino di Geofisica Teorica e Applicata*, XII(48), 275–311.
- Moritz, H. (1980). Geodetic reference system 1980. *Bulletin Geodesique*, 54, 395–405. doi:10.1007/BF02521480
- Orlando, L. (2005). Interpretation of Tuscan gravity data. *Bollettino-Societa Geologica Italiana*, 3, 179–186.
- Peccerillo, A. (2017). Cenozoic volcanism in the Tyrrhenian Sea Region. In K. Nemeth (Ed.), *Advances in volcanology* (2nd ed.). Springer International Publishing. doi:10.1007/978-3-319-42491-0
- Poli, G. (1992). Geochemistry of Tuscan Archipelago granitoids, Central Italy: The role of hybridization processes in their genesis. *The Journal of Geology*, 100(1), 41–56. doi:10.1086/629570
- Principi, G., Bortolotti, V., Pandeli, E., Fazzuoli, M., Fanucci, F., Innocenti, F., ... Reale, V. (2015). Carta geologica d'Italia alla scala 1:50.000 Foglio 316, 317, 328, 329 Isola d'Elba – Geological Map of Italy at 1:50.000 scale, Sheet Isola d'Elba. Pratovecchio, AR: ISPRA – Serv. Geol. d'It., Selca, Firenze, IT, S.EL.CAS S.r.l.
- Rahmouni, A., Boulanouar, A., Boukalouch, M., & Géraud, Y. (2013). Prediction of porosity and density of calcarenite rocks from P-wave velocity measurements. *International Journal of Geosciences*, 4, 1292–1299.
- Rocchi, S., Westerman, D. S., Dini, A., & Farina, F. (2010). Intrusive sheets and sheeted intrusions at Elba island, Italy. *Geosphere*, 6(3), 225–236. doi:10.1130/GES00551.1
- Rocchi, S., Westerman, D. S., Dini, A., Innocenti, F., & Tonarini, S. (2002). Two-stage growth of laccoliths at Elba island, Italy. *Geology*, 30(11), 983–986. doi:10.1130/0091-7613(2002)030<0983:TSGOLA>2.0.CO;2
- Rocchi, S., Westerman, D. S., & Innocenti, F. (2003). Montecristo island: Intrusive magmatism. *Periodico di Mineralogia*, 72, 105–118.
- Rosenbaum, G., & Lister, G. S. (2004). Neogene and quaternary rollback evolution of the Tyrrhenian Sea, the Apennines, and the sicilian maghrebides. *Tectonics*, 23. doi:10.1029/2003TC001518
- Ruotoistenmaki, T., & Birungi, N. R. (2015). Petrophysical database of Uganda. *Journal of African Earth Sciences*, 106, 17–39.
- Sandberg, C. H. (1959). Terrain correction charts for transition from Hammer charts to Hayford-Bowie charts. *Geophysics*, 24(2), 323–329. doi:10.1190/1.1438589
- Serri, G. (1997). Neogene-quaternary magmatic activity and its geodynamic implications in the central Mediterranean region. *Annals of Geophysics*, 40, 681–703. doi:10.4401/ag-3896
- Serri, G., Innocenti, F., & Manetti, P. (1993). Geochemical and petrological evidence of the subduction of delaminated Adriatic continental lithosphere in the genesis of the neogene-quaternary magmatism of central Italy. *Tectonophysics*, 223(1), 117–147. doi:10.1016/0040-1951(93)90161-C
- Sharma, P. V. (1997). *Environmental and engineering geophysics*. Cambridge, UK: Cambridge University Press.
- Trevisan, L. (1951). La 55° Riunione Estiva della Società Geologica Italiana. Isola d'Elba. Settembre 1951. *Bollettino-Societa Geologica Italiana*, 70(1953), 435–472.
- Westerman, D. S., Innocenti, F., & Rocchi, S. (2003). Giglio island: Intrusive magmatism. *Periodico di Mineralogia*, 72, 119–126.
- Wilson, M., & Bianchini, G. (1999). In B. Durand, L. Jolivet, F. Horvath, & M. Seranne (Eds.), *The Mediterranean basins: Tertiary extension within the alpine orogen* (Vol. 156, pp. 141–168). Geological Society of London Special Publications.
- Woollard, G. P. (1966). Regional isostatic relations in the United States. In J. S. Steinhardt & T. J. Smith (Eds.), *The Earth beneath the continents* (Vol. 10, pp. 557–594). Geophysical Monograph. Washington, DC: American Geophysical Union.