

Buried volcanic structures in the Gulf of Naples (Southern Tyrrhenian Sea, Italy) resulting from high resolution magnetic survey and seismic profiling

Gemma Aiello ⁽¹⁾, Antimo Angelino ⁽¹⁾, Bruno D'Argenio ⁽¹⁾ ⁽²⁾, Ennio Marsella ⁽¹⁾, Nicola Pelosi ⁽¹⁾,
Stefano Ruggieri ⁽¹⁾ ⁽³⁾ and Agata Siniscalchi ⁽⁴⁾

⁽¹⁾ Istituto per l'Ambiente Marino Costiero (IAMC), CNR, Napoli, Italy

⁽²⁾ Dipartimento di Scienze della Terra, Università degli Studi di Napoli «Federico II», Napoli, Italy

⁽³⁾ Consorzio tra le Università degli Studi di Napoli «Parthenope», Stazione Zoologica «Anton Dohrn»,
Istituto per l'Ambiente Marino Costiero, Napoli, Italy

⁽⁴⁾ Dipartimento di Geologia e Geofisica, Università degli Studi di Bari, Italy

Abstract

In this paper we present a correlation between volcanic structures and magnetic anomalies in the Gulf of Naples (Southern Tyrrhenian Sea) based on high resolution magnetic profiling. A densely spaced grid of magnetic profiles coupled with multichannel seismics (seismic source Watergun 15 cubic inch) was recorded in the Gulf of Naples, representing an active volcanic area during the Late Quaternary (volcanic centers of Somma-Vesuvius, Phlegraean Fields and Ischia and Procida islands). The dataset was collected during the oceanographic cruise GMS00-05 which took place during October-November 2000 in the South Tyrrhenian Sea onboard of the R/V Urania (National Research Council, Italy). Shallow volcanic structures in the subsurface of the gulf were recognized by seismo-stratigraphic analysis of high resolution profiles; the volcanic nature of some of these structures was inferred identifying the magnetic anomalies on a high resolution magnetic anomaly map of the gulf. Even if qualitative, the correlations between seismic and magnetic profiles allow us to better assess the geological structure of the Gulf of Naples.

Key words *Gulf of Naples – Southern Tyrrhenian Sea – magnetic anomalies – high-resolution reflection seismics – volcanic structures*

1. Introduction

Aim of this paper is to present an integrated study of magnetic and seismic profiles recorded in the Gulf of Naples (Southern Tyrrhenian Sea, Italy) finalized to reconstruct the Late Quaternary geological framework of the gulf. Significant interest has been focused on the interpretation of high-resolution multichannel seismic profiles coupled to maps of total magnetic field in order to contribute to the understanding of volcanic structures in the Gulf of Naples and the reconstruction of the Late Qua-

Mailing address: Dr. Gemma Aiello, Istituto per l'Ambiente Marino Costiero (IAMC), CNR, Calata Porta di Massa, Porto di Napoli, 80133 Napoli, Italy; e-mail: gemma.aiello@iamc.cnr.it

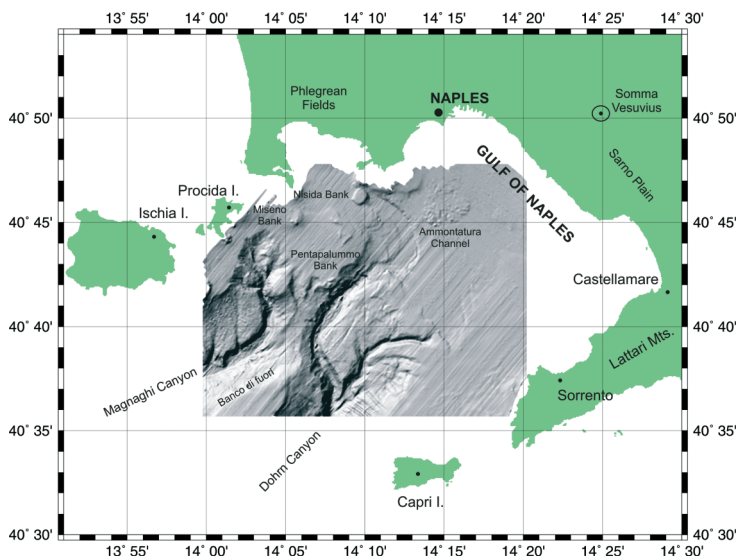


Fig. 1. Sketch map showing the location of the study area and main morphological lineaments in the Gulf of Naples reported from Multibeam bathymetry recorded by CNR-IAMC Geomare Institute (Aiello *et al.*, 2001a).

ternary geological setting of the investigated area.

Acoustically-transparent, mounded and/or wedge-shaped bodies have been identified by seismic interpretation; they correspond to significant volcanic bodies genetically related both to the Phlegraean Fields and to the Somma-Vesuvius volcanic complexes. The evaluation of the volcanic nature of the buried mounds recognized by seismic interpretation through their correlation with the magnetic anomalies represents another goal of this paper.

The Gulf of Naples was involved during the Late Quaternary and since historical times in active volcanism, due to the occurrence of volcanic centers of Somma-Vesuvius, Phlegraean Fields and Ischia and Procida islands (Rosi and Sbrana, 1987; Santacroce, 1987; Vezzoli, 1988). The investigated area, into which magnetic and seismic coverage presented in this paper is located, is bounded towards the Tyrrhenian shoreline by the -50 isobath (figs. 1 and 3) and seawards by the Sorrento Peninsula-Capri Island structural elongment (fig. 1). Several geological and geophysical surveys in the Gulf of Naples have al-

ready been carried out (Latmiral *et al.*, 1971; Finetti and Morelli, 1973; Bartole *et al.*, 1983; Bartole, 1984; Pescatore *et al.*, 1984; Fusi *et al.*, 1991; Aiello *et al.*, 1995, 1997a,b, 2001a,b, 2002, 2003; Milia, 1996, 1998, 2000; Marsella *et al.*, 1996; Milia *et al.*, 1998; Judenherc and Zollo, 2004; Nisii *et al.*, 2004). Moreover, the Tomoves seismic experiment, carried out from 1994 to 2003 by the Tomoves Working Group (Zollo *et al.*, 1996, 1998; Gasparini and Tomoves Working Group, 1998; Capuano *et al.*, 2003) recently obtained significant results on the shallow crustal structure in the Somma-Vesuvius volcanic district and the relationships between seismic velocities and rock lithologies in volcanic environments based on the passive seismic tomography of the volcano. The Serapis active seismic survey recently covered the entire Bay of Naples, allowing the computation of three-dimensional *P*-wave velocity distribution of the gulf, including a small-scale high-resolution model of the Phlegraean Fields caldera (Judenherc and Zollo, 2004). In this model no magma chamber exists in the upper 6 km beneath the Bay of Naples. The feeding system of the Phle-

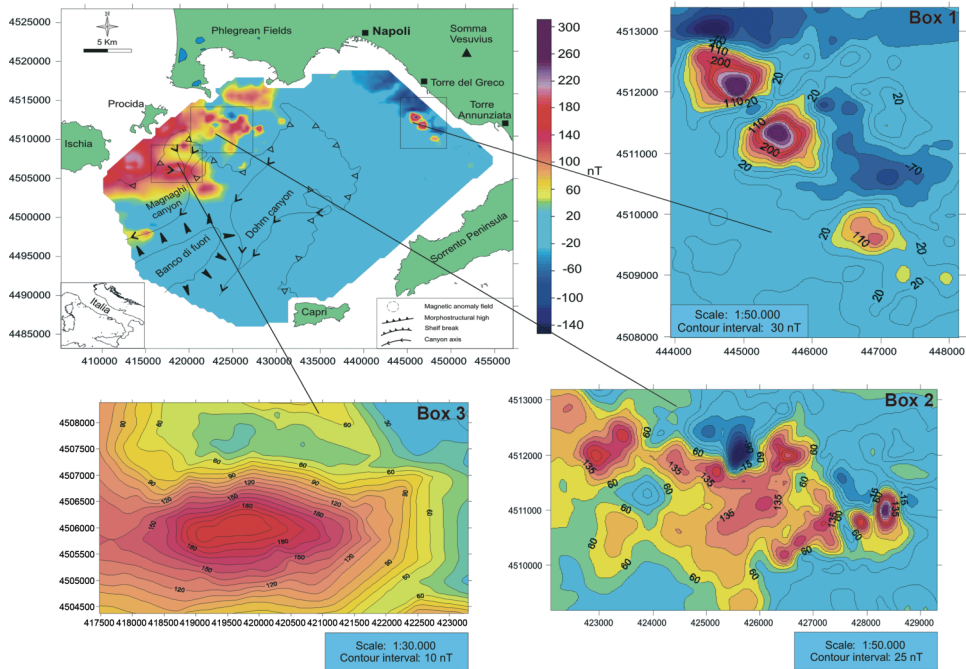


Fig. 2. High resolution magnetic anomaly map of the Gulf of Naples, reporting also main morphostructural lineaments recognized by the interpretation of Multibeam bathymetry. Box 1 represents a magnetic anomaly area located offshore the Somma-Vesuvius volcanic complex, while Box 2 represents another magnetic anomaly area located offshore the Phlegrean Fields volcanic complex. Box 3 represents a magnetic anomaly area located on the continental slope of the gulf, in the Magnaghi canyon's head.

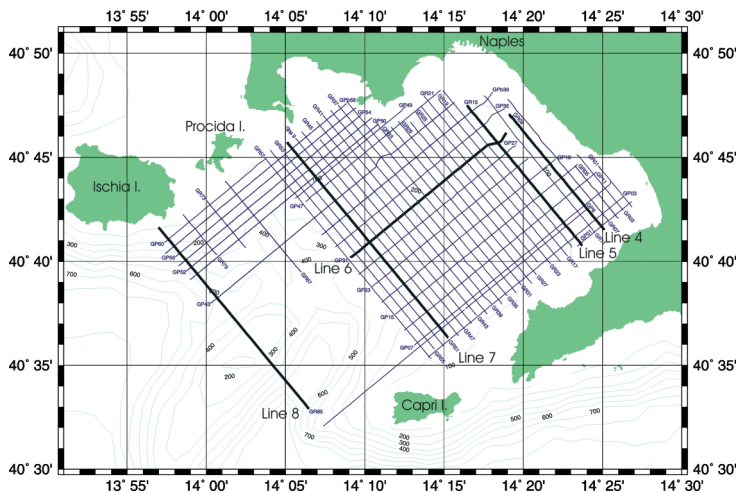


Fig. 3. Navigation map of magnetic and seismic lines recorded in the Gulf of Naples plus bathymetry (bold lines are shown and discussed in the text).

graeae Fields caldera is hypothesized as directly controlled by the tectonic structures affecting the Mesozoic limestone unit occurring in the subsurface of the Bay (Bruno *et al.*, 1998; Lomax *et al.*, 2001). Two NE-SW normal faults running beneath the Vesuvius volcano and the Phlegraean Fields are suggested and related to the Pre-Pleistocene Apenninic tectonics (Judenharc and Zollo, 2004).

The choice of the orientation of magnetic and seismic lines shown in this paper was made taking into account the main structural trends of the Southern Apenninic Chain (NW-SE Apenninic trending and NE-SW Antiapenninic trending). This allows us to cross the geological structures in the Gulf of Naples in the best way. Magnetic and seismic lines are respectively oriented N321° (GR lines; fig. 1) and N51° (GP lines; fig. 3).

Shallow geological structures have been investigated based on the techniques of seismic stratigraphy, whose basic concepts are reported by Vail *et al.* (1991); the volcanic nature of some of these structures has been inferred by qualitative correlation with the magnetic anomalies. The magnetic anomalies have been singled out by the processing and the interpretation of magnetic lines recorded along the same navigation lines of seismics (fig. 3), resulting in a high resolution magnetic anomaly map of the gulf (Siniscalchi *et al.*, 2002; Aiello *et al.*, 2004).

The high resolution magnetic anomaly map of the Gulf of Naples (Siniscalchi *et al.*, 2002) is reported in fig. 2. Qualitative geologic interpretation of this map disclosed the occurrence of complex magnetic anomaly fields in the gulf, associated with shallow volcanic structures, as evidenced by the interpretation of seismic reflection profiles and/or to volcanic morphological and structural highs, identified on high resolution Multibeam bathymetry of the gulf (Aiello *et al.*, 2001a; Marsella *et al.*, 2002; Siniscalchi *et al.*, 2002).

The aeromagnetic anomaly map of Italy produced by the Agip oil company (Agip, 1981) has been the best reference point for many magnetic interpretations also in this area to date. The revised and recent version of magnetic anomaly map of Italy (Chiappini *et al.*, 2000) outlines the lack of detailed magnetic measurements in the area covered by our sur-

vey. The map of Chiappini *et al.* (2000) is based on onshore measurements collected in the frame of the CNR-Progetto Finalizzato Geodinamica (1977-1981), while offshore magnetic measurements have been collected by the Osservatorio Geofisico Sperimentale (OGS; Trieste, Italy; 1965-1972). The most important result of the magnetic map published by Chiappini *et al.* (2000) is a new approach to the interpretation of the magnetic signature associated with the main regional tectonic structures in their geological framework. There is a good regional correlation between structural geology of shallow structures and magnetic anomalies.

2. Geologic setting

The structural framework of sedimentary basins along the Tyrrhenian margin of Campania and their regional subsidence have been intensively studied based both on field geology and on offshore and onshore seismic and well data (D'Argenio *et al.*, 1973; Finetti and Morelli, 1973; Ippolito *et al.*, 1973; Ortolani and Aprile, 1978; Fabbri *et al.*, 1981; Bartole *et al.*, 1983; Bartole, 1984; Trincardi and Zitellini, 1987; Mariani and Prato, 1988). Nonetheless, the lack of deep geothermal wells in the Gulf of Naples makes the reconstruction of the age of basin formation and the chronological calibration of seismic sequences filling the basin more complex.

The Gulf of Naples represents an excellent natural laboratory, in which basin filling recorded the interplay of tectonic, volcanic and depositional/erosional processes, together with the tectonic uplift and deformation of adjacent onshore areas during the Pleistocene. The stratigraphic architecture of continental shelf and upper slope settings appears strongly influenced by the volcanoclastic input of centers of the Phlegraean Fields, Somma-Vesuvius and Ischia and Procida islands (Rosi and Sbrana, 1987; Santacroce, 1987; Vezzoli, 1988; fig. 1). Rapid lateral variations between acoustically-transparent seismic units, interpreted as volcanic deposits which erupted during multiphase volcanic activity of the Phlegraean Fields, Ischia and Procida islands complexes and regularly stratified sedimentary units sup-

plied by the Paleo-Sarno River mouth and by the Sorrento Peninsula tectonic uplift occur.

The Phlegraean Fields are a volcanic district surrounding the western part of the Gulf of Naples, where volcanism has been active since at least 50 kyr (Rosi and Sbrana, 1987; fig. 2). They correspond to a resurgent caldera (Rosi and Sbrana, 1987; Orsi *et al.*, 2002) with a diameter of 12 km (Phlegraean caldera) and resulting from the volcano-tectonic collapse induced from the eruption of the pyroclastic flow deposits of the «Campanian Ignimbrite» (35 kyr BP). Coastal sediments ranging in age from 10000 and 5300 years crop out at 50 m altitude on the sea level in the marine terrace of «La Starza» (Gulf of Pozzuoli), indicating a volcano-tectonic uplift of the calderic center (Rosi and Sbrana, 1987; Dvorak and Mastrolorenzo, 1991).

The continental shelf of the Gulf of Naples has a variable width, ranging between 2.5 km (offshore the western sector of the Capri Island) and 10-15 km (offshore the Sorrento coast; fig. 1). Such a submarine topography is controlled by the interactions between subaerial and submarine volcanism, strongly involving the gulf during the Late Pleistocene and the linear erosion and sediment drainage along main axis of the Dohrn and Magnaghi canyons (fig. 1).

The eruption centres occurring on the islands of Procida, Vivara and Ischia have an age ranging between 150 kyr and historical times (Rosi and Sbrana, 1987; Vezzoli, 1988; fig. 2). The volcanic activity in these islands played a major role in the formation and the activity of the Dohrn canyon western branch and of the Magnaghi canyon, since they drained a great volcanoclastic input on the slope during major eruptive phases. Polyphasic submerged volcanic edifices around Ischia Island (*i.e.* Banco di Ischia) and monogenic edifices in the Phlegraean Fields offshore (Banco di Pentapalumbo, Banco di Nisida, Banco di Miseno; Latmiral *et al.*, 1971; Pescatore *et al.*, 1984; Fusi *et al.*, 1991; Milia, 1996; fig. 1) are also known. These banks represent volcanic relic morphologies characterized by polycyclic erosional surfaces cropping out at the sea bottom, eroding volcanic deposits and covered by Holocene sediments (Banco di Pentapalumbo, Banco di Ischia) or by a thick Holocene sedimentation.

In the center of the Gulf of Naples, between Capri and Ischia islands a NE-SW trending morpho-structural high («Banco di Fuori» or «Banco di Bocca Grande»; fig. 1) occurs. This bank looks like an asymmetrical ridge with the southeastern flank steeper than the north-western one. As later inferred by the data presented in this paper, it results from the regional uplift and tilting of Mesozoic carbonatic acoustic basement along the Sorrento Peninsula-Capri Island structural high (fig. 1).

3. Data acquisition and processing

3.1. Magnetic data

Magnetic data were recorded by using the G-811 Proton Magnetometer. The sensor was placed in a towed fish generally at 200 m from the ship and 15 m b.s.l.; the depth of the magnetometer was regularly controlled and recorded. The cruising speed did not exceed 6 knots. The data were sampled at 3 s, which corresponds to an average spatial sampling rate of about 6.25 m.

Accurate magnetic data processing was performed to preserve data information contents. Initially, raw data were edited manually or using a non-linear filter to remove spikes due to non-geological sources. The marine paths were repositioned taking into account the offset distance between the fish and the GPS positioning system. The elimination of the diurnal component was carefully controlled adopting as base magnetic station the geomagnetic observatory of L'Aquila (42°N; 12°E) kindly supplied by the Istituto Nazionale di Geofisica e Vulcanologia (INGV, Rome, Italy). The measuring periods were characterized by quiet magnetic activity. For further details on the magnetic data processing see Siniscalchi *et al.* (2002) and Aiello *et al.* (2004).

3.2. Seismic data

In the Gulf of Naples 950 km of high-resolution seismic profiles were recorded (fig. 1), reaching a maximum penetration of almost 1 s, that is enough to provide a detailed image of the

depositional geometries and stratal patterns in continental shelf and upper slope settings.

Seismic acquisition was performed at constant distance interval of 6.25 m (or 3 s). The receiver interval was 6.25 m, the minimum offset was 130.00 m and therefore the fold was 1200%. The sample interval was set to 1 ms (sampling rate: 1000 Hz).

Data acquired by the hydrophones were recorded with the Stratavisor NX of Geometrics Inc. Stratavisor recorded 24-channels with a group interval of 6.25 m. Anti-alias analog filters of 500 Hz 48 DB/octava were applied to the seismic signals before sampling. Seismic data were stored in tape drives during acquisition using a SEG-Y format.

Preliminary processing of Watergun profiles limited to the production of single-channel profiles was carried out onboard, using Seismic Unix software (Center for wave Phenomena, 2000) and according to the following steps to perform data processing:

- Extraction of the first channel from the shot gathers.
- Application of AGC (Automatic Gain Control).

- Spectrum analysis of the traces (Fourier transform).

- Application of a butterworth bandpass filter ($f = 40$ Hz, 45 Hz, 240 Hz, 250 Hz).

4. Results

4.1. Eastern Gulf of Naples

Selected examples of interpreted seismic and magnetic profiles in the eastern sector of the Gulf of Naples are here discussed to improve the correlation of some volcanic features with corresponding magnetic anomalies.

Line 4 (fig. 4) runs from the offshore of Somma-Vesuvius volcanic complex (starting from Torre del Greco town) towards the Sarno River plain with a NW-SE trending (fig. 3). It is located in the inner continental shelf, at water depths less than -100 m; consequently, the penetration of the single-channel profile is not excellent because of the occurrence at shallow depths of the sea bottom multiple reflection.

The first seismic unit (fig. 4) is characterized by highly continuous and parallel seismic

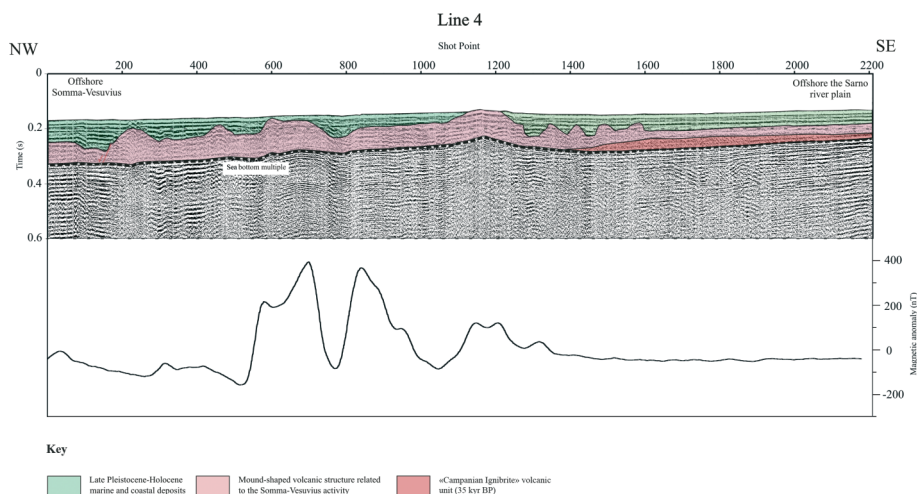


Fig. 4. Seismic profile GR09 and corresponding interpretation. The relative magnetic profile is reported in the inset. Note the occurrence of an important magnetic anomaly (in the order of 500 nT) in a wide volcanic structure located offshore of the Torre del Greco town and related to the Somma-Vesuvius volcanic complex.

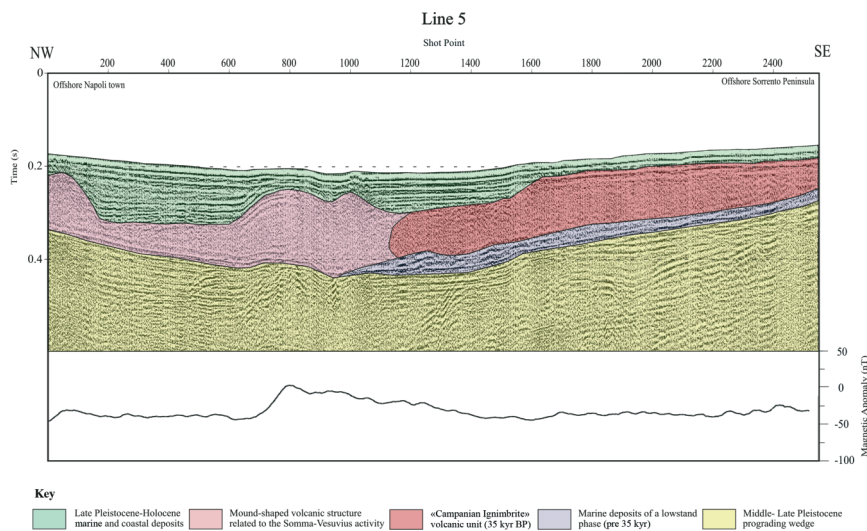


Fig. 5. Seismic profile GR15 and corresponding interpretation. The relative magnetic profile is reported in the inset. Two large, mound-shaped, acoustically-transparent volcanic structures (see the left on the profile) warp the top of a seismic unit correlatable with the Campanian Ignimbrite pyroclastic flow deposits (35 kyr BP). The age of the domes could be very recent, nevertheless they are fossilised by about 300 m of Holocene sediments. A magnetic anomaly with a relative intensity of 40 nT confirms the volcanic nature of these structures.

reflectors, interpreted as Late Pleistocene and Holocene coastal and marine sediments supplied by the Sarno River mouth. The sediments overlie an acoustically transparent volcanic unit, characterized by a tabular external shape; the upper boundary of the seismic unit is highly irregular and runs along the top of volcanic mound-shaped structures. The latter seismic unit is interpreted as the «Campanian Ignimbrite» pyroclastic flow deposits (Rosi and Sbrana, 1987); the dome-shaped structures warping the Campanian Ignimbrite are interpreted as submerged and/or buried parasitic vents, genetically related to the Somma-Vesuvius volcanic complex (Vezzoli, 1988). These volcanic features were already singled out by Milia *et al.* (1998) in their paper on the Somma-Vesuvius offshore volcanology and by Aiello *et al.* (2001a) in their geomorphological map based on the interpretation of high resolution Subbottom Chirp profiles. The widest of these vents extends for about 7.5 km offshore of the Torre del Greco town; its top shows three main

peaks (CDP 600-1300), correlating to the maximum values of the recognized anomalies (fig. 4). The above mentioned structures correspond to a magnetic anomaly field composed of several anomalies, reaching maximum values of 500 nT (fig. 2 and 4). This represents one of the maximum values of the observed anomalies in the Gulf of Naples.

Line 5 running in NW-SE direction offshore of the Napoli town up to the Sorrento Peninsula offshore (fig. 3) is reported in fig 5. Seismic stratigraphic interpretation shows three units (Pleistocene-Holocene coastal and marine sediments, Campanian Ignimbrite volcanic unit and Middle-Late Pleistocene prograding wedge). A package of parallel reflectors with high continuity and amplitude, interposed between the prograding wedge and the Campanian Ignimbrite is interpreted as pre-35 kyr lowstand marine deposits (Milia, 1996). This unit is not seen at water depth less than 140 m: thus, it was beneath the sea throughout the last major glacial maximum and lowering of sea level.

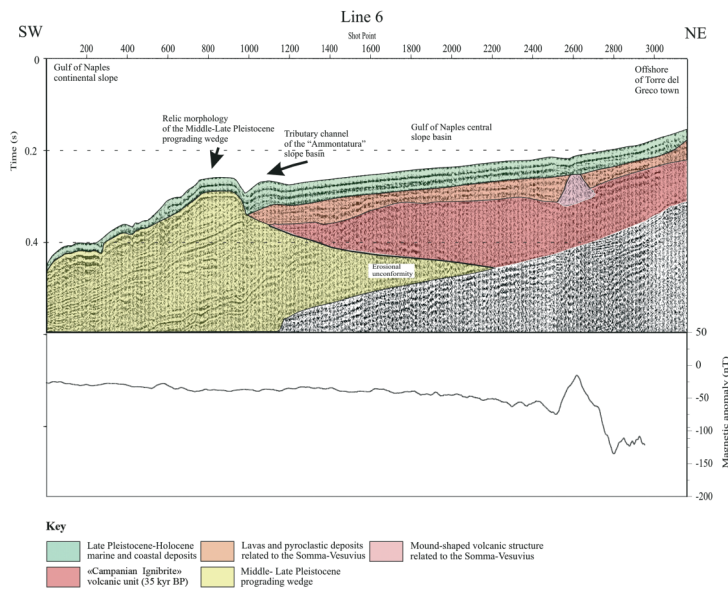


Fig. 6. Seismic profile GP31 and corresponding interpretation. The relative magnetic profile is reported in the inset. No magnetic anomaly occurs in the seismic units interpreted as the Middle-Late Pleistocene sedimentary basin filling of the Gulf of Naples continental slope (see the left part of the profile). Offshore the Somma-Vesuvius volcanic complex a magnetic anomaly whose value is in the order of 120 nT corresponds to a dome-shaped volcanic structure warping the Campanian Ignimbrite pyroclastic flow deposits.

Large volcanic, acoustically-transparent, dome-shaped structures, were recognized near the top of the Campanian Ignimbrite unit, fossilized by Pleistocene and Holocene coastal and marine sediments and warping the Campanian Ignimbrite unit (fig. 5). The structures are similar to those previously described on Line 4 (fig. 4). The occurrence of a magnetic anomaly, in the order of 40 nT, in one of the dome-shaped structures, confirms its volcanic nature. The age of the domes could be very recent, nevertheless they are fossilized by about 300 m of Holocene sediments. Normal faults bound a basin between the two domes, where sediments significantly thicken.

The same seismic units were recognized on Line 6 (fig. 6), which runs in NE-SW direction offshore of the Vesuvian area (Torre del Greco town) up to the Gulf of Naples continental slope (fig. 3). The thickness of the Campanian Ignimbrite seismic unit is of about 100 m, compar-

able with that of the Campanian Ignimbrite in the «Trecase 1» well, drilled on land in the Somma-Vesuvius area (Balducci *et al.*, 1985). During its deposition the unit probably overlay an inclined paleomorphology, as evidenced by the landward dipping of the erosional unconformity located at its base, or alternatively, the unconformity was involved by a tectonic tilting of the shelf (Milia, 1996). Relic morphological highs located in the central part of the gulf, occur near to the present-day shelf break (Aiello *et al.*, 2001b).

The qualitative correlation between the seismic profile and corresponding magnetic line confirms the volcanic nature of the dome-shaped structure warping the Campanian Ignimbrite unit. The maximum variation of the observed magnetic anomaly is in the order of 120 nT. The intersection of the GP31 and GR15 lines is localised just near to this magnetic anomaly, which is related to the dome-shaped structure identified in both profiles.

The preferential alignment of magnetic anomalies and related seismic structures along a NNW-SSE trending suggest such a structural elongment offshore the volcano (Aiello *et al.*, 2003), never singled out by previous papers which evidenced systems of NE-SW normal faults (Bernabini *et al.*, 1973; Finetti and Morelli, 1974; Cassano and La Torre, 1987; Bruno *et al.*, 1998; Simini *et al.*, 2003; Judenherc and Zollo, 2004). Such a structural elongment is evidenced by the map of the total magnetic field offshore the Somma-Vesuvius volcanic complex shown in the Box 1 of fig. 2. Three intense, dipolar, magnetic anomalies are aligned along a direction parallel to the Gulf of Naples shoreline. These anomalies correlate to dome-shaped volcanic structures located along a NNW-SSE

elongment in water depths ranging from -80 m and -110 m. These structures, located in the outer shelf of the Somma-Vesuvius offshore, are located in some convexities of the isobaths at water depths ranging from -70 m up to -110 m.

4.2. Western Gulf of Naples

Line 7 (fig. 7) runs from the offshore of the Phlegraean Fields volcanic complex to the Gulf of Naples continental slope with a NW-SE trending.

In the western part of the gulf (offshore the Phlegraean Fields volcanic complex) the interpretation of the Line 7 has shown the stratigraphic architecture of the external continental shelf of

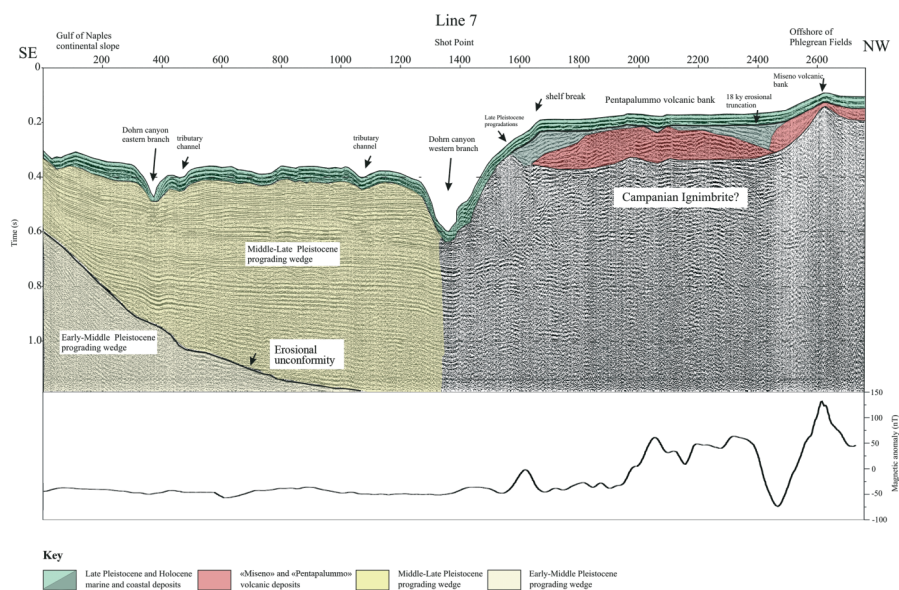


Fig. 7. Seismic profile GR51 and corresponding interpretation. The relative magnetic profile is reported in the inset. Several main magnetic anomalies have been identified on this profile corresponding to main volcanic bodies offshore the Phlegraean Fields volcanic complex (see on the right in seismic and magnetic profile). A first pronounced anomaly, in the order of 130 nT correlates to the Miseno volcanic bank. A large, terraced anomaly with a relative intensity of 100 nT is related to the Pentapalumbo volcanic bank, whose external sector is crossed by the GR51 line. The terraced shape of the anomaly reflects in some way the bathymetric setting of the bank, characterized by a terraced top reaching water depths of -50 m. The flat trending of the magnetic profile confirms the occurrence of sedimentary packages on the Gulf of Naples continental slope, deeply eroded by two branches of the Dohrn canyon.

the Gulf of Pozzuoli area (fig. 7). The Miseno volcanic bank (fig. 7) pertains to a belt of volcanic mounds located in the westernmost part of the Gulf of Naples, to the south of the Gulf of Pozzuoli. This submarine belt presents several oval and round-shaped mounds, well evident in the Multibeam bathymetry of the gulf (fig. 1), some of which are characterized by positive magnetic anomalies (Latmiral *et al.*, 1971; Finetti and Morelli, 1974; Pescatore *et al.*, 1984; Fusi *et al.*, 1991). These volcanic submarine features have not been studied in detail, mainly concealing their age and their relationships with the volcanism in the Campania Region.

An acoustically-transparent, wedge-shaped seismic unit, interpreted as a volcanic acoustic

basement, occurs under the Miseno submarine bank (fig. 7). The excursion of the magnetic anomalies near to the bank is up to 200 nT. This unit grades laterally into a seismic unit characterized by alternating parallel and continuous reflectors with chaotic intervals, showing an erosional truncation near the sea bottom. The last unit could be interpreted as the external part of the Pentapalumbo bank volcanic deposits (fig. 7; see the fig. 1 for the location). The shape of the magnetic anomaly in the lateral part of the Pentapalumbo volcanic bank reflects the terraced shape of the top of the bank (fig. 7). The excursion of the magnetic anomaly is in the order of about 100 nT. Late Pleistocene marine and coastal progradations, pertaining to the last

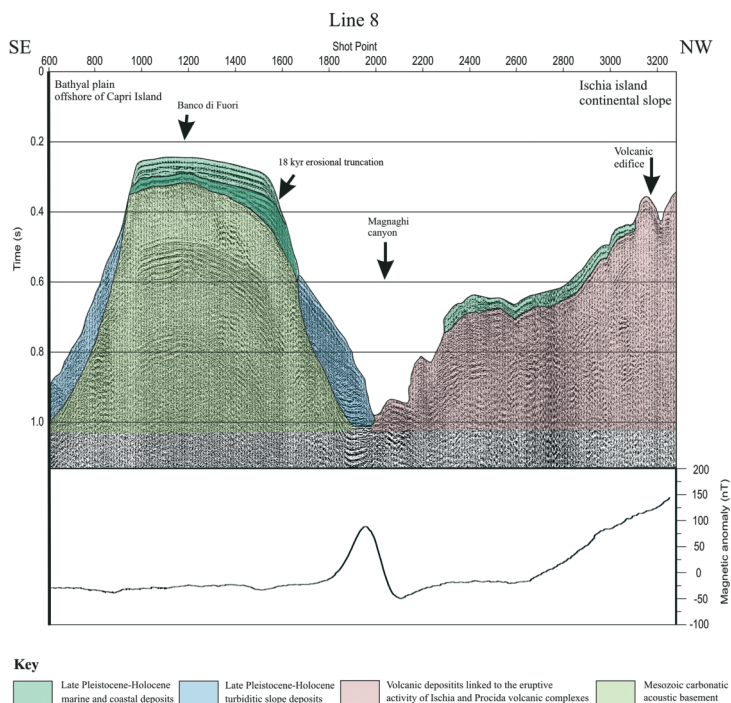


Fig. 8. Seismic profile GR85 and corresponding interpretation. The relative magnetic profile is reported in the inset. The flat trending of the magnetic anomaly in the Banco di Fuori structural high suggests that it could represent a tilted block of Mesozoic carbonatic acoustic basement. A pronounced magnetic anomaly has been singled out on the northwestern flank of the Magnaghi canyon, incised in the volcanic deposits of the Procida Island continental slope.

glacio-eustatic cycle, well developed under the present-day shelf break are located at water depths of about 150 m.

The Dohrn canyon western branch, whose bottom reaches a water depth of about 650 m in this area, erodes volcanic units of its western flank and sedimentary units on its eastern flank (fig. 7). A local maximum of the magnetic profile (about 50 nT) is associated with a volcanic intrusion identified along the western slope of the Dohrn western branch. Sedimentary units pertaining to Middle-Late Pleistocene slope sequences of the prograding wedge supplied by the Paleo-Sarno River mouth are truncated by both flanks of the canyon (fig. 7). On the bottom of the profile there is an erosional unconformity, representing also the basal unconformity of the Middle Pleistocene prograding wedge, evidenced by the onlap of seismic reflectors.

Line 8, NW-SE trending, runs from the bathyal plain offshore of Capri Island to the continental slope of the Ischia island (fig. 3). A major morphostructural high («Banco di Fuori» and/or «Banco di Bocca Grande») is crossed by Line 8 (fig. 8). The Banco di Fuori high separates the Dohrn and the Magnaghi canyons and is presumably formed by a Mesozoic carbonate block, resulting from regional uplift and tilting of the carbonatic acoustic basement. The high is covered by Pleistocene-Holocene sediments; its southern flank is steeper than the northern one, thus probably suggesting the occurrence of a normal fault.

Line 8 crosses the axis of the Dohrn canyon westward of Capri Island (fig. 8) in the zone of the confluence of the two branches of the canyons, reaching water depths of more than 1100 m. The northern slope of the Banco di Fuori high bounds the Magnaghi canyon, reaching water depths of about -750 m. The erosion and the transport of the volcanoclastic input in the western sector of the Gulf of Naples (offshore of Ischia and Procida islands) have acted along the axis of the Magnaghi canyon (fig. 1), which appears unrelated to the present or past fluvial drainage system on land. As shown by Line 8, the Magnaghi canyon incises an acoustically transparent seismic unit, interpreted as volcanic deposits, probably pertaining

to the Procida volcanic complexes (55 kyr-18 kyr BP; Rosi and Sbrana, 1987).

The correlation between the magnetic anomaly profile and the seismic line suggests that the northwestern flank of the Magnaghi canyon could be incised in volcanic deposits. This is shown by the trending of the magnetic anomaly along the same profile, which is flat in the first half of the line despite the complex sea floor topography, while it follows the morphology of the sea bottom, starting from the northwestern flank of the Banco di Fuori high. The flat trending of the magnetic anomaly in the first part of the profile confirms the sedimentary nature of the Banco di Fuori high. The high could represent a tilted block of Meso-Cenozoic carbonates located along the structural high Sorrento Peninsula-Capri Island (fig. 4). Moreover, the Banco di Fuori high seems to have acted as a morphological and structural barrier for the propagation of the volcanic deposits coming from the eruptive cycles of Ischia Island.

Along the northwestern flank of the Magnaghi canyon, a pronounced magnetic anomaly, in the order of 90 nT was observed. Moreover, starting from the canyon towards the Ischia continental slope the values of the magnetic anomaly increase progressively from 0 to 150 nT, confirming the volcanic nature of intensively magnetized volcanic deposits cropping out near the sea bottom. The correspondance between the sea floor topography and the shape of the magnetic anomaly along the Ischia continental slope is worth noting.

5. Discussion and conclusions

One main goal of this paper was to adopt an approach to the study of marine geophysical data based on the integrated interpretation of high resolution magnetic and seismic data. This method, even if qualitative in the present discussion, improved the geological knowledge in an active volcanic area as the Gulf of Naples, since it disclosed and located several main volcanic bodies based on seismic interpretation, well constrained by the occurrence of significant magnetic anomalies.

Volcanic bodies occurring in the subsurface of the Gulf of Naples are significantly linked to eruptive phases of Somma-Vesuvius, Phlegraean Fields and Ischia and Procida islands volcanic complexes, strongly conditioning the geological setting of the Gulf of Naples. The role of the Dohrn canyon as a main morphological and structural lineament in the investigated area has also been confirmed by our data analysis. The Dohrn canyon western branch sharply separates a southeastern sector of the Gulf of Naples, characterized by the occurrence of sedimentary units by a northwestern one, where main volcanic bodies and units are localized, as well shown by Line 7 (fig. 7).

Sharp and delineated magnetic anomalies have been recognized in the eastern part of the Gulf of Naples, offshore of the Somma-Vesuvius volcanic complex, where a shallow continental shelf occurs (Box 1 in fig. 2). Seismic interpretation identified submerged or buried parasitic vents, located offshore Torre del Greco town, genetically related to activity of the Somma-Vesuvius volcano during recent times. One of these vents, well shown by Line 4 (fig. 4) extends for almost 7.5 km and corresponds to a main magnetic anomaly, in the order of about 500 nT. The age of this vent could be only hypothesized, but it could be historical, taking into account both the reduced thickness of the Late Pleistocene-Holocene sedimentary cover and the results of the volcanological map of Somma-Vesuvius edited by Vezzoli (1988). This map shows how on the flank of the volcano facing on the Tyrrhenian Sea *i.e.* lava flows before 1631 and after A.D. 79 eruptions, frequently covered by thick pyroclastic deposits (glowing clouds, ash clouds, lahars) of the A.D. 1631 eruption extensively crop out. The offshore vent herein recognized can be probably ascribed to recent phases of the historical activity of the volcano.

The seismic unit correlated with the Campanian Ignimbrite pyroclastic flow deposits, widely present in the subsurface of the eastern part of Bay, from the Sorrento Peninsula to Napoli town offshore does not seem to produce significant magnetic anomalies. Sharp and delineated magnetic anomalies are associated with dome-shaped magmatic structures warp-

ing this unit in its upper part (figs. 4 and 5). In this case relatively small magmatic bodies are interstratified into Campanian Ignimbrite pyroclastic deposits produced by extensive explosive activity of the Phlegraean Fields volcanic complex.

The volcanic bodies recognized in the offshore of Somma-Vesuvius are interpreted as a strip of eruptive vents, which have settled on a system of NNW-SSE normal faults. These vents are associated with a magnetic anomaly field composed of several anomalies and reaching a maximum intensity of 500 nT. The largest of these structures shows three main elevated peaks, corresponding to several magnetic maximums in the map of the total magnetic field shown in the Box 1 of fig. 2. The preferential alignment of magnetic anomalies and related seismic structures along a NNW-SSE trending (fig. 2) suggest such a structural elongment offshore the volcano, never singled out by previous papers, which evidenced systems of NE-SW normal faults (Bernabini *et al.*, 1973; Finetti and Morelli, 1973; Cassano and La Torre, 1987; Bruno *et al.*, 1998; Simini *et al.*, 2003; Judenherc and Zollo, 2004).

In the western part of the gulf significant magnetic anomalies are located in a belt of submarine volcanic banks located in the external part of Gulf of Pozzuoli, offshore the Phlegraean Fields volcanic complex. Box 2 in fig. 2 shows as the Phlegraean Field offshore represents a relatively complex magnetic anomaly area, characterized by several magnetic anomaly fields with different intensity. Two dipolar anomalies, characterized by a maximum-minimum couple, have been identified. The first anomaly, E-W oriented and located in the northernmost part of the area shows a minimum of -200 nT, associated to a maximum of +185 nT. Such values, which are relatively not so high, could be associated with volcanic bodies not cropping out at the sea bottom, but buried by sediments. The second anomaly, NW-SE oriented and located in the easternmost part of the area shows a maximum-minimum couple with a relative intensity similar to that of the previously discussed field. Besides these two magnetic anomaly fields, corresponding to magnetic bodies and/or volcanic edifices, other

anomalies, not dipolar and of lower intensity, ranging between 40 and 135 nT are due to the occurrence of small volcanic edifices (fig. 2).

Direct sampling and age determination of the Phlegraean volcanic banks are not yet available, since the volcanic acoustic basement constituting the banks cannot be easily dredged, because they are covered by Late Pleistocene-Holocene marine sediments. Some constraints on the evolution of the Miseno and Pentapalumbo volcanic banks have been published by Pescatore *et al.* (1984) based on the dredging of a trachitic block in the area, correlated to the Campanian Ignimbrite pyroclastic flow deposits (Rosi and Sbrana, 1987). The identification and activity of the Miseno and Pentapalumbo volcanic banks can be probably correlated to the first phase of activity of the Phlegraean Fields volcanic complex (before than 35 kyr BP). Moreover, the two banks seem to be older than the last glacio-eustatic regression (Wurmian regression; 18 kyr BP), as evidenced by the occurrence of a main seismic reflector truncating the volcanic deposits of the banks and interpreted as the Wurmian erosional truncation, well correlated in the Gulf of Pozzuoli area (Pescatore *et al.*, 1984).

It is worth noting that there is no precise correlation between the submarine morphology of the Pentapalumbo bank (fig. 1) and the shape of related magnetic anomalies (Box 2 in fig. 2). It is probable that after the formation of the bank the intrusion of small volcanic bodies occurred. They seem to be magmatic bodies, elevated with respect to the top of the bank, which was terraced during the last glacio-eustatic oscillations (Milia, 1998). Several anomalies of this area are then interpreted as corresponding to small volcanic structures. At the time of their emplacement and consolidation these structures probably recorded a magnetization showing an intensity and direction different from the magnetization of the volcanic deposits of the Pentapalumbo bank.

A significant magnetic anomaly, in the order of 150 nT occurs in Magnaghi canyon's head (Box 3 in fig. 2), deeply eroding the volcanic deposits of the continental slope of Procida Island. This confirms that the Magnaghi canyon is entirely incised in volcanic deposits, as al-

ready evidenced by the occurrence of pronounced magnetic anomalies both in the canyon's head and its axis (fig. 2). On the contrary, the slope of the Gulf of Naples in the Dohrn canyon, a kilometric feature characterized by two branches joining into a main axis reaching water depths of more than 1000 m (Milia, 2000; Aiello *et al.*, 2001a) does not show magnetic anomalies, confirming that this canyon deeply erodes sedimentary units supplied by the Paleo-Sarno River mouth. An important, rounded-shaped magnetic anomaly has been identified in the continental slope of the Bay, in the sector between Dohrn and Magnaghi canyons. This evidence suggests the occurrence of a previously unknown volcanic edifice, located between the two canyons (fig. 2). The lack of magnetic anomalies in the «Banco di Fuori» high (fig. 8), a main morphostructural high separating the two canyons and bounding southwards the gulf (fig. 1), confirms that it probably represents a Mesozoic carbonatic block, located along the Sorrento Peninsula-Capri Island structural elongation, resulting from the regional uplift and tilting of the acoustic basement.

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