

# **Seismic Stratigraphy and Marine Magnetics of the Naples Bay (Southern Tyrrhenian Sea, Italy): The Onset of New Technologies in Marine Data Acquisition, Processing and Interpretation**

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## **1. Introduction**

Seismic stratigraphy and marine magnetics in the case histories of the Somma-Vesuvius volcanic complex, Phlegrean Fields offshore and Ischia and Procida islands offshore (Naples Bay, Southern Tyrrhenian sea) are here discussed. Detailed geo-volcanologic setting of these areas is presented to give a better framework of the presented data. Seismo-stratigraphic techniques and methodologies are discussed, focussing, in particular, on the Naples area, where the Quaternary volcanic activity prevented the application of classical stratigraphic concepts, due to the occurrence of interlayered sedimentary sequences and intervening volcanic bodies (volcanites and volcanoclastites). The onset of new technologies in marine data acquisition, processing and interpretation is also discussed taking into account some historical aspects.

## **2. Seismo-stratigraphic techniques and methodologies**

The applied stratigraphic subdivision derives from the type of data utilized in marine geology (reflection seismics) and by the methods of seismic interpretation (high resolution sequence stratigraphy). The geological structures recognized through the seismic interpretation are the acoustically-transparent volcanic units, representing the rocky acoustic basement and the systems tracts of the Late Quaternary depositional sequence (Fabbri et al., 2002). The widespread volcanic activity, which controlled the stratigraphic architecture of the Naples Bay during the Late Quaternary, has disallowed the application of a classical stratigraphic approach, due to the occurrence of interlayered sedimentary sequences and intervening volcanic bodies (volcanites and volcanoclastites).

In the Late Quaternary Depositional Sequence (SDTQ) the seismo-stratigraphic analysis has allowed to characterize depositional systems respectively referred to the sea level fall (FST; Helland Hansen & Gjelberg, 1994), to the sea level lowstand (LST) and related internal subdivisions (Posamentier et al., 1991), to the transgressive phase (TST; Posamentier &

Allen, 1993; Trincardi et al., 1994) and to the highstand phase of sea level (HST; Posamentier & Vail, 1988). A sketch stratigraphic diagram of the SDTQ and its components has been constructed in order to clarify the stratigraphic relationships between systems tracts (Fig. 1).

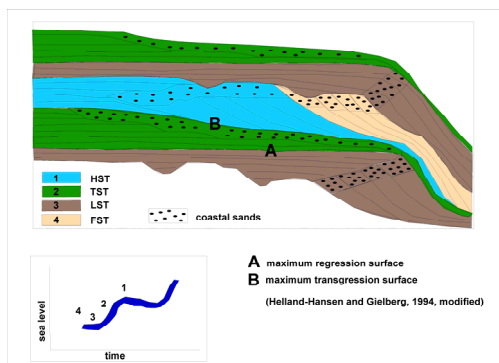


Fig. 1. Sketch stratigraphic diagram as a function of both depth (upper diagram) and time (lower diagram) showing the geometric relationships between systems tracts and distribution of siliciclastic facies in unconformity-bounded depositional sequences (modified after Vail et al., 1977; Christie-Blick, 1991; Helland Hansen & Gjelberg, 1994).

## 2.1 Main components of the Late Quaternary depositional sequence

The main characteristics of the system tracts related to main phases of the last sea level glacio-eustatic cycle are here discussed, focussing, in particular, on the Naples Bay. The stratigraphic meaning and the map representation of each system tract are also resumed.

### 2.1.1 Highstand deposits (HST)

The highstand deposits are younger than the phase of maximum marine ingression happened at the end of the sea-level rise (about 4-5 ky B.P.) and show their maximum thickness in the inner shelf, next to the main deltas (i.e. Po, Tiber, Arno, etc.) along the Italian coast, while reduce to a few meters on the outer shelf (Fabbri et al., 2002). Highstand deposits of the Naples Bay have been intensively studied in the frame of research projects of marine geological mapping of the Campania Region (Aiello et al., 2001; D'Argenio et al., 2004; Sacchi et al., 2005; Insinga et al., 2008; Molisso et al., 2010; Fig. 2).

### 2.1.2 Transgressive deposits (TST)

The transgressive deposits, originated in continental, coastal paralic or marine environment during the phases successive to the Late Quaternary sea level rise generally appear reduced in thickness and studied with very high resolution seismic profiles and piston cores. The Italian continental margins document the variability of facies, internal geometry, sedimentologic expression and marker horizons (Trincardi et al., 1994). In the Naples Bay the TST was deposited during the rising of sea level (18-6 ky). It has been widely documented by Milia & Torrente (2000; 2003) and consists of three minor stratigraphic units. The second of them corresponds to a thick progradational unit overlying the Neapolitan Yellow Tuff (18 ky B.P.), the Penta Palummo Bank and the Miseno Bank.

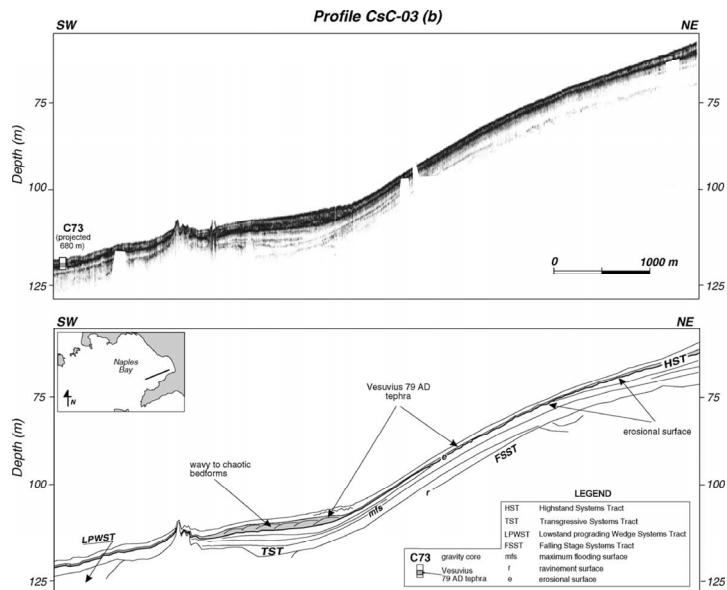


Fig. 2. Subbottom Chirp profile CsC-03 (b) across the Sarno prodelta highstand deposits (eastern Naples Bay) and corresponding geological interpretation (slightly modified after Sacchi et al., 2005).

### 2.1.3 Lowstand system tract deposits (LST)

The deposits originated in sea level lowstand during the last Quaternary glacial episode (isotopic stage 2; Martinson et al., 1987) may be separated in mass transport deposits, base of slope turbiditic systems and shelf margin progradational wedges. Each sector of continental margin does not include all the three types of deposits, but only one or two. The development of each of the three types of lowstand deposits is a function of the morphological setting and regime of clastic supply. The mass transport deposits usually have a great lateral extension and are characterized by chaotic reflections or acoustic transparency, erosional base and thickness from several meters (Marani et al., 1986; Mongardi et al., 1995; Trincardi & Normark, 1988; Trincardi et al., 1994).

### 2.1.4 Falling sea level system tract deposits (FST)

The Mediterranean continental margins show several examples of falling sea level deposits, which can be characterized by different geometries, thickness, areal extension and lithology (Tesson et al., 1993; Trincardi & Field, 1991; Hernandez Molina et al., 1994). They consist of progradational wedges emplaced through a mechanism of erosional or forced regression recognized through the progressive seaward and downward shifting of the coastal onlap. In the Naples Bay progradational units (FST and LST), the tops of which are located at depths ranging from - 130 m and - 150 m, occur at the seaward termination of the wide subaerial erosional surface that affects the volcanic banks (Milia & Torrente, 2000; 2003; Aiello et al., 2005).

### **2.1.5 Sequence boundaries (SB)**

Two sequence boundaries have been defined as a function of the ratio between the rate of sea level fall and the rate of subsidence at the shelf margin (Vail et al., 1984; Posamentier & Allen, 1993). Type 1 sequence boundaries form when the rate of eustatic sea level fall exceeds the rate of subsidence; as a consequence, the subaerial exposure of the whole continental shelf occurs. Type 2 sequence boundaries characterize the continental margins in which the rate of subsidence of the outer shelf is higher than the rate of sea level fall; more or less extended parts of the continental shelf rest submerged or subject to deposition. Type 1 sequence boundaries are characterized by more extended phenomena of fluvial incision.

## **2.2 Facies analysis and schematic representation of the depositional environments**

The system tracts of the Late Quaternary depositional sequence include deposits characterized by facies related to continental, paralic coastal, shelf and deep sea depositional environments. The marker horizons constituting the base and the top of the system tracts may be represented by variable sedimentological expressions due to the differences between the facies and the occurrence and entity of related erosional phenomena.

### **2.2.1 Continental deposits**

The continental deposits may occur in shallow areas controlled by subaerial exposure during Quaternary glacial periods. They consist of alluvial plain deposits in which extended fluvial systems have been recognized, characterized by channel deposits with incised thalwegs and levees. The inter-channel zones are characterized by soil formation. The filling of the fluvial incisions may be characterized by sediments highly varying in grain-size and by filling geometries related to meanders or braided streams.

### **2.2.2 Paralic and coastal deposits**

The coastal and paralic depositional systems greatly vary both in morphology and depositional style. This variability reflects different budgets between the available sediments (type and quantity) and the oceanographic regime (wave-dominated, tide-dominated or mixed). As a general rule, the Mediterranean is characterized by a microtidal regime; the most of the coastal systems on the Italian margins is dominated by the waves. Coastal and paralic deposits may theoretically form in each phase of a relative sea level fluctuation cycle, but are characterized by different facies; regressive systems form in condition of sea level fall (forced regressions; Posamentier et al., 1992) or when the siliciclastic supply counterbalances the relative sea level rate.

### **2.2.3 Continental shelf deposits**

The sediments of the actual continental shelves may be summarized into three main types (Fabbri et al., 2002):

- Sediments deposited in a phase during which the shoreline was seaward advanced with respect to the present-day location and successively drowned (relic sediments).
- Sediments deposited in a phase during which the shoreline was seaward advanced with respect to the present-day location and successively drowned, but then reworked due to currents, storm waves or tides (palimpsest sediments).

- Sediments related to the Late Quaternary highstand in equilibrium with the present-day depositional processes.

The continental shelf of the Naples Bay has a variable width, ranging between 2.5 km (offshore the western sector of Capri island) and 10-15 km (offshore the Sorrento coast). 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 Dohrn and Magnaghi canyons (Aiello et al., 2005; Di Fiore et al., 2011). The eruption centres occurring on the islands of Procida, Vivara and Ischia range in age between 150 kyr and historical times (Rosi & Sbrana, 1987; Vezzoli, 1988).

#### **2.2.4 Deep sea deposits**

Slopes, basins or submarine highs are less influenced by the sea level fluctuations during the Late Quaternary. Based on the piston core data acquired during the last 30 ky in all the Mediterranean sea it is clear that the last sea level rise and the successive sea level highstand are represented by drapes of clayey sediments (Holocene drapes). Under the Holocene drapes four main types of deposits occur (Fabbri et al., 2002):

- Turbidite deposits having variable nature (referred to specific depositional elements as channel-levee systems, lobes and distal, not channelised deposits).
- Mass gravity transport deposits.
- Deposits originated by bottom currents and related erosional or condensed surfaces.
- Pelagic drapes.

Different types of turbiditic deposits, mass gravity transport deposits and pelagic drapes have been widely recognized on the sea bottom of the Naples Bay, in the frame of research programmes of submarine geological mapping (Aiello et al., 2001; 2008; 2009b; 2009c).

#### **2.2.5 Mass gravity transport deposits**

Mass gravity transport deposits, varying in nature, internal organization and areal extension have been recognized in the Late Quaternary successions of the Italian Peninsula. Their emplacement may happen under conditions of lowstand, relative sea level rise and highstand of the sea level (Galloway et al., 1991; Correggiari et al., 1992; Trincardi & Field, 1991; Trincardi et al., 2003; Aiello et al., 2009c; Di Fiore et al., 2011). Sketched tables of the geological interpretation of selected Subbottom Chirp profiles have been constructed in order to show significant instability processes occurring in the Naples Bay (Aiello et al., 2009c; Fig. 3).

### **3. Geo-volcanologic setting**

The Campania Tyrrhenian margin is characterized by the occurrence of marine areas, strongly subsident during the Plio-Quaternary, sites of thick sedimentation, as the Volturno Basin, the Naples Bay, the Salerno Valley and the Sapri and Paola basins (peri-tyrrhenian basins; Argnani & Trincardi, 1990; Boccaletti et al., 1990; Tramontana et al., 1995; Gabbianelli et al., 1996; Aiello et al., 2000). Under the Plio-Quaternary sedimentary cover, the Campania continental margin is characterized by the occurrence of tectonic units of Apenninic chain, resulting from the seaward prolongation of corresponding units cropping out on the coastal belt of Southern Apennines (D'Argenio et al., 1973; Bigi et al., 1992; Fig. 4).

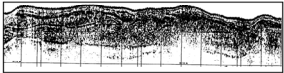
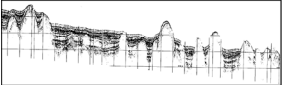
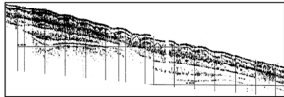
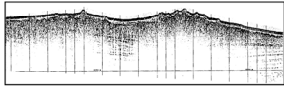
	DESCRIPTION	GEOLOGIC INTERPRETATION
	<b>A</b> Chaotic reflections with interrupted lateral continuity	Volcanoclastic and/or pyroclastic deposits (mud flow, lahars, piroclastic flows), genetically linked to the deposition in submarine environment of the pyroclastic fluxes of the recent vesuvian activity (< 2 ky; see also Milla et al., 2008)
	<b>B</b> Acoustically-transparent bodies strongly convex buried and/or cropping out at the sea bottom alternated to parallel reflectors wavy or concave.	Pyroclastic mounds constituted by alternating coarse volcanogenic sands and pumice levels, with fillings or covers of shales. The mounds are genetically linked to the "Tufo Giallo Napolitano" Auct. (12 ka) and/or to the "Pomici Principali" Auct. (10Ka), since they are located in the upper part of a seismic unit interpreted as the "Tufo Giallo Napoletano" Auct., developed starting from the coastal cliff off Posillipo (Naples town) up to the outer shelf off the Naples town (see also Aiello et al., 2001).
	<b>C</b> Convex reflectors with high lateral continuity (periodically interrupted) overlying a strong seismic reflector bounding their base.	Holocene marine sediments involved into creeping (probably due to high contents of organic matter) overlying a sharp surface of separation corresponding to the maximum flooding surface of the last glacio-eustatic cycle (see also Aiello et al., 2001).
	<b>D</b> Parallel to slightly inclined seismic reflectors, grading upwards to an acoustically-transparent seismic facies, overlain by a thin drape of parallel and continuous seismic reflectors	Outcrops of relic sands deposited during the last phase of sea level lowstand (18-20 ky) of the last glacio-eustatic cycle, covered by a thin drape of Holocene sediments (highstand drape).

Fig. 3. Sketched table showing significant acoustic facies related to submarine gravity instability on the continental shelf of the Naples Bay (reported after Aiello et al., 2009c).

The main structural trends of the Campania margin are NW-SE and NNW-SSE (Apenninic) and are characterized, on the continental slope and in the bathyal plain, by the occurrence of intra-slope basins and structural highs, showing hints of intense synsedimentary tectonics (Aiello et al., 2009a). Two main NE-SW (counter-Apenninic) trending lineaments, i.e. the Phlegrean Fields-Ischia fault and the Capri-Sorrento Peninsula fault, control the structural setting of the Naples Bay. These lineaments have controlled the emplacement of main morpho-structures on the continental slope and in the bathyal plain. In a time interval spanning from the Middle to the Late Pleistocene the synsedimentary tectonics has played a major role in triggering submarine gravity instabilities.

### 3.1 Somma-Vesuvius volcanic complex

The Vesuvius volcano has been intensively studied, mainly with respect to the eruptive events, the recent seismicity, the geochemistry and the ground movements of the volcano and the related volcanic hazard (Cassano & La Torre, 1987; Santacroce et al., 1987; Castellano et al., 2002; Esposti Ongaro et al., 2002; Mastrolorenzo et al., 2002; Saccorotti et al., 2002; Scarpa et al., 2002; Todesco et al., 2002).

The eruption of the Campanian Ignimbrite pyroclastic flow deposits (37 ky B.P.; Rosi & Sbrana, 1987) covered the whole Campania Region and part of the adjacent offshore with grey tuff deposits, upon which the Somma edifice started to grow. The eruptive activity ranges from the "Pomici di Base" (18 ky) and the "Pomici Verdoline" plinian eruptions, enabling the collapse of the Somma edifice and the consequent calderization, with the formation of a new volcanic edifice, i.e. the Vesuvius. The period from 8000 B.C. to 79 A.D. was characterized by

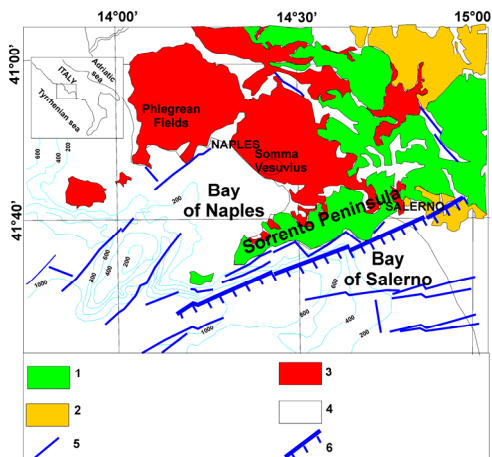


Fig. 4. Tectonic sketch map of western Campania Apennines (modified after D'Argenio et al., 2004). Key. 1: Shallow water carbonate and deep basinal units (Mesozoic). 2: Piggy-back siliciclastic units (Tertiary). 3: Pyroclastic deposits and lavas (Quaternary). 4: Continental and marine deposits (Quaternary). 5: Normal fault. 6: Detachment faults (barbs indicate downthrown side).

three main plinian eruptions: “Mercato” (7900 B.C.), “Avellino” (3800 B.C.) and the Pompei eruptions (79 A.D.). The activity continued with the Pollena eruption (472 A.D.) and the 1631 A.D. eruption and then with several small energy, effusive and explosive, giving rise to lava flows along the western and southern slopes of the volcano (Sheridan et al., 1981; 1982; Sigurdsson et al., 1982; 1984; Santacroce, 1987). The variability in the eruptive behaviour of the Vesuvius volcano has been explained by volcanologists with an alternation between periods of open conduits and periods of closed conduits, the latter being characterized by a relative quiescence followed by Plinian eruptions. The periods with open conduits were characterized by a permanent strombolian activity, frequent lava flows and mixed eruptions, both effusive and explosive (Rosi & Santacroce, 1983; Rosi et al., 1983; Arnò et al., 1987). Constraints on the sedimentary basement overlying the volcano and its stratigraphic relationships with the Phlegrean volcanic products can be explained by the deep geothermal well Trecase 1, drilled by the AGIP-ENEL joint venture on the south-eastern slopes of the volcano (Balducci et al., 1985; Brocchini et al., 2001). Sketch stratigraphy of the Trecase 1 exploration well is reported in Fig. 5.

The total magnetic field map of of Somma-Vesuvius volcano shows interpretative elements that have an indicated value for the trend of volcanites in the volcanic complex's peripheral areas (Cassano & La Torre, 1987; fig. 6). From the main sub-circular anomaly centred on the volcano, two positive appendages diverge towards SE and SW. They might correspond to a great thickness of lava products, possibly in pre-existing depressions of the sedimentary basement of the graben of the Campania Plain. This assumption might explain an elongated magnetized body, which tends to move towards Naples Bay from the Vesuvius volcano through Torre del Greco; an alternative explanation would be the presence of a strip of eruptive vents, settled on a system of NE-SW normal faults (Bernabini et al., 1971; Finetti & Morelli, 1973).

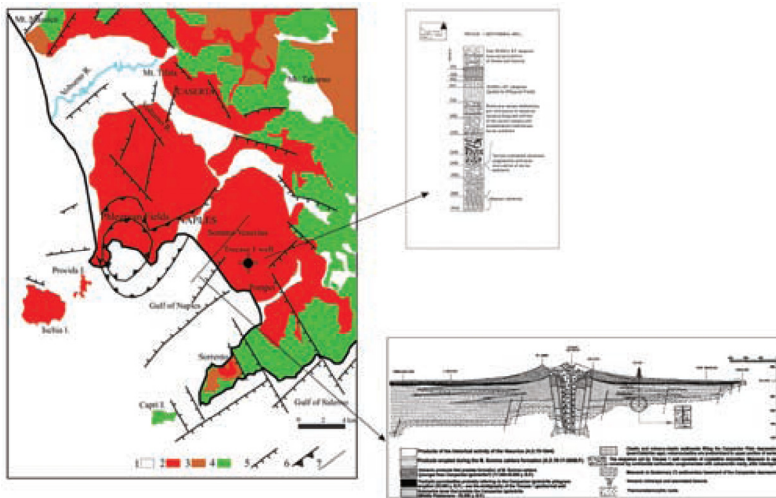


Fig. 5. Geological and structural sketch map of the Southern Campania Plain (after Aiello et al., 2010) . 1: Quaternary siliciclastic sediments. 2: Somma-Vesuvius volcanic deposits; Neapolitan-Phlegrean, Procida and Ischia volcanic deposits. 3: Pliocene and Miocene siliciclastic sediments. 4: Meso-Cenozoic carbonatic units. 5: faults. 6: caldera rims. 7: geological cross-sections. In the inset on the right: geological cross-section of the Somma-Vesuvius volcanic complex (from Principe et al., 1987). In the other inset: stratigraphy of the Trecase 1 exploration well drilled on the Somma-Vesuvius volcanic complex.

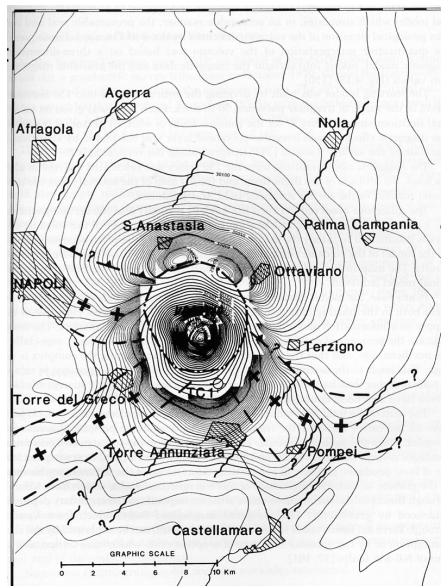


Fig. 6. Total magnetic field map of the Somma-Vesuvius area with sketch structural interpretation (slightly modified after Cassano & La Torre, 1987)



A new aeromagnetic map of the Vesuvian area has been recently produced (Paoletti et al., 2005; fig. 7). It is dominated by a large dipolar anomaly related to the Somma-Vesuvius volcanic complex, having an elliptical shape elongated towards south. Main geological structures of the area are a narrow anomaly on the western flank of the edifice (A in fig. 7) and an irregular shape of the anomaly on the south-eastern slope of the volcano, where small anomalies have been observed (B, C and D). A double minimum at the top of the volcano is articulated in a bigger one placed north of Mt. Somma and a larger one next to Valle dell'Inferno. High frequency anomalies occur in the area surrounding the edifice, related to the high cultural noise of this densely inhabited area.

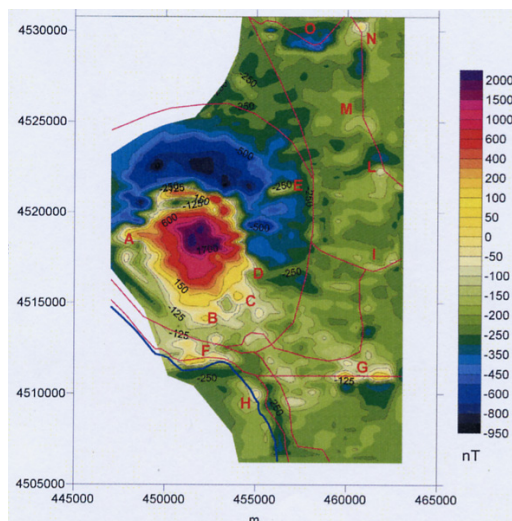


Fig. 7. Aeromagnetic map of the Vesuvian area (after Paoletti et al., 2005). The red lines show the railway lines, the blue line shows the coastline (see the text for the description of the magnetic anomalies).

### 3.2 Phlegrean Fields volcanic complex

The Phlegrean 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 & Sbrana, 1987). They correspond to a resurgent caldera (Rosi & Sbrana, 1987; Orsi et al., 2002) with a diameter of 12 km (Phlegrean caldera) and resulting from the volcano-tectonic collapse induced from the eruption of pyroclastic flow deposits of the Campanian Ignimbrite (37 ky B.P.). Coastal sediments ranging in age from 10.000 to 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 caldera center (Rosi & Sbrana, 1987; Dvorak & Mastrolorenzo, 1991).

Monogenic volcanic edifices, probably representing the offshore rim of the caldera center (Banco di Pentapalumbo, Banco di Miseno, Banco di Nisida) are well known from a geological and volcanological point of view (Latmiral et al., 1971; Pescatore et al., 1984; Fusi et al., 1991; Milia, 1996; Aiello et al., 2001; 2005; Fig. 8).

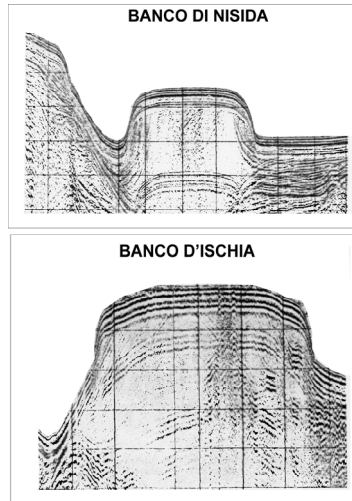


Fig. 8. Sparker seismic profiles showing the Banco di Nisida (upper inset) and the Banco di Ischia (lower inset) relic volcanic edifices (modified after Latmiral et al., 1971). The vertical scale is of 250 msec (tw).

The geological setting of the Phlegrean Fields and their stratigraphy have been discussed by Rosi & Sbrana (1987). The Quaternary volcanic area of the Phlegrean Fields is located in a central position within the graben of the Campania Plain.

The main structural element is represented by a wide caldera (the Phlegrean caldera; fig. 9), individuated after the volcano-tectonic collapse following the emplacement of the Campanian Ignimbrite (Barberi et al., 1991), a large pyroclastic flow, which covered the whole plain about 37 ky ago. Within the Phlegrean caldera and along its margins, the volcanic activity continued since to historical times (Rosi & Sbrana, 1987).

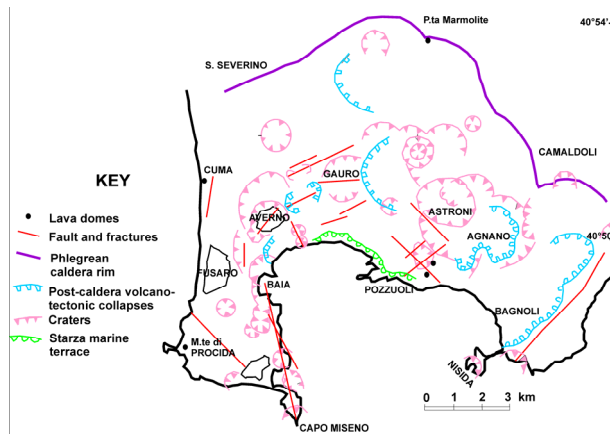


Fig. 9. Volcano-tectonic sketch map of the Phlegrean Fields volcanic complex (modified after Rosi & Sbrana, 1987).

Main volcano-tectonic structures are the Starza marine terrace, the Miseno-Baia area., the Mofete area and the central zone of Pozzuoli-Solfatara-Agnano (Rosi & Sbrana, 1987; fig. 9). The Starza terrace is a marine erosional terrace placed near the centre of the caldera, composed of littoral deposits overlain by thin subaerial pyroclastic deposits. It is articulated in two levels separated by a step; the upper one, on which the town of Pozzuoli is superimposed, reaches a height of 50-54 m, while the lower one develops at heights of 40 m. The Miseno-Baia area is characterized by an active fault at the Bacoli harbour, downthrowing the tuffs of the Bacoli volcano. Contemporaneous eruption in different sectors of the caldera have been suggested (Isaia et al., 2009).

Gravimetric and magnetometric informations available for Phlegrean Fields have been summarized (Cassano and La Torre, 1987) focussing on volcanological and structural reconstruction of the area. From north to south, the most important gravimetric elements are the positive anomaly related to the carbonatic horst of Massico Mt., the negative anomaly of the Volturmo graben, the positive gravimetric anomalies of Villa Literno and Parete, a marked gravimetric gradient with a counter-Appenninic trend, crossing the Somma-Vesuvius volcanic complex, and, to the south, separating the Acerra graben from the Pompei graben and finally, the gravimetric gradient corresponding to the Sorrento Peninsula. The total magnetic field map (Cassano & La Torre, 1987; fig. 10) has evidenced a strong positive anomaly in the area of Monte di Procida, related to the weaker anomalies of the Procida Channel, Procida and Ischia. It may be related to considerable volumes of lavas, confirmed by the presence of trachybasaltic and latitic eruptive centres at Procida. Another large magnetic anomaly characterizes the Astroni-Agnano volcanic area, probably the result of the overlapping of several lava bodies. Positive anomalies have been found at Camaldoli, probably related to pre-calderic lavas. The absence of magnetic anomalies in the Bagnoli-Posillipo area may be due to several factors, such as the limited presence of buried lavas or hydrothermal phenomena.

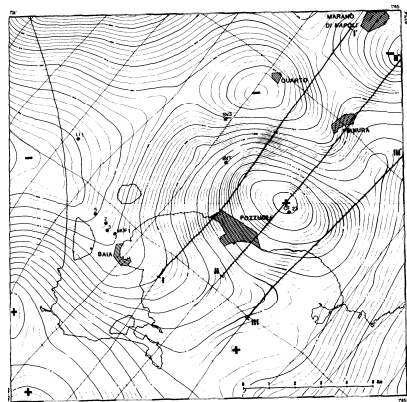


Fig. 10. Total magnetic field map of the Phlegrean Fields area (after Cassano and La Torre, 1987).

A new aeromagnetic map supplement of the northern sector of the Phlegrean Fields allows for a better geological interpretation of the structural patterns and morpho-structural features of the Volturmo Plain and the Gulf of Pozzuoli and its offshore areas (fig. 11). Main magneto-structural features are the caldera rims of the Neapolitan Yellow Tuff (fig. 11; A)

and the Torregaveta anomaly (fig. 11; B). A small anomaly corresponds to an isolated volcanic body (fig. 11; C). The Patria Lake anomaly (fig. 11; D) has a sub-circular shape and a diameter of about 10 km. A complex pattern of magnetic anomalies (fig. 11; E) coincides with the Parete volcanic complex (Aiello et al., 2011), while another isolated anomaly (fig. 11; F) corresponds to the Volturno river.

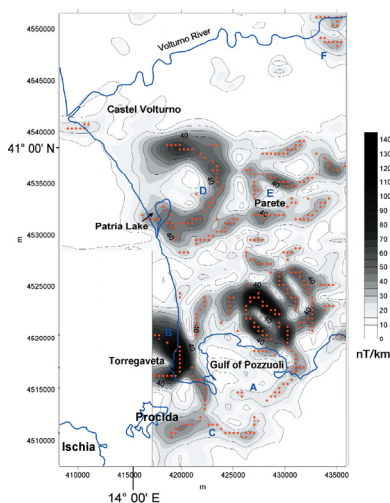


Fig. 11: Map of the horizontal derivative plotted in the gray scale of the southern Volturno Plain (reported from Paoletti et al., 2004). The letters A-F indicate the main magnetic anomalies recognized in the area.

### 3.3 Ischia and Procida volcanic complexes

The Ischia island represents an alkali-trachytic volcanic complex, whose eruptive activity lasted from the Late Pleistocene up to historical times (Vezzoli, 1988). A resurgent caldera, about 10 km wide, where the eruptive activity and tectonics gave rise to the uplift along faults of the Mount Epomeo block (Orsi et al., 1991). The main eruptive events of the Ischia-Procida-Phlegrean Fields system suggest at least five eruptive cycles, ranging in age from 135 ky to prehistorical and historical times. On the Ischia island volcanic deposits, resulting from both effusive and eruptive eruptions, extensively crop out and have constructed volcanic edifices; some of them are already well preserved, other ones are completely dismantled or buried (Forcella et al., 1981; Gillot et al., 1982; Luongo et al., 1987; Vezzoli, 1988). On the island landslide deposits, derived from the accumulation and fragmentation of pre-existing volcanic rocks, extensively crop out (Guadagno & Mele, 1995; Mele & Del Prete, 1998; Calcaterra et al., 2003; De Vita et al., 2006; 2007; Di Maio et al., 2007; Di Nocera et al., 2007).

Many geo-volcanologic studies have been carried out on the island, starting from the syntheses of Rittmann (1930; 1948) and then on the specific aspects of the eruptive activity of the island and related geological processes (Forcella et al., 1981; Gillot et al., 1982; Chiesa et al., 1985; 1987; Poli et al., 1987; 1989; Civetta et al., 1991; Orsi et al., 1991; Luongo et al., 1997). Particular meaning is covered by the aspects concerning the geochronology of the volcanic deposits in the island (Orsi et al., 1996) and the time evolution of the magmatic system (Luongo et al., 1997).

The geologic and volcanologic history of the Ischia island has been characterized by a main event, represented by the eruption of the Green Tuff of the Epomeo Mt., which verified 55 ky B.P. ago, allowing for the downthrowing of the central sector of the island consequent to a caldera formation (Orsi et al., 1991; Acocella et al., 1997; Acocella & Funciello, 1999). Consequently, the volcanic activity of the island has been conditioned by a complex phenomenon of calderic resurgence, started from 30 ky B.P., allowing for the gradual uplift and emersion of the rocks deposited in the caldera, initially submerged under the sea level. The rate of uplift, indicating the caldera resurgence, has been evaluated in about 800-1100 m (Barra et al., 1992).

The tectonic activity is characterized by systems of extensional faults, NW-SE and NE-SW trending, Plio-Quaternary in age (Acocella & Funciello, 1999; Acocella et al., 2004). NW-SE and NE-SW systems of extensional fractures predominate in all the island and around the resurgent caldera block, suggesting a relationship with regional extensional structures. N-S and E-W trending normal faults have been found along the rims of the Epomeo block and interpreted as controlled by the caldera resurgence. The process of resurgence has locally substituted the volcanic activity during the last 33 ky, since the most of the pyroclastic products coeval with the resurgence has been erupted out of the uplifted area.

Marine geological studies already showed that the Ischia island lies on a E-W trending volcanic ridge (Bruno et al. 2002; Passaro, 2005; de Alteriis et al., 2005). A Digital Elevation Model (DEM) of the Ischia island, based on Multibeam bathymetric surveys and integrated by onshore topography is shown in fig. 12.

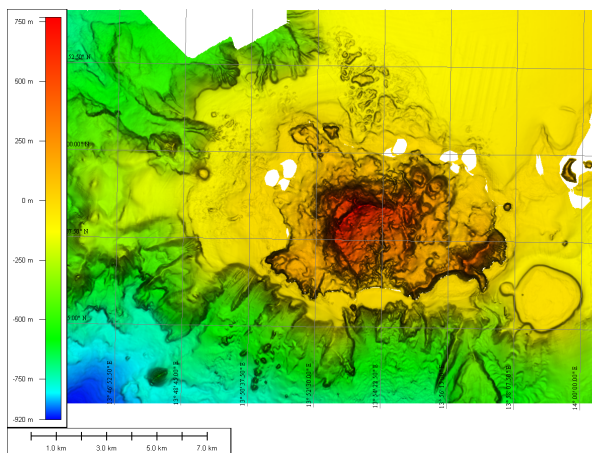


Fig. 12. DEM of the Ischia island resulting from the merging of different datasets of Multibeam bathymetry. The marine DEM has been merged with a Digital Terrain Model of the coastal area derived from topographic maps.

The continental slope off south-western Ischia island is incised by a dense network of canyons and tributary channels, starting from a retreating shelf break, parallel to the coastline and located at varying depths. Large scars characterize the platform margin off south-western Ischia island, in particular the scar of the southern flank of the island, corresponding onshore to the Mount Epomeo block and probably at the origin of the Ischia

Debris Avalanche (Chiocci & de Alteriis, 2006). Volcanic banks, having irregular morphologies, have been identified on the south-western flank of the island, as the "Banco di Capo Grosso" and the banks "G. Buchner" and "P. Buchner" (Passaro, 2005; de Alteriis et al., 2006). A large field of hummocky deposits, named the Ischia Debris Avalanche has put in evidence by swath bathymetric surveys coupled with Sidescan Sonar imagery and seismic profiles. Detailed piston coring and tephrostratigraphy suggested that the volcano-tectonic collapse originating the avalanche occurred during prehistorical times (Chiocci & de Alteriis, 2006). A stratigraphic framework for the last 23 ky marine record in the southern Ischia offshore has been recently constructed based on AMS  $^{14}\text{C}$  dating and tephrostratigraphic analysis (de Alteriis et al., 2010).

Previous studies on the stratigraphic sequences cropping out in the Procida island have been carried out (Rosi et al., 1988a; 1988b), improving the geological knowledge of the volcanic district (Di Girolamo & Stanzone, 1973; Pescatore & Rolandi, 1981; Di Girolamo et al., 1984). Five monogenic volcanoes (Vivara, Terra Murata, Pozzo Vecchio, Fiumicello and Solchiaro) have been active over the last 80 ky, producing pyroclastic deposits and lava domes. New stratigraphic data on Procida based on geochemistry of major and trace element of volcanic deposits older than 14 ky have been recently presented (De Astis et al., 2004).

#### **4. Marine seismic reflection and magnetic data in the Naples Bay: from old to new technologies**

Seismic exploration is commonly performed by means of sources that can generate elastic waves from a rapid expansion of underwater gas bubbles. This can generate many pulses that take the form of double exponential spikes of gradually decreasing amplitude (Cole, 1965). Several technologies can be used in order to produce an acoustic pressure wave into water such as free-falling weights, chemical explosives, piezoelectric or magneto-resistive sources, sparkers, boomers, airguns and water-guns. Each of these sources has a precise signature and wave frequency that can be considered optimal in function of depth, resolution, etc. The main characteristic of a seismic source is to produce a single high-energy spike that is detectable, despite the presence of noise, after crossing the portion of the seabed that we wish to study. A broad range of frequencies can be reproduced, as well as a broad range of waveforms can be generated in function of frequency-dependent absorption of elastic waves and nearby boundaries presence.

Seismic sources for offshore investigation may be impulsive, providing a short-lived burst of elastic wave energy and swept-frequency, producing a low-amplitude sinusoidal signal. Impulsive sources such as explosives can cause damages to marine flora and fauna; for this reason towed sources activated for only few seconds must be preferred. The type of source should be chosen depending on the required resolution and signal penetration. Vibration of piezoelectric and magnetic materials, electric pulses, or pressured fluid discharge, often organised into arrays, can be considered good seismic sources whose signature, spectra and energy output can vary considerably. Sparkers (Knott & Hersey, 1956) and Boomers (Edgerton & Hayward, 1964) systems are based respectively on an electrode array powered by high voltage capacitor bank and on an electromagnetic source. Sparkers and boomers can generate seismic energy to explore continental margin when there are near surface or deep-towed (10-50 m off the sea), moreover boomers with pulse length of 0.1-0.2 ms can be used to explore very shallow waters. Sparker system can produce low-frequency acoustic wave (the maximum frequency contained in the spectrum of acoustic signal is approximately 2000 Hz) that can penetrate several hundred meters of sediment.

The Multispot Extended Array Sparker (M.E.A.S.) is a seismic source consisting of sparker electrodes disposed on a square metal cage. This kind of system, patented by Institute of Oceanology of Istituto Universitario Navale of Naples (Italy) allows obtaining a good signal penetration and high resolution seismic data with relative small energy use. The M.E.A.S. signal is a short impulse with a large frequency spectrum content (fig. 13).

Mirabile et al. (1991) tested the acquisition geometry in order to reduce a superimposing of source signal with return echoes that respect the “far field” condition and demonstrated the utility of some techniques for signal de-convolution in order to produce the so-called seismic profiles “deghosting”. Seismic reflection data require a complex series of numerical treatments to increase the signal/ noise ratio of a single profile as well as obtaining a high resolution seismic section to improve the geological interpretation.

A more recent technology is the Sparker source SAM that is characterized by a varying number of electrodes that can be disposed as “dual-in line” (SAM96) and “planar array” multi electrode electro-acoustic source (SAM 400/800; fig. 14).

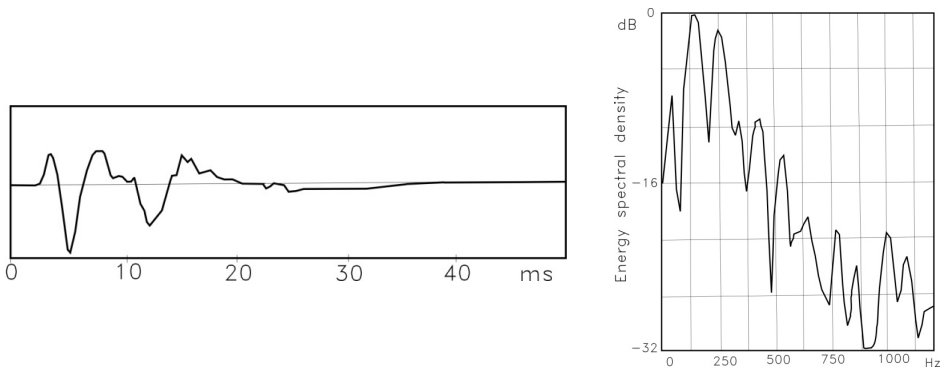


Fig. 13. Signature and spectrum of Multispot Extended Array System (modified after Mirabile et al., 1991).

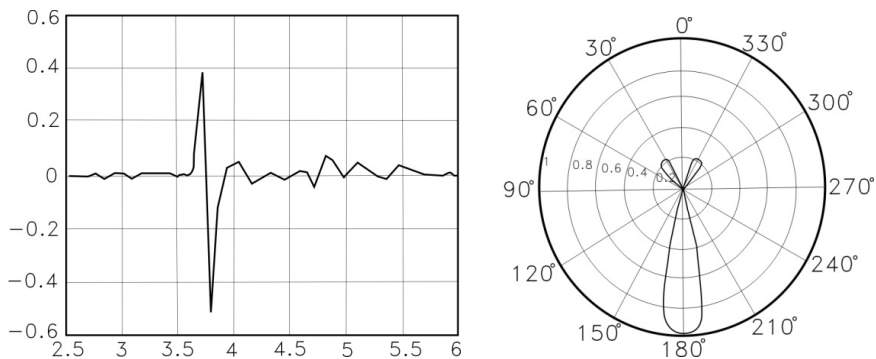


Fig. 14. Left: Signal (received by a sub-surface hydrophone) generated by SAM system at firing energy 200 J duration of primary impulse 0.3 ms (from Corradi et al., 2009); Right: Square radiation diagram that shows the high system directivity.

Other seismic sources are the Airguns and Waterguns, recently used in the Naples Bay in submarine geological mapping and basin studies (D'Argenio et al., 2004; Aiello et al., 2005; 2011). The former one produces high-energy seismic pulses short in duration by means of a discharge of compressed air into water (fig. 15), while the latter one produces the sudden collapse of a cavitation volume into water that is proportional to kinetic energy of the water plug. Airguns produce a wide range of pulse shapes and source spectra.

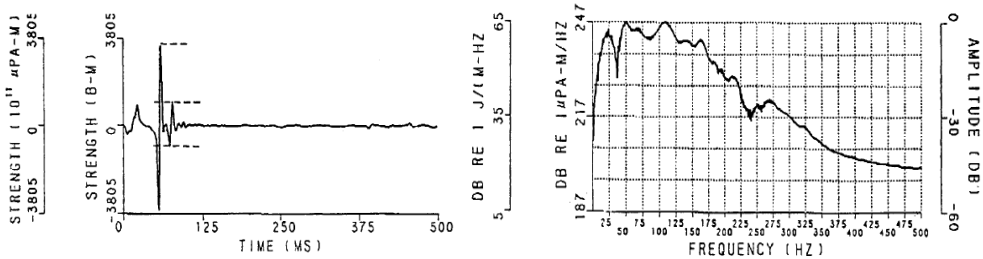


Fig. 15. Example of water-gun signature in far field and the frequency spectrum (modified after Ranieri & Mirabile, 1991).

The seismic exploration of Naples Bay has been performed mainly through Sparker systems and Watergun sources. The evolution of sources capability in terms of technological advances together with processing techniques refinement allowed high resolution studies of main intermediate and deep geological structures in the Bay of Naples. Historically some of the first surveys were conducted by R/V Atlantis II (Woods Hole Ocean. Cruise 59) using an Airgun System. Subsequently, in 1970 R/V Dectra owned by Istituto Universitario Navale of Naples (Italy) obtained a densely-spaced seismic survey through SPARKER E.G.G. (8 kjoules) and BOOMER systems in the Naples and Pozzuoli Bays (Latmiral et al., 1971; Bernabini et al., 1973).

Since the 70's until now many attempts have been carried out in order to improve seismic technologies performance, data acquisition, and processing. In the practice of seismic prospecting, Sparker systems technologies were widely analyzed using different acquisition systems. Some ones consist of a single electrode hotter than a mass electrode, other ones of more electrodes over distributed mass (eg. Sparker Teledyne and Sparker EGG).

De Vita et al. (1979) tried to identify, also based on experimental data, which one is more appropriate than the two configurations (single electrode or multi-electrode) based on the fundamental equations for the design of an "array". Sparker signals are the base band signals, transitory and continuous spectrum. Based on these measurements it has been demonstrated that energy should never exceed 400 joules/electrode to achieve the best compromise between resolution and electro-acoustic performance.

Ranieri and Mirabile (1991) reported technical and scientific results obtained through the geophysical survey of the deep geological structure of the Phlegrean Fields volcanic complex. It was aimed at improving the knowledge on technologies and sources that are more appropriated for the investigation of the continental margins, particularly in complex volcanic areas like the Gulf of Naples (Fusi et al., 1991).



Among the sources tested in studies of the Gulf of Naples there are the explosives (Mirabile et al., 1989), the Sparker and the Watergun, while the details to study geomorphological data were analyzed through the Surfboom and the Side Scan Sonar. MEAS (Multispot Extended Array Sparker; Mirabile et al., 1991) seismic source (12 and 16 KJ), consists of an array of 36 (6x6) electrodes placed inside a metal cage in a square size 4.5x4.5 m, spaced 0.75 m and fed in phase. The energy used by the MEAS has a pulse of short duration, the order of 10 milliseconds and a significant spectral content up to 1000 Hz, with maximum energy output around 150 - 200Hz. Each echo corresponds to an acoustic discontinuity (impedance contrast) that can generally be interpreted in geological terms.

MEAS system has been largely used in order to acquire a large database of single channel reflection seismics in the Bay of Naples (Mirabile, 1969; Latmiral et al., 1971; Mirabile et al., 1991).

Recently, by means of Multi- tip SAM 96 (0.1-1kJ), SAM400 (1-4KJ) transducer it was possible to record high resolution seismic data in the Bay of Naples both in coastal and deep sea research (Corradi et al., 2009). Some evidences on magnetic field anomalies in the Gulf of Pozzuoli come from the magnetic map of Galdi et al. (1988) who reported a NE-SW interruption of main regional trend where some circular local anomalies are related to products of post-calderic volcanic activity (Rosi & Sbrana, 1987).

Significant correlations between geophysical data come from the comparative analysis of seismic and magnetometric datasets. A magnetometer usually measures the strength or direction of the Earth's magnetic field. This last can vary both temporally and spatially for various reasons, including discontinuities between rocks and interaction among charged particles from the Sun and the magnetosphere. Most technological advances dedicated to measure the Earth's magnetic field have taken place during World War II. Presently, the most common are: the fluxgate, the proton precession, Zeeman-effect, sensor suspended-magnet, and satellite magnetometers. The fluxgate and the proton precession are effectively the most used for marine surveys, they are both cable drawn. The fluxgate magnetometer was the first ship-towed instrument, and it can measure vector components of the magnetic field. Its sensor consists of two magnetic alloy cores that are mounted in parallel configuration with the windings in opposition. The proton precession magnetometer consists of a sensor containing a liquid rich in protons surrounded by a coil conductor, the sensor is towed from the vessel through an armoured coaxial cable whose length depends on vessel length and seafloor depth. Circulating current within the coil generates a magnetic field of approximately two orders of magnitude the Earth's field, in this way 1 proton each 10 will follow the coil positioning. Stopping the induced magnetic field, the protons will align according to the Earth's magnetic field through a movement of precession.

The proton precession magnetometer is one of the most used for offshore surveys and it records the strength of the total field by determining the precessional frequency ( $f$ ) of protons spinning about the total field vector ( $F$ ) as follows:

$$f = \gamma_p F / 2\pi \quad (1)$$

where  $\gamma_p$  is the gyromagnetic ratio of the proton uncorrected for the diamagnetic effect, so that knowing its from laboratory measurements, the total field in nanotesla can be calculated as:

$$F=23.4866 \times f \quad (2)$$

The total field calculated by means of equation (2) is stored by magnetometer into a string of data containing position data that is displayed as an  $x,y$  chart. The signal frequency is measured on a time span of 0.5 seconds when the signal-noise ratio is highest. To ensure a maximum value of initial value of proton precession the angle between the axis of the coil and the Earth's field it is necessary to use two orthogonal coils. The measured field must be corrected with respect to the regional field in order to evaluate the anomalies.

The proton precession magnetometer was largely used to explore magnetic anomalies in the Bay of Naples. Interesting examples of magnetic data acquisition related in the Bay of Pozzuoli and Naples is reported in Galdi et al. (1988) and Aiello et al. (2004). As shown in Fig. 16 (modified after Galdi et al., 1988) both positive and negative anomalies were detected, using a magnetometer model Geometrics G-856, globally the area shows an interruption of the regional trend from NE-SW where circular anomalies are probably connected to a post-calderic activity of the Phlegrean Fields. Moreover, the internal area of the Pozzuoli Bay is characterized by a negative anomaly that increases towards the south. Conversely, in the external area there is mainly an alternance of positive and negative anomalies with a dominance of positive values near the area of Bagnoli. For a detailed analysis of the magnetic anomaly field of the volcanic district of the bay of Naples see Secomandi et al. (2003). Recently, Aiello et al. (2004) presented a high resolution map of the Bay of Naples based on data acquired during oceanographic cruise GMS2000-05 performed in October-November 2001 on board of the R/V Urania using the EG&G Geometrics proton magnetometer G-811.

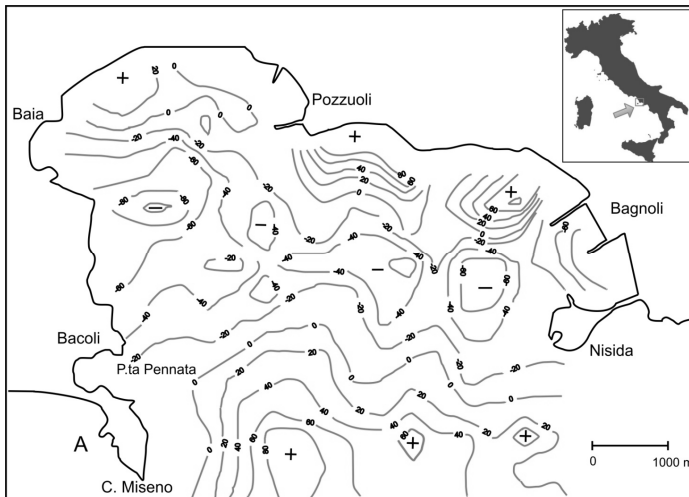


Fig. 16. Magnetic field anomalies in the Bay of Pozzuoli (modified after Galdi et al., 1988).

## 5. Results

Main results on seismic stratigraphy and marine magnetics of selected areas in the Naples Bay, i.e. Somma-Vesuvius volcanic complex offshore, Naples Gulf and Phlegrean Fields

volcanic complex offshore and Ischia and Procida volcanic complexes offshore are illustrated in the following paragraphs based on seismic and magnetic datasets.

### **5.1 Seismic stratigraphy and marine magnetism of the Somma-Vesuvius volcanic complex offshore**

A three-dimensional reconstruction of a large volcanic structure located offshore the Somma-Vesuvius volcano, next to the town of Torre del Greco (Naples, Italy) has been recently carried out (Aiello et al., 2010). It represents the seaward prolongation of the Vesuvius volcano and has been carried out using integrated geological interpretation of densely spaced Watergun seismic profiles and magnetic data recorded on the same navigation lines. Magneto-seismic modelling makes available new information on the geological structure of the Vesuvius volcano, relatively to its offshore.

In the study area the magnetic properties allow one to categorize the volcanic nature of seismo-stratigraphic units recognized through seismic interpretation. A semi-quantitative integrated interpretation of bathymetric and seismic data has been obtained resulting in a 3D topographic and seismic reconstruction of the Torre del Greco volcanic structure.

Significant results on the shallow crustal structure of the Vesuvius volcano and the relationships between seismic velocities and rock lithologies in volcanic environment have been recently obtained based on seismic passive tomography of the volcano (Zollo et al., 1996; 1998; 2003; Capuano et al., 2003). Onshore seismic reflection data on the volcano indicated a SW lateral collapse, which probably occurred between 35 and 11 ky ago (Bruno and Rapolla, 1999). Buried seismic units with reflection free interiors have been interpreted as volcanic deposits erupted during and since the formation of the breached crater of the Monte Somma volcano, preceding the growth of Vesuvius (Milia et al., 1998). Other features include the warping of lowstand marine deposits by undersea cryptodomes, normal faults indicating a seaward collapse of a volcano and a small undersea slump produced by Vesuvius eruption of 1631. The AD 79 Plinian eruption of Vesuvius that buried Pompei and Herculaneum began with pumice falls followed by pyroclastic currents (Milia et al., 2008). These currents reached Herculaneum and entered the sea, forming a fan.

A belt of sharp magnetic anomalies has been already highlighted offshore the Vesuvius volcano (Aiello et al., 2004), suggesting the occurrence of a NNW-SSE structural alignment of magnetic anomalies and related seismic structures. This has not been mentioned by previous authors, who had suggested NE-SW trending normal faults (Bernabini et al., 1973; Finetti & Morelli, 1973; Cassano & La Torre, 1987). Slight magnetic anomalies, located offshore the town of Torre Annunziata, probably correspond to the seaward prolongation of the Vesuvian lavas.

Seismic interpretation already enabled the identification of acoustically transparent, mound-shaped volcanic structures. These correspond to sharp and delineated magnetic anomalies, overlying the top of a seismic unit, interpreted as Campanian Ignimbrite pyroclastic flow deposits (CI; 35 ky B.P.; fig. 17). The volcanic domes represent submerged or buried parasitic vents, genetically related to the activity of the Somma-Vesuvius volcano during recent times (Aiello et al., 2004; 2005).

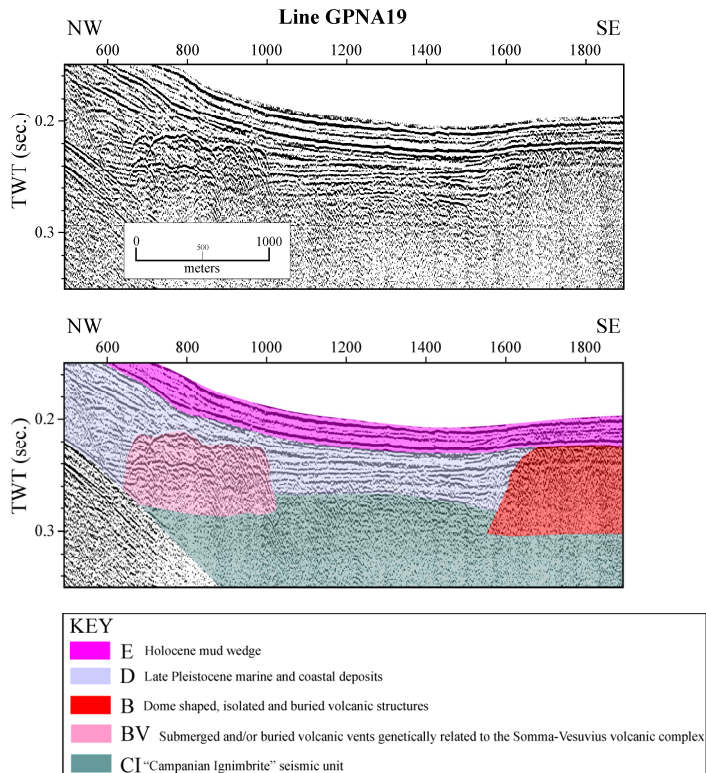


Fig. 17. Multichannel seismic profile GPNA19 located offshore the Vesuvius and corresponding geologic interpretation (reported after Aiello et al., 2010). Two isolated buried volcanic mounds occur near the top of the Campanian Ignimbrite volcanic unit (in grey-blue in the profile). If we consider the CI unit as a stratigraphic marker (35 ky B.P.) the age of the establishment of the volcanic domes on the Naples Bay continental shelf is probably post 35 ky B.P.

Several seismic units and related unconformities have been recognized (D, CI, BV, B, E units in the figures). The deepest one (D unit) is represented by the upper part of a Middle-Late Pleistocene prograding wedge, supplied by the Sarno river mouth, characterized by low angle dipping reflectors, indicating a NW-SE progradation. Its top is truncated by an erosional unconformity marking also the base of the CI unit.

The CI represents an important seismic unit occurring in the eastern Naples Bay (Fig. 17). The CI pyroclastic flow deposits carpeted the whole Campania Plain during a major eruption related to the Phlegrean Fields about 35 ky B.P. (Rosi & Sbrana, 1987). This unit underlies both the Torre del Greco volcanic structure and buried and isolated mounds. Since the CI represents an important stratigraphic marker in the Naples Bay, it can be assessed that both the isolated domes and the Torre del Greco volcanic structure are younger than 35 ky B.P. (age dating of the CI deposits). Buried and isolated volcanic mounds, genetically related to the Vesuvius activity, have been distinguished through seismic interpretation (fig. 17).

The Torre del Greco volcanic structure extends for about 7.5 km offshore the Vesuvius and corresponds to a main magnetic anomaly (fig. 18) reaching intensity of 400 nT. It shows an acoustically transparent seismic facies and three main elevated peaks.

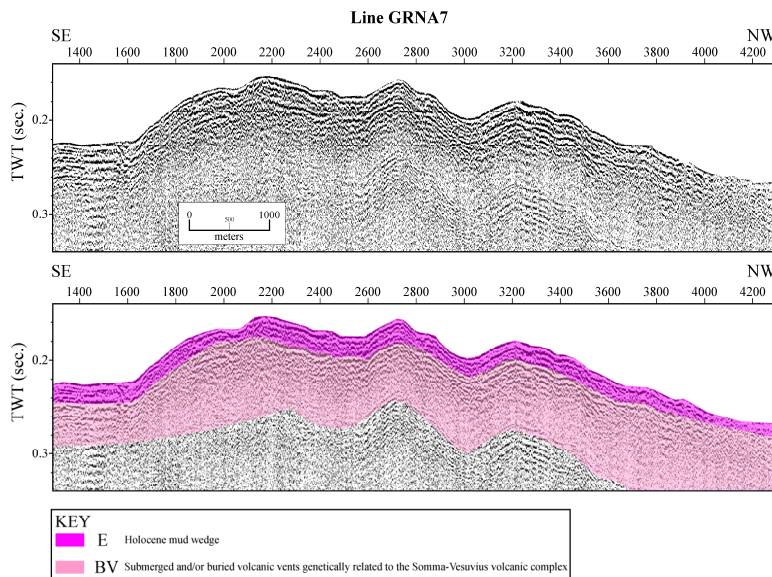


Fig. 18. Multichannel seismic profile GRNA07 located offshore the Vesuvius and corresponding geologic interpretation (reported after Aiello et al., 2010). The Torre del Greco volcanic structure is depicted by the profile.

The total magnetic field offshore the Somma-Vesuvius volcanic complex shows that the shape of the anomalies is dipolar; there is no apparent effect caused by the occurrence of remnant magnetization with a different direction to that of the present-day main field (fig. 19). Three main anomalies are evident following a NW-SE direction, the most southern of which being the least intense, in a relatively magnetically quiet area. The volcanic structures recognized on seismic profiles are located in a complex magnetic anomaly area, which is made up of several anomalies, reaching a maximum intensity of 400 nT. This is one of the highest values detected in the whole Naples Bay. These volcanic bodies represent the seaward prolongation of the Vesuvius volcano. They are interpreted as a strip of volcanic vents, which have been settled on a system of NNW-SSE normal faults, as confirmed by the integrated interpretation of seismic, magnetic and bathymetric data.

## 5.2 Seismic stratigraphy and marine magnetics of the Naples Bay and Phlegrean Fields volcanic complex offshore

A grid of Sparker Multitip seismic profiles recorded in the Gulf of Pozzuoli in the frame of research projects of submarine geologic cartography has been interpreted to give new insights on seismic stratigraphy of Pozzuoli, i.e. the submarine prolongation of the Phlegrean Fields volcanic complex. The navigation map of the interpreted sections in the Gulf of Pozzuoli is shown in fig. 20.

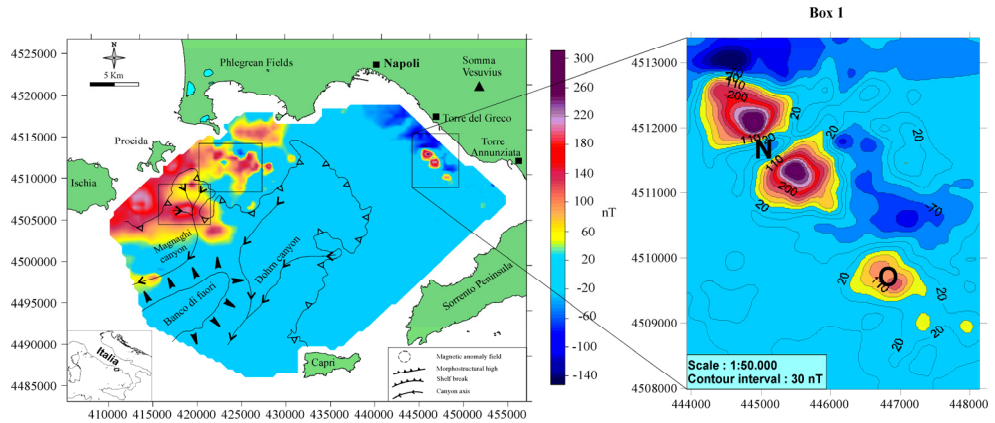


Fig. 19. Map of the total magnetic field offshore the Somma-Vesuvius volcanic complex. In the inset on the left map of the total magnetic field of the Naples Bay (reported after Aiello et al., 2010). In the inset on the right detailed map of the magnetic anomalies off the volcano. Three intense and dipolar magnetic anomalies are aligned along a direction parallel to the Tyrrhenian coast, having settled along a system of NNW-SSE trending normal faults offshore the volcano.

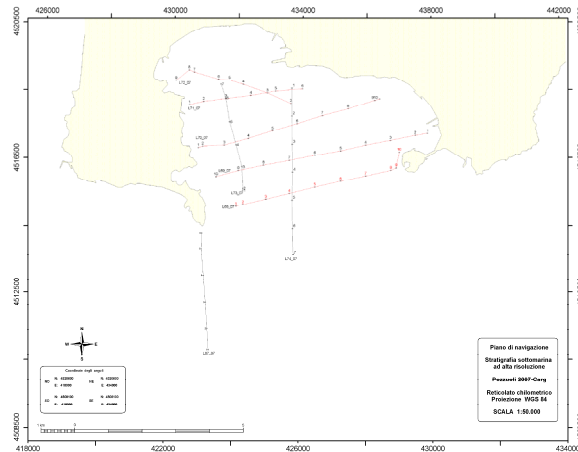


Fig. 20. Navigation map of interpreted seismic profiles in the Pozzuoli Bay

The seismic profile L68\_07 (fig. 21) running from the western continental shelf of the Pozzuoli Gulf and the Nisida island has been interpreted to show the main stratigraphic and structural features of the Pozzuoli Gulf, reported in the geological interpretation (in the low inset of fig. 21).

A sketch stratigraphic table (Fig. 22) represents the key to the geological section of fig. 21 and describes the main characteristics and possible chronostratigraphic attribution of the seismic units (Milia, 1998). Large compressional features have been individuated on the seismic section, i.e. the Punta Pennata anticline, the central syncline of the Pozzuoli Gulf and the

Nisida anticline. These features involve intensively in deformation the volcano-sedimentary unit V3 (fig. 21) and have individuated during compressional events genetically related to main tectonic and magmatic events involving the Pozzuoli area during the Late Quaternary.

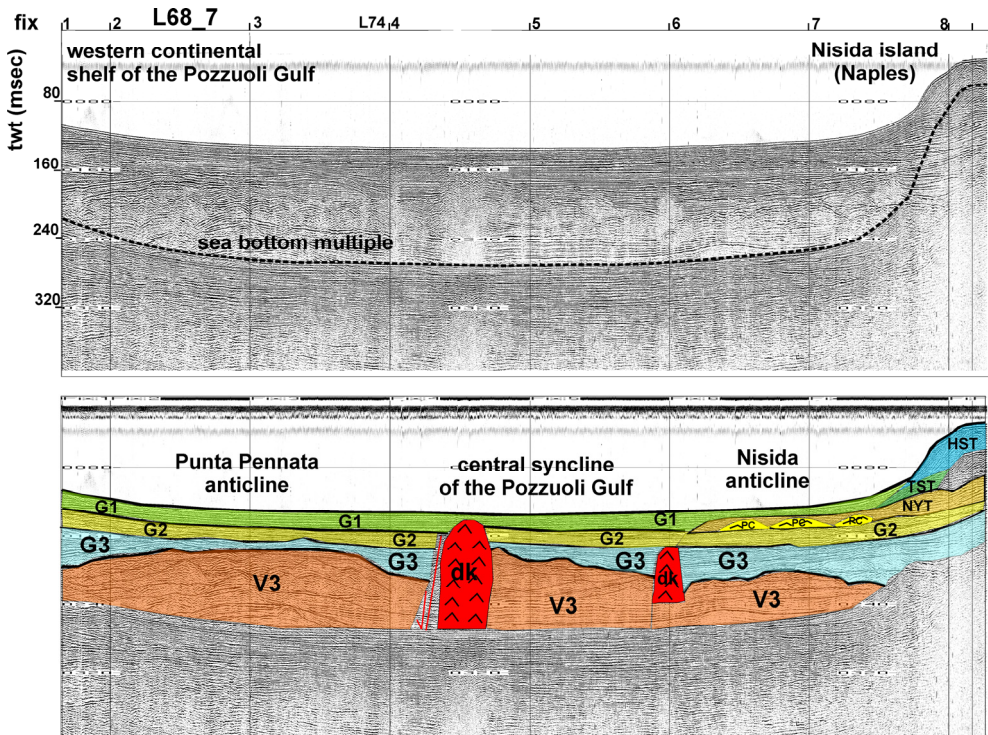


Fig. 21. Seismic profile L68\_07 in the Pozzuoli Gulf and corresponding geological interpretation

Kilometer-scale folding deformed the Pozzuoli sequences during an important compressional event. In fact, the uplift of the marine terrace of "La Starza", on which the Pozzuoli town is located (Colantoni et al., 1972; Dvorak & Mastrolorenzo, 1991; Barra, 1992) and the formation of an erosional platform on the inner Pozzuoli continental shelf are linked to an anticlinal crest, while the present basin depocenter is located on a syncline (fig. 21). These folds formed during the deposition of the seismic sequence G3 (fig. 21), characterized by wedging geometries thinning towards the hinge of the anticline.

The seismo-stratigraphic analysis has allowed to distinguish eight main seismic units (figs. 27 and 28). The oldest one (V3 figs. 21 and 22) is a volcano-sedimentary unit related to the northern margin of the Pentapalumbo Bank, characterized by discontinuous seismic reflectors. The unit is intensively deformed in correspondence to Punta Pennata and Nisida anticlines, separated by the central syncline of the Pozzuoli Gulf. The overlying unit (G3 figs. 21 and 22) is composed of clastic deposits, characterized by discontinuous to parallel seismic reflectors. It has deposited in the whole Pozzuoli Gulf and is characterized by wedging and growth due to synsedimentary deformation contemporaneous to the individuation of folds.









<b>KEY</b>	
	<b>HST</b> Highstand system tract of the Late Quaternary depositional sequence, characterized by progradational seismic reflectors at the foot of the Nisida island
	<b>TST</b> Transgressive system tract of the Late Quaternary depositional sequence, characterized by retrogradational seismic reflectors at the foot of the Nisida island
	<b>G3</b> Sedimentary unit probably composed of clastic deposits (4 ky B.P.) characterized by parallel seismic reflectors, deposited in whole Pozzuoli Gulf
	<b>NYT/PC</b> Wedge shaped unit composed of the pyroclastic deposits of the Neapolitan Yellow Tuff (12 kyB.P.) deposited in the Naples offshore; PC: tuff cones of the Nisida complex, genetically related to the Nisida Bank and to the Nisida island, in facies heterophy with the NYT unit.
	<b>G2</b> Sedimentary unit probably composed of clastic deposits (8-4 ky B.P.) characterized by parallel seismic reflectors, deposited in whole Pozzuoli Gulf
	<b>dk</b> Volcanic dykes, characterized by sub-vertical volcanic bodies, acoustically transparent and locally bounded by normal faults
	<b>G3</b> Sedimentary unit probably composed of clastic deposits (12-8 ky B.P.) characterized by discontinuous to parallel seismic reflectors, deposited in whole Pozzuoli Gulf; characterized by wedging and growth due to synsedimentary deformation contemporaneous to the individuation of anticlines and synclines
	<b>V3</b> Volcano-sedimentary unit related to the northern margin of the Pentapalummo bank (150<V3<18 ky B.P.), characterized by discontinuous seismic reflectors; intensively deformed in correspondence to anticlines (Punta Pennata anticline and Nisida anticline) and synclines (central syncline of the Pozzuoli Gulf), individuated due to compressional deformation genetically related to main magmatic events

Fig. 22. Sketch table of the seismic units recognized in the stratigraphic sketch diagram of fig. 21 (Pozzuoli Gulf).

The dk unit distinguishes volcanic dykes, characterized by acoustically transparent sub-vertical volcanic bodies, locally bounded by normal faults. The G2 unit is composed of clastic deposits and is characterized by parallel seismic reflectors in the whole Pozzuoli Gulf.

From the central Pozzuoli Gulf to Nisida a wedge-shaped seismic unit, genetically related to the Neapolitan Yellow Tuff (NYT; 12 ky B.P.; Scarpati et al., 1993) has been identified (fig. 21). It interstratifies with the tuff cones of the Nisida complex, genetically related to the Nisida bank and the Nisida island (PC fig. 21). The NYT/PC unit is overlain by the G3 unit, the most recent one in the sedimentary filling of the Pozzuoli area (fig. 21). TST and HST deposits of the Late have also been identified off the Nisida island.

The interpreted map of the magnetic anomalies in the Gulf of Pozzuoli is shown in fig. 23 (modified after Galdi et al., 1988). It has allowed to distinguish both areas characterized by positive anomalies (represented in yellow) and areas characterized by negative anomalies (represented in light yellow). The inner continental shelf of the Gulf of Pozzuoli is regarded as negative magnetic anomalies. In particular, the area surrounding the Pozzuoli harbour (from the Caligola pier to the Pirelli jetty) does not show significant magnetic anomalies. On the contrary the area adjacent the resort Lucrino-Punta Pennata owns a negative anomaly increasing southwards up to the magnetic minimum at 600-700 m in correspondence to the



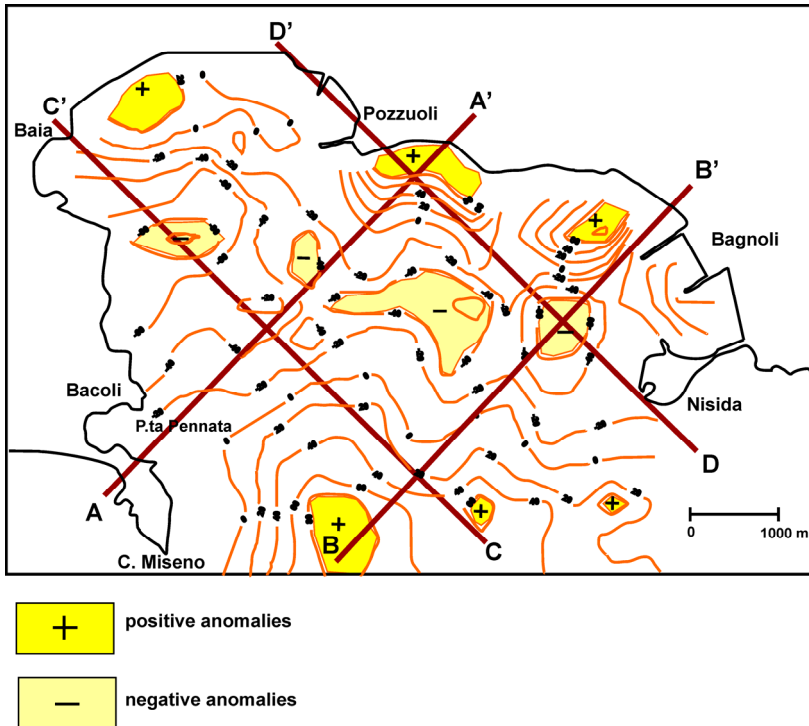


Fig. 23. Interpreted map of the magnetic anomalies of the Gulf of Pozzuoli (modified after Galdi et al., 1988). The positive anomalies are represented in yellow and the negative anomalies in light yellow.

Baia Castle ( - 100 nT). On the outer shelf of the Gulf of Pozzuoli it is possible to observe alternating magnetic maxima and minima. In particular, an area of magnetic maximum is located on a belt long about 1.7 km, NE-SW oriented. At the same time, the inner continental shelf of the Gulf of Pozzuoli, from Bagnoli to the Rione Terra of Pozzuoli shows two strong magnetic anomalies, separated by a thin belt having a normal magnetic value. Proceeding seawards, in the offshore surrounding Bagnoli, two magnetic minima (- 40 nT and - 60 nT) are positioned, which result slightly E-W elongated, culminating with the absolute magnetic minimum (-100 nT) in correspondence to the Baia Castle. Four magnetic sections, respectively NE-SW and NW-SE oriented have also been constructed (fig. 24; modified after Galdi et al., 1988). On the vertical axis the magnetic anomalies (nT) and the depths (m) have been reported on the same scale, while on the horizontal axis the distances, expressed in meters have been reported (fig. 24).

The magnetic section A-A' (in the upper inset of fig. 24) runs from Punta Pennata to the Pozzuoli town (Via Napoli). The total magnetic intensity shows a trending with a magnetic minimum of - 80 nT in the central area (corresponding to a depth of the sea bottom of - 90 m) and a magnetic maximum of 70 nT in correspondence to the Pozzuoli shoreline. The magnetic section B-B', translated of 2.4 km towards south-east, shows, starting from south-west a monotonous magnetic trend up to the offshore surrounding Nisida, where a strong

increase of the gradient occurs. The magnetic highs occurring nearshore appear to be related not to the geology, but to the occurrence of the industrial systems of Bagnoli.

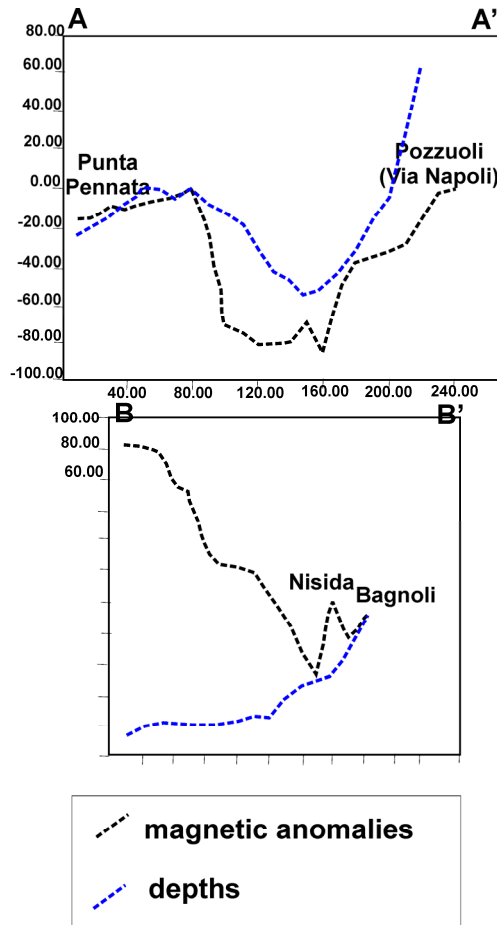


Fig. 24. Magnetic sections of the iso-anomalies NE-SW oriented in the Pozzuoli Gulf (modified after Galdi et al., 1988).

### 5.3 Seismic stratigraphy and marine magnetics of Ischia and Procida volcanic complexes offshore

Marine geophysical data, in particular Multibeam bathymetry and reflection seismics have allowed to study the submerged sectors of the Ischia island (Naples Bay; Aiello et al., 2009c; Passaro, 2005). They are the site of submarine instability processes, having both catastrophic (instantaneous) and continuous characteristics (accelerated erosion along submarine canyons or channels, debris fluxes along channels and creeping). The geological interpretation of the marine DEM of Ischia island, already shown in fig. 12 has put in evidence an articulated topography of the sea bottom. A complex stratigraphic architecture,

with intercalations between volcanic and sedimentary units is revealed by the interpretation of high resolution seismic reflection profiles.

A sketch stratigraphic scheme has been constructed in the northern Ischia offshore (fig. 25). Forced regression prograding wedges (FST), pertaining to the Late Quaternary depositional sequence, appear on the continental shelf off the northern Ischia island. Debris avalanche deposits, having a wedge-shaped external geometry and chaotic facies are arranged in two distinct, superimposed bodies (H1 and H2). The wedges are characterized by facies heterogeneity with the upper seismic unit of the basin filling. The lower seismic unit has parallel reflectors and shows bidirectional onlaps in correspondence to depressions eroding the top of the underlying seismic unit. The intermediate unit is characterized by parallel to sub-parallel seismic reflectors. It shows a strong wedging in correspondence to a normal

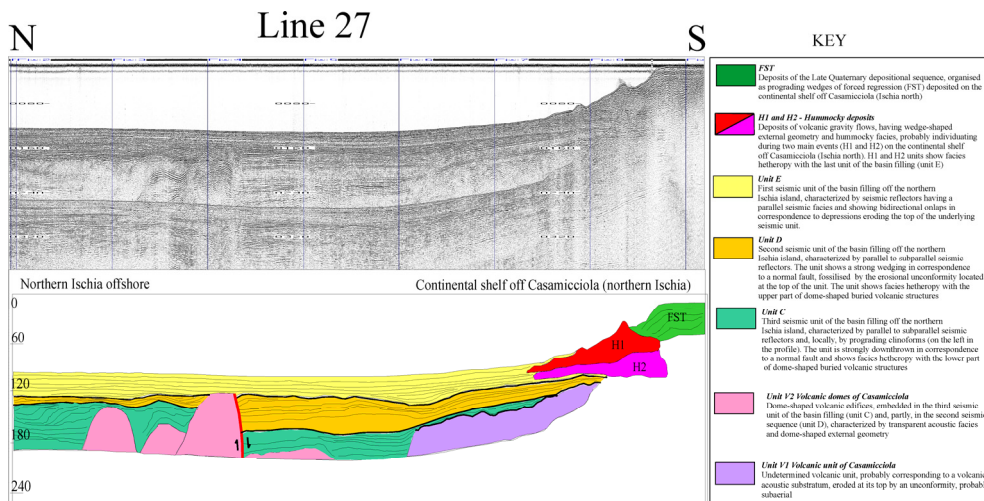


Fig. 25. Seismic profile L27 offshore northern Ischia and corresponding geological interpretation (modified after Aiello et al., 2009).

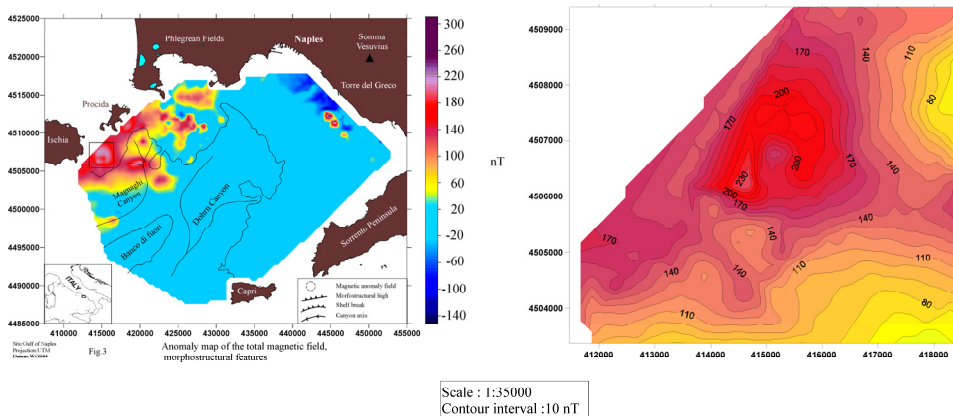


Fig. 26. Total magnetic field map of the Ischia Bank (south-eastern Ischia offshore)

fault (fossilized by an erosional unconformity located at the top of the unit) and stratigraphic relationships of facies heteropy with the upper part of dome-shaped, buried volcanic structures. The upper unit is characterized by parallel to sub-parallel seismic reflectors and locally by prograding clinoforms. It appears to strongly downthrown in correspondence to a normal fault and shows facies heteropy with the lower part of dome-shaped buried volcanic structures. Mounded volcanic edifices are in lateral contact with the lower seismic unit of the basin filling and partly, with the second one and are truncated by an erosional unconformity located at the top of the unit 3. An undetermined volcanic unit, having facies heteropy with the unit 3 is eroded at the top by a subaerial unconformity and interpreted as volcanic acoustic basement. A total magnetic field map of the Ischia Bank is shown in fig. 26.

## 6. Conclusions

Seismic stratigraphy and marine magnetics in the case histories of Somma Vesuvius offshore, Phlegrean Fields offshore and Ischia and Procida offshore (Naples Bay) have been studied through the interpretation of seismic and magnetic data. The obtained results have improved the geological knowledge in an active volcanic area such as the Naples Bay, since they have disclosed and located several main volcanic bodies based on seismic interpretation, well constrained by the occurrence of significant magnetic anomalies.

Offshore the Somma-Vesuvius volcanic complex, the integrated interpretation of seismic and magnetic data suggests a correlation of the anomalies with three main elevated peaks of the large volcanic structure located offshore the Torre del Greco town, along a NNW-SSE direction in water depths ranging from - 80 m to - 110 m.

Seismo-stratigraphic evidence is represented by acoustically-transparent seismic facies and high contrasts of acoustic impedance compared to the overlying sediments, mound-shaped external geometry and average dimensions measurable in terms of kilometres. The base of the volcanic bodies is not acoustically evident, because they overlie the seismic unit correlated with the Campanian Ignimbrite pyroclastic flow deposits. The top of the structures is irregularly eroded and can show several culminations, as in the case of the Torre del Greco volcanic structure. The thickness of the overlying Holocene sediments is significantly reduced in correspondence to most structures, while other mounds appear to have fossilized by Late Pleistocene-Holocene sediments.

The total magnetic field offshore the Somma-Vesuvius volcanic complex shows three main maximum values for the anomalies, dipolar in shape. These maximum values correspond to the culminations of the structure observed in the Torre del Greco offshore based on seismic stratigraphy. Other minor volcanic structures, identified by seismic interpretation and fossilized by sediments, do not correspond to any magnetic anomaly field. This is probably due to their composition, more similar to that of tuff cones (rather than lavas), which are not related to any magnetic anomaly field, similarly to the important seismic unit related to the Campanian Ignimbrite pyroclastic flow deposits. The rising of the Torre del Greco volcanic structure corresponds to the occurrence of topographic undulations of the sea bottom of up to ten metres. This is confirmed by the interpretation of seismic profiles, showing three main vertical culminations of the volcanic structure, where overlying sediment drape is significantly reduced. These culminations are linked to magnetic anomaly extremes, with values ranging between 250-350 nT.

Offshore the Phlegrean Fields volcanic complex significant magnetic anomalies are located in a belt of submarine volcanic banks located in the outer shelf of the Gulf of Pozzuoli (fig. 27). Box 2 in fig. 27 shows that the Phlegrean Fields offshore represents a relatively complex magnetic anomaly area. Two dipolar anomalies, characterized by a maximum-minimum couple, have been identified. The first anomaly, E-W oriented and located in the northern area shows a minimum of  $-200$  nT, associated to a maximum of  $+185$  nT. These values may 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 eastern area, shows a maximum-minimum couple with a similar intensity. Other anomalies, not dipolar and of lower intensity, ranging between  $40$  and  $135$  nT are due to the occurrence of small volcanic edifices (fig. 27). A significant magnetic anomaly, in the order of  $150$  nT occurs at the Magnaghi canyon head (Box 3 in fig. 27), deeply eroding the volcanic deposits of the continental slope of Procida island. This confirms that the Magnaghi canyon is incised in volcanic deposits. On the contrary, the slope of the Gulf of Naples in correspondence to the Dohrn canyon, a kilometric feature crossing the Bay does not show magnetic anomalies, confirming that this canyon deeply erodes sedimentary units supplied by the palaeo-Sarno river mouth.

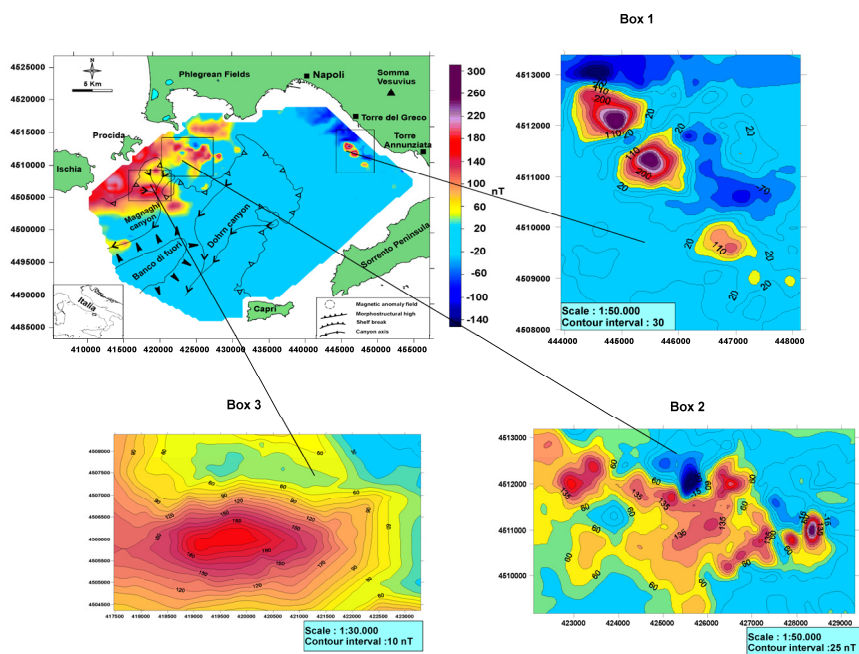


Fig. 27. High resolution magnetic anomaly map of the Naples Bay (modified after Aiello et al., 2005). Box 1 represents a magnetic anomaly area located offshore the Somma-Vesuvius volcanic complex, while Box 2 represents another magnetic anomaly area located offshore the Phlegrean Fields volcanic complex. Box 3 represents a magnetic anomaly area located on the continental slope of the gulf, at the Magnaghi canyon's head.

The interpreted map of the magnetic anomalies in the Gulf of Pozzuoli (fig. 23) has allowed to distinguish positive and negative magnetic anomaly areas. The inner continental shelf of the Gulf of Pozzuoli is regarded as negative magnetic anomalies and the correlation with the volcanic structures evidenced by the Sparker data is not clear. This is probably due to the necessity to record a densely-spaced magnetic survey, in order to identify on marine magnetics the volcanic dykes shown by seismic profiles. The volcanoclastic unit identified on seismic profiles does not seem to produce significant magnetic signatures, probably due to its composition (tuffs rather than lavas).

In order to describe some morphological features of the study area, elevation versus average slope plots have been used, allowing to highlight where steep and flat areas occur (Moore & Mark, 1993). Such a plots have been derived by DEMs and slope maps through an opportunely built routine. Their use helps to identify morphological domains through the individuation of elevation/slope pairs, attributed to specific domains. The calculation has been carried out using a depth window of 1 m and then evaluating average slope value of all DEM cells, that fallen inside each window (fig. 28). A median filter (25 points window) was applied to smooth the progress of plot examination. The Ischia volcanic emerged and submerged volcanic edifice includes several morphological ranges, each one characterized by a well-defined elevation interval vs. average slope (fig. 28).

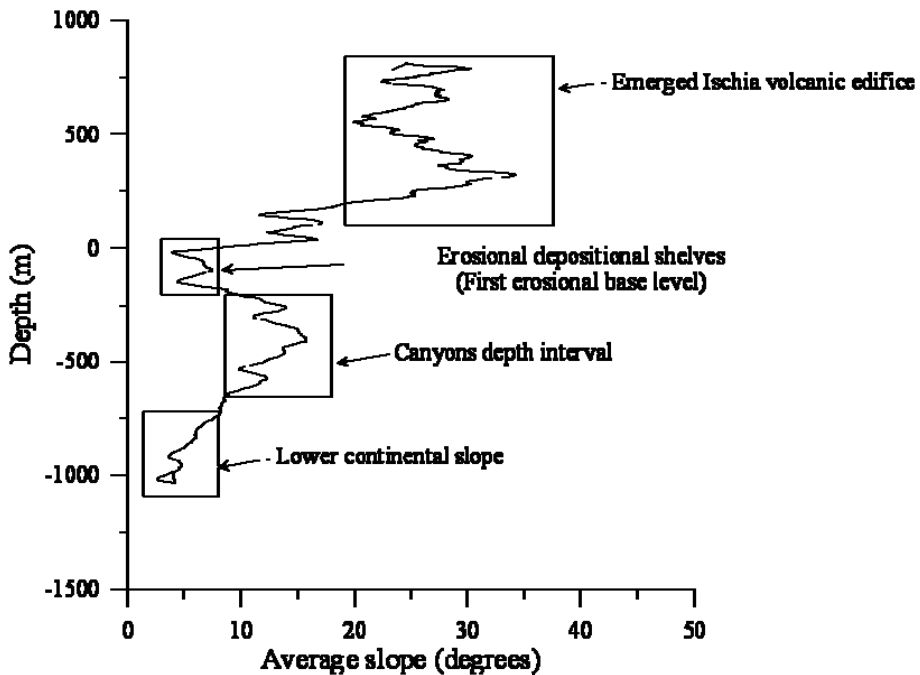


Fig. 28: Sketch diagram showing elevation intervals versus average slopes offshore the Ischia island.

The following morphological ranges have been identified (fig. 28):

- A) The Ischia outcropping “central” edifice, at depth > 0, characterized by a slope range of about 20°-40° on average;
- A2) An intermediate stage, that acts as an according layer towards the continental shelf;
- B) The continental shelf, between the coastline and the - 140-150 m (200 m in some cases) isobath (slopes 3°/8°, on average);
- C) The upper continental slope, located between the platform edge and the 650 m isobath (slopes 8°/20°, on average);
- D) The lower continental slope, deeper than 650 meters in depth (average slopes 0°/8°).

These domains include several morphological elements, each representing a tectonic and/or sedimentary process or a volcanic event. On the shelf terraces of abrasion and/or deposition, relic morphologies of volcanic edifices, canyons and gullies can be recognized. The depositional shelf break is partially eroded at the head of some canyons. Contrary to what recorded in normal depth distribution, it has been outlined the increasing of dip angles in the lower portion of the A physiographic unit, probably due to basal faulting of the Mt. Epomeo resurgent block. Submarine canyons are present on A and C units, acting as a morphological link between ranges. Debris avalanches develop between these volcanic features both in the southern and in the northern sides; on the contrary lateral collapses that characterize this area seems to be originated within morphological protrusion.

## 7. References

- Acocella, V.; Funicello, R. & Lombardi S. (1997). Active tectonics and resurgence in Ischia island (southern Italy). *Il Quaternario (Italian Journal of Quaternary Sciences)*, Vol. 10, No.2, pp. 427-432.
- Acocella, V. & Funicello, R. (1999). The interaction between regional and local tectonics during resurgent doming: the case of the island of Ischia, Italy. *Journal of Volcanology and Geothermal Research*, Vol. 88, pp. 109-123.
- Acocella, V.; Funicello, R., Marotta, E., Orsi G. & De Vita, S. (2004). The role of extensional structures on experimental calderas and resurgence. *Journal of Volcanology and Geothermal Research*, Vol. 129, pp. 199-217.
- Aiello, G.; Marsella, E. & Sacchi, M. (2000). Quaternary structural evolution of Terracina and Gaeta basins. *Rendiconti Lincei Scienze Fisiche e Naturali*, Vol. 9, No.11, pp. 41-58.
- Aiello, G.; Budillon, F., Cristofalo, G., D'Argenio, B., de Alteriis, G., De Lauro, M., Ferraro, L., Marsella, E., Pelosi, N., Sacchi, M. & Tonielli, R. (2001). Marine geology and morphobathymetry in the Bay of Naples, In: *Structures and Processes of the Mediterranean Ecosystems*, F.M. Faranda, L. Guglielmo & G. Spezie (Eds.), 1-8, Springer Verlag Italy.
- Aiello, G.; Angelino, A., Marsella, E., Ruggieri, S. & Siniscalchi, A. (2004). Carta magnetica di alta risoluzione del Golfo di Napoli (Tirreno meridionale). *Bollettino della Società Geologica Italiana*, Vol. 123, pp. 333-342.
- Aiello, G.; Angelino, A., D'Argenio, B., Marsella, E., Pelosi, N., Ruggieri, S. & Siniscalchi, A. (2005). Buried volcanic structures in the Gulf of Naples (Southern Tyrrhenian sea,

- Italy) resulting from high resolution magnetic survey and seismic profiling. *Annals of Geophysics*, Vol.48, No6, pp. 883-897.
- Aiello, G.; Conforti, A., D'Argenio, B. & Putignano, M.L. (2008). Explanatory Notes to the Geological Map n. 465 "Isola di Procida". Scale 1: 50.000. APAT, Department of Soil Defense, National Geological Survey of Italy, Editorial House Systemcart, Rome, Italy.
- Aiello, G.; Marsella, E., Di Fiore, V. & D'Isanto, C. (2009a). Stratigraphic and structural styles of half-graben offshore basins in Southern Italy: multichannel seismic and Multibeam morpho-bathymetric evidences on the Salerno Valley (Southern Campania continental margin, Italy). *Quaderni di Geofisica*, Vol.77, pp. 1-33.
- Aiello, G.; Budillon, F., Conforti, A., D'Argenio, B., Putignano, M.L. & Toccaceli, R.M. (2009b). Explanatory Notes to the Geological Map n. 464 "Isola d'Ischia". Scale 1: 25.000. APAT, Department of Soil Defense, National Geological Survey of Italy, Editorial House Systemcart, Rome, Italy.
- Aiello, G.; Marsella, E. & Passaro S. (2009c). Submarine instability processes on the continental slopes off the Campania Region (Southern Tyrrhenian sea, Italy): the case history of Ischia island (Naples Bay). *Bollettino di Geofisica Teorica Applicata*, Vol.50, No2, pp. 193-207.
- Aiello, G.; Marsella E & Ruggieri S. (2010). Three-dimensional magneto-seismic reconstruction of the "Torre del Greco" submerged volcanic structure (Naples Bay, Southern Tyrrhenian sea, Italy): Implications for Vesuvius' marine geophysics and volcanology. *Near Surface Geophysics*, Vol.8, No1, pp. 17-31.
- Aiello, G.; Cicchella, A.G., Di Fiore, V. & Marsella E. (2011). New seismo-stratigraphic data of the Volturno Basin (northern Campania, Tyrrhenian margin, southern Italy): implications for tectono-stratigraphy of the Campania and Latium sedimentary basins. *Annals of Geophysics*, Vol. 54, No3, pp. 265-283.
- Argnani, A.; & Trincardi, F. (1990). Paola slope basin: evidence of regional contraction on the Eastern Tyrrhenian margin. *Memorie della Società Geologica Italiana*, Vol.44, pp. 93-105.
- Arnò, V.; Principe, C., Rosi, M., Santacroce, R. & Sheridan M.F. (1987). Eruptive history. In: *Somma-Vesuvius*, R. Santacroce (Ed.), Quaderni De La Ricerca Scientifica, CNR, Italy.
- Balducci, A.; Vaselli, M. & Verdini G. (1985). Exploration well in the Ottaviano permit, Italy. *European Geothermal Update, Proceedings 3<sup>rd</sup> International Seminar on the Results of the EC Geothermal Energy Research*, Reidel, Dordrecht.
- Barra, D.; Cinque, A., Italiano, A. & Scorziello R. (1992) Il Pleistocene superiore marino di Ischia: Paleoecologia e rapporti con l'evoluzione tettonica recente. *Studi Geologici Camerti*, Suppl. 1, pp. 231-243.
- Bernabini, M., Latmiral, G., Mirabile, L. & Segre, A.G. (1973). Alcune prospezioni sismiche per riflessione nei Golfi di Napoli e Pozzuoli. *Rapp. Comm. Int. Mer. Medit.*, Vol.21, pp. 929-934.
- Bigi, G.; Cosentino, D., Parotto, M., Sartori, R. & Scandone, P. (1992). Structural Model of Italy. *Monografie Progetto Finalizzato Geodinamica*, CNR, Roma, Italy.
- Boccaletti, M., Ciaranfi, N., Cosentino, D., Deiana, G., Gelati, R., Lentini, F., Massari, F., Moratti, G., Pescatore, T.S., Ricci Lucchi, F. & Tortorici, L. (1990). Palinspastic



- restoration and paleogeographic reconstruction of the peri-Tyrrhenian area during the Neogene. *Palaeogeography, Palaeoclimatology, Palaeoecology*, Vol.77, No1, pp. 41-42.
- Brocchini, D.; Principe, C., Castradori, D., Laurenzi, M.A. & Gorla L. (2001). Quaternary evolution of the southern sector of the Campanian Plain and early Somma-Vesuvius activity: insights from the Trecase 1 well. *Mineralogy and Petrology*, Vol. 73, pp. 67-91.
- Bruno, P.P.G. & Rapolla, A. (1999). Study of the sub-surface structure of Somma-Vesuvius (Italy) by seismic reflection data. *Journal Volcanology and Geothermal Research*, Vol. 92, No3-4, pp. 373-387.
- Bruno, P.P.G.; de Alteriis, G. & Florio, G. (2002). The western undersea section of the Ischia volcanic complex (Italy, Tyrrhenian sea) inferred from marine geophysical data. *Geophysical Research Letters*, Vol.29, No9, pp. 1-4.
- Calcaterra, D., De Riso, R., Evangelista, A., Nicotera, M.V., Santo, A. & Scotto Di Santolo, A. (2003). Slope instabilities in the pyroclastic deposits of the Phlegrean district and the carbonate Apennine (Campania, Italy). *International Workshop on Occurrence and Mechanisms of Flows in Natural Slopes and Earthfills IW-Flows 2003*, Sorrento, May, 14-16, 2003.
- Capuano, P.; Gasparini, P., Zollo, A., Virieux, J., Casale M. & Yeroyanni M. (2003). The Internal Structure of Mt. Vesuvius. *Liguori Editore*, Napoli, ISBN88-207-3503-2, pp. 1-591.
- Cassano, E. & LaTorre, P. (1987). Geophysics. In: *Somma-Vesuvius*, R. Santacroce (Ed.), Quaderni De La Ricerca Scientifica, CNR, Italy.
- Castellano, M., Buonocunto, C., Capello, M. & La Rocca, M. (2002). Seismic surveillance of active volcanoes: the Osservatorio Vesuviano seismic network (OVSN-Southern Italy). *Seismology Research Letters*, Vol.73, pp. 177-184.
- Chiesa, S., Cornette, Y., Forcella, F., Gillot, P.Y., Pasquarè, G. & Vezzoli, L. (1985). Carta Geologica dell'Isola d'Ischia. *Monografie Progetto Finalizzato Geodinamica*, CNR, Roma, Italy.
- Chiesa, S.; Civetta, L., De Lucia, M., Orsi, G. & Poli, S. (1987). Volcanological evolution of the island of Ischia, In: *The volcanoclastic rocks of Campania (Southern Italy)*, P. De Girolamo (Ed.), Rendiconti Acc. Sc. Fis. e Mat. in Napoli Special Issue, pp. 69-83.
- Chiocci, F.L. & de Alteriis, G. (2006). The Ischia Debris Avalanche: first clear submarine evidence in the Mediterranean of a volcanic island prehistorical collapse. *Terra Nova*, Vol.18, No3, pp. 202-209.
- Christie-Blick, N. (1991). Onlap, offlap and the origin of unconformity-bounded depositional sequences. *Marine Geology*, Vol.97, pp.35-56.
- Civetta, L., Gallo, G. & Orsi, G. (1991). Sr and Nd isotope and trace element constraints on the chemical evolution of the magmatic system of Ischia (Italy) in the last 55 ky. *Journal of Volcanology and Geothermal Research*, Vol.46, pp.213-230.
- Colantoni, P., Del Monte, M., Fabbri, A., Galignani, P., Selli, R. & Tomadin L. (1972). Ricerche geologiche nel Golfo di Pozzuoli. *Quaderni De La Ricerca Scientifica*, CNR, Vol.83, pp. 26-71.
- Cole, R.H. (1965). Underwater Explosions. *Dover Publications*, New York.

- Corradi, N.; Ferrari, M.; Giordano, F., Giordano, R., Ivaldi, R. & Sbrana, A. (2009) SAM source and D-Seismic system: The use in Marine Geological Mapping C.A.R.G and P.n.r.a projects. *27th IAS Meeting of Sedimentologists*, Alghero (Italy), pp. 85-90.
- Correggiari, A., Roveri, M. & Trincardi, F. (1992). Regressioni forzate, regressioni deposizionali e fenomeni di instabilità in unità progradazionali tardo-quadernarie. *Giornale di Geologia*, Vol.54, pp.19-36.
- D'Argenio, B., Pescatore, T.S. & Scandone P. (1973). Schema geologico-strutturale dell'Appennino meridionale (Campania e Lucania). *Quaderni dell'Accademia Nazionale dei Lincei*, Problemi Attuali di Scienza e Cultura, Vol.183, pp. 49-72.
- D'Argenio, B.; Aiello, G., de Alteriis, G., Milia, A., Sacchi, M. et al. (2004). Digital Elevation Model of the Naples Bay and adjacent areas, Eastern Tyrrhenian sea, In: *Mapping Geology in Italy*, E. Pasquarè & G. Venturini (Eds.), APAT, National Geological Survey of Italy, Spec. Vol. SELCA, Florence, 22-28.
- de Alteriis, G., Tonielli, R., Passaro, S. & De Lauro, M. (2005). Isole Flegree (Ischia e Procida). Batimetria dei fondali marini della Campania. Scala 1:30.000. *Liguori Editore*, Napoli.
- de Alteriis, G., Insinga, D.D., Morabito, S., Morra, V., Chiocci, F.L., Terrasi, F., Lubritto, C., Di Benedetto, C. & Pazzanese, M. (2010) Age of submarine debris avalanches and tephrostratigraphy offshore Ischia island, Tyrrhenian sea. *Marine Geology*, V. 278, pp. 1-18.
- De Astis, G., Pappalardo, L. & Piochi, M. (2004). Procida volcanic history: new insights into the evolution of the Phlegrean Volcanic District (Campania, Italy). *Bulletin of Volcanology*, Vol.66, pp. 622-641.
- De Vita, S.; Esposito, B. & Mirabile, L. (1979). Criteri di Progetto di Sparker a cortina per sismica ad alta risoluzione. *Atti del convegno Scientifico Nazionale Progetto Finalizzato Oceanografia e Fondi Marini*.
- De Vita, P., Agrello, D. & Ambrosino, F. (2006). Landslide susceptibility assessment in ash-fall pyroclastic deposits surrounding Mount Somma-Vesuvius. Application of geophysical surveys for soil thickness mapping. *Journal of Applied Geophysics*, Vol.59, pp. 126-139.
- De Vita, P., Celico, P., Di Clemente, E. & Rolandi, M. (2007). Engineering geological models of the initial landslides occurred on 30 April 2006 at the Mount of Vezi (Ischia island). *Italian Journal of Engineering Geology and Environment*.
- Di Fiore, V., Aiello, G. & D'Argenio, B. (2011). Gravity instabilities in the Dohrn canyon (Bay of Naples, Southern Tyrrhenian sea): potential wave and run-up (tsunami) reconstruction from a fossil submarine landslide. *Geologica Carpathica*, Vol.62, No1, pp.55-63.
- Di Girolamo, P. & Stanzione, D. (1973). Lineamenti geologici e petrologici dell'isola di Procida. *Rendiconti Soc. Italiana Mineralogia Petrologia*, Vol.29, pp. 81-125.
- Di Girolamo, P., Ghiara, M.R., Lirer, L., Munno, R., Rolandi, G. & Stanzione, D. (1984). Vulcanologia e petrologia dei Campi Flegrei. *Bollettino della Società Geologica Italiana*, V.103, pp. 349-413.
- Di Maio, R., Piegari, E., Scotellaro, C. & Soldovieri M.G. (2007). Tomografie di resistività per la definizione dello spessore e del contenuto d'acqua delle coperture piroclastiche a M.te di Vezi (Isola d'Ischia). *Italian Journal of Engineering Geology and Environment*.

- Di Nocera, S., Matano, F., Rolandi, G. & Rolandi R. (2007). Contributo sugli aspetti geologici e vulcanologici di Monte di Vezzi (Isola d'Ischia) per lo studio degli eventi franosi dell'Aprile 2006. *Italian Journal of Engineering Geology and Environment*
- Dvorak, J.J. & Mastrolorenzo, G. (1991). The mechanisms of recent vertical crustal movements in Campi Flegrei caldera, southern Italy. *Geol. Soc. Am. Special Paper*, Vol. 263.
- Edgerton, H.E. & Hayward, G.G. (1964). The boomer sonar source for seismic profiling. *Journal of Geophysical Research*, Vol. 68, pp. 3033-3042.
- Esposti Ongaro, T., Neri, A., Todesco, M. & Macedonio, G. (2002). Pyroclastic flow hazard at Vesuvius from numerical modelling II. Analysis of local flow variables. *Bulletin of Volcanology*, Vol.64, pp. 178-191.
- Fabrizi, A., Argnani, A., Bortoluzzi, G., Correggiari, A., Gamberi, F., Ligi, M., Marani, M., Penitenti, D., Roveri, M. & Trincardi, F. (2002). Carta geologica dei mari italiani alla scala 1:250.000. Guida al rilevamento. *Presidenza del Consiglio dei Ministri, Dipartimento per i Servizi Tecnici Nazionali, Servizio Geologico, Quaderni serie III*, Vol.8, pp. 1-93.
- Finetti, I. & Morelli, C. (1973). Esplorazione sismica per riflessione nei Golfi di Napoli e Pozzuoli. *Bollettino di Geofisica Teorica Applicata*, Vol.16, pp. 175-222.
- Forcella, F., Gnaccolini M. & Vezzoli, L. (1981). Stratigrafia e sedimentologia dei depositi piroclastici del settore sud-orientale dell'Isola d'Ischia. *Rivista Italiana Paleontologia Stratigrafia*, 87, pp. 329-366.
- Fusi, N., Mirabile, L., Camerlenghi, A. & Ranieri, G. (1991). Marine geophysical survey of the Gulf of Naples (Italy): relationship between submarine volcanic activity and sedimentation. *Memorie della Società Geologica Italiana*, 47, pp. 95-114.
- Gabbianelli, G., Tramontana, M., Colantoni, P. & Fanucci F. (1996). Lineamenti morfostrutturali e sismostratigrafici del Golfo di Patti (Margine nord-siciliano). In: *Caratterizzazione ambientale marina del sistema Eolie e dei bacini limitrofi di Cefalù e Gioia*, F.M. Faranda & P. Povero (Eds.), Data Report, pp.443-454.
- Galdi, A., Giordano, F., Sposito, A. & Vultaggio, M. (1988) Misure geomagnetiche nel Golfo di Pozzuoli: Metodologia e risultati. *Atti del 7° Convegno GNGTS-CNR*, Vol.3, pp. 1647-1658.
- Galloway, W.E., Dings, W.F. & Paige R.E. (1991). Seismic and depositional facies of Paleocene-Eocene Wilcox Group submarine canyon fills, Northwest Gulf Coast, USA, In: *Seismic Facies and Sedimentary Processes of Submarine Fans and Turbidite Systems*, P. Weimer & M.H. Link (Eds.), Springer-Verlag, pp. 247-271.
- Gillot, P.Y., Chiesa, S., Pasquarè, G. & Vezzoli, L. (1982). 33.000 yr. K/Ar dating of the volcano-tectonic horst of the isle of Ischia, Gulf of Naples. *Nature*, Vol.229, pp.242-245.
- Guadagno, F.M. & Mele, R. (1995) La fragile isola d'Ischia. *Geologia Applicata e Idrogeologia*, Vol.30, No1, pp.177-187.
- Holland Hansen, W. & Gjelberg, J.G. (1994). Conceptual basis and variability in sequence stratigraphy: a different perspective. *Sedimentary Geology*, Vol.92, pp.31-52.
- Hernandez Molina, F.J., Somoza, L., Rey, J. & Pomar, L. (1994). Late Pleistocene-Holocene sediments on the Spanish continental shelves: model for high resolution sequence stratigraphy. *Marine Geology*, Vol.120, pp. 120-174.

- Knott, S.T. & Hersey, J.B. (1956). Interpretation of high resolution echo-soundings techniques and their use in bathymetry, marine geophysics and biology. *Deep Sea Research*, Vol.4, pp. 36-44.
- Insinga, D., Molisso F., Lubritto, C., Sacchi, M., Passariello, I. & Morra, V. (2008). The proximal marine record of Somma-Vesuvius volcanic activity in Naples and Salerno bays, Eastern Tyrrhenian sea, during the last 3 kyrs. *Journal of Volcanology and Geothermal Research*, Vol. 177, pp. 170-186.
- Isaia, R., Marianelli, P. & Sbrana, A. (2009). Caldera unrest prior to intense volcanism in Campi Flegrei (Italy) at 4.0 ka B.P.: Implications for caldera dynamics and future eruptive scenarios. *Geophysical Research Letters*, Vol. 36, doi: 10.1029/2009GL040513.
- Latmiral, L., Segre, A.G., Bernabini, M. & Mirabile, L. (1971). Prospezioni sismiche per riflessione nei Golfi di Napoli e Pozzuoli ed alcuni risultati geologici. *Bollettino della Società Geologica Italiana*, Vol.90, pp.163-172.
- Luongo, G., Cubellis, E. & Obrizzo, F. (1987). Ischia: storia di un'isola vulcanica. *Liguori Editore*, Napoli.
- Luongo, G., Cubellis, E. & Obrizzo, F. (1997). Storia e strumenti per un Museo Vulcanologico, In: *Mons Vesuvius*, G. Luongo (Ed.), Fiorentino Editore, Napoli, pp. 383-408.
- Marani, M., Taviani, M., Trincardi, F., Argnani, A., Borsetti, A.M. & Zitellini, N. (1986). Pleistocene progradation and postglacial events of the NE Tyrrhenian continental shelf between the Tiber river delta and Capo Circeo. *Memorie della Società Geologica Italiana*, Vol.36, pp. 67-89.
- Martinson, D.G., Pisias, N.G., Hays, J.D., Imbrie, J., Moore, T.C. & Shackleton, N.J. (1987). Age dating and orbital theory of the Ice Ages: development of a high resolution 0 to 300.000 year chronostratigraphy. *Quaternary Research*, Vol.27, No1, pp. 1-29.
- Mastrolorenzo, G., Palladino, D., Vecchio, G. & Taddeucci, J. (2002). The 472 AD Pollena eruption at Somma-Vesuvius, Italy and its environmental impact at the end of Roman Empire. *Journal of Volcanology and Geothermal Research*, Vol.113, pp. 19-36.
- Mele, R. & Del Prete, S. (1998). Fenomeni di instabilità dei versanti in Tufo Verde del Monte Epomeo (Isola d'Ischia, Campania). *Bollettino della Società Geologica Italiana*, Vol.117, No1, pp. 93-112.
- Milia, A. (1998) Stratigrafia, strutture deformative e considerazioni sull'origine delle unità deposizionali oloceniche del Golfo di Pozzuoli (Napoli). *Bollettino della Società Geologica Italiana*, vol. 117, pp. 777-787.
- Milia, A. & Torrente, M.M. (2000). Fold uplift and syn-kinematic stratal architectures in a region of active transtensional tectonics and volcanism, Eastern Tyrrhenian sea. *Geological Society of America Bulletin*, Vol.112, pp.1531-1542.
- Milia, A. & Torrente, M.M. (2003). Late Quaternary volcanism and transtensional tectonics in the Bay of Naples, Campanian continental margin, Italy. *Mineralogy and Petrology*, vol.79, pp. 49-65.
- Milia, A., Mirabile, L., Torrente, M.M. & Dvorak J.J. (1998). Volcanism offshore of Vesuvius volcano (Italy): Implications for hazard evaluation. *Bulletin of Volcanology*, 59, 404-413. *Journal of the Geological Society of London*, Vol.160, pp.309-317.
- Milia, A.; Molisso, F., Raspini, A., Sacchi, M. & Torrente, M.M. (2008). Syneruptive features and sedimentary processes associated with pyroclastic currents entering the sea:

- the AD 79 eruption of Vesuvius, Bay of Naples, Italy. *Journal of the Geological Society*, V.165, No4, pp. 839-848.
- Mirabile, L., (1969). Prime esperienze di stratigrafia sottomarina eseguite presso l'Istituto Universitario Navale. *Annali IUN*, Vol. 38.
- Mirabile, L., Nicolich, R., Piermattei, R. & Ranieri, G. (1989). Identificazione delle strutture tettonico-vulcaniche dell'area flegrea: sismica multicanale del Golfo di Pozzuoli. *Atti del 7° Convegno GNGTS*, Vol.2, Roma, Italy, pp. 829-838.
- Mirabile, L., Fevola, F., Galeotti, F., Ranieri, G. & Tangaro, G. (1991). Sismica monocanale ad alta risoluzione con sorgente multi spot di tipo sparker: applicazione ai dati di tecniche di deconvoluzione. *Atti del 10° Convegno GNGTS-CNR*, Roma, Italy.
- Molisso, F., Insinga, D., Marzaioli, F., Sacchi, M. & Lubritto, C. (2010). Radiocarbon dating versus volcanic event stratigraphy: age modelling of Quaternary marine sequences in the coastal region of the Eastern Tyrrhenian sea. *Nuclear Instruments and Methods in Physics Research B*, Vol. 268, pp.1236-1240.
- Mongardi, S., Correggiari, A. & Trincardi, F. (1995). Regional drape deposits in a Quaternary turbidite succession. Inferences from high resolution study of the Late Quaternary drape of the sea floor of the Paola basin (Tyrrhenian sea). *16<sup>th</sup> IAS European Sedimentological Meeting*, Aix-le-bains, France, p. 106.
- Moore, J.G. & Mark, R.K. (1992). Morphology of the island of Hawaii. *GSA Today*, Vol. 2, pp. 257-262.
- Orsi, G., Gallo, G. & Zanchi, A. (1991). Simple-shearing block resurgence in caldera depressions. A model from Pantelleria and Ischia. *Journal of Volcanology and Geothermal Research*, Vol.71, p.249-257.
- Orsi, G., Piochi, M., Campajola, L., D'Onofrio, A., Gialanella, L. & Terrasi, F. (1996). <sup>14</sup>C geochronological constraints for the volcanic history of the island of Ischia (Italy) over the last 5000 years. *Journal of Volcanology and Geothermal Research*, Vol.71, p.249-257.
- Paoletti, V.; Fedi, M. Florio, G., Supper, R. & Rapolla, A. (2004). The new integrated aeromagnetic map of the Phlegrean Fields  
Fields volcano and surrounding areas. *Annals of Geophysics*, Vol. 47, No 5, pp. 1569-1580.
- Passaro, S. (2005). Integrazione di dati magnetici e batimetrici in aree vulcaniche e non vulcaniche: esempi dall'isola d'Ischia e dal Banco di Gorringe (Oceano Atlantico). *PhD Thesis*, Università di Napoli "Federico II".
- Pescatore, T.S. & Rolandi, G. (1981). Osservazioni preliminari sulla stratigrafia dei depositi vulcanoclastici del settore sud-occidentale dei Campi Flegrei. *Bollettino della Società Geologica Italiana*, Vol. 100, pp. 233-254.
- Poli, S., Chiesa, S., Gillot, P.Y., Gregnanin A. & Guichard, F. (1987). Chemistry versus time in the volcanic complex of Ischia (Gulf of Naples, Italy). *Contributions to Mineralogy and Petrology*, Vol.95, No3, pp.322-335.
- Poli, S., Chiesa, S., Gillot, P.Y., Guichard, F. & Vezzoli, L. (1989). Time dimension in the geochemical approach and hazard estimation of a volcanic area: the isle of Ischia case (Italy). *Journal of Volcanology and Geothermal Research*, Vol.36, pp. 327-335.
- Posamentier, H.W. & Allen, G.P. (1993). Variability in the sequence stratigraphic model: effects of local basin factors. *Sedimentary Geology*, Vol.86, pp.91-109.

- Posamentier, H.W. & Vail, P.R. (1988). Eustatic control on clastic deposition II - sequence and system tracts models, In: *Sea level changes: an integrated approach*, C.K. Wilgus, B.S. Hastings et al. (Eds.), SEPM Special Publication., Vol.42, pp.125-154.
- Posamentier, H.W., Erskine R.D. & Mitchum, R.M. (1991). Models for Submarine Fan Deposition within a Sequence Stratigraphic Framework, In: *Seismic Facies and Sedimentary Processes of Submarine Fans and Turbidite Systems*, P. Weimer & M.H. Link (Eds.), New York, Springer Verlag, pp. 127-136.
- Posamentier, H.W., James, D.P., Allen, J.P. & Tesson, M. (1992). Forced regressions in a sequence stratigraphic framework: concepts, examples and exploration significance. *AAPG Bulletin*, Vol.76, pp. 1687-1709.
- Ranieri, G. & Mirabile, L. (1991). Ricerca ed applicazione di metodi geofisici al rilievo sperimentale della struttura medio-profonda dell'area flegrea con uso di sorgenti sismiche water-gun. *Annali Istituto Universitario Navale di Napoli*, Vol.63
- Rittmann, A. (1930). Geologie der Insel Ischia. *Ergn vur Vulk*, Berlin.
- Rittmann, A. (1948) Origine e differenziazione del magma ischitano. *Schweiz Miner Petrogr Mitt.*, Vol. 28, pp. 643-698.
- Rosi, M. & Santacroce, R. (1983) The A.D. 472 "Pollena" eruption: volcanological and petrological data for this poorly known plinian type event at Vesuvius. *Journal of Volcanology and Geothermal Research*, Vol.17, pp. 249-271.
- Rosi, M. & Sbrana, A. (1987). Phlegrean Fields. *Quaderni De La Ricerca Scientifica*, CNR, Vol.114, No9, 175 pp.
- Rosi, M., Sbrana A. & Vezzoli, L. (1988a). Tephrostratigraphy of Ischia, Procida and Campi Flegrei volcanic products. *Memorie della Società Geologica Italiana*, 41, pp. 1015-1027.
- Rosi, M., Sbrana, A. & Vezzoli, L. (1988b) Stratigraphy of Procida and Vivara islands. *Bollettino GNV*, Vol.4, pp. 500-525.
- Sacchi, M., Insinga, D., Milia, A., Molisso, F., Raspini, A., Torrente, M.M. & Conforti, A. (2005) Stratigraphic signature of the Vesuvius 79AD event off the Sarno prodelta system, Naples Bay. *Marine Geology*, Vol.222-223, pp. 443-469.
- Saccorotti, G., Ventura, G. & Vilardo, G. (2002). Seismic swarms related to diffusive processes: the case of Somma-Vesuvius volcano, Italy. *Geophysics*, Vol.67, pp.199-203.
- Santacroce, R. (1987). Somma-Vesuvius. CNR, *Quaderni De La Ricerca Scientifica*, Vol.114, pp.1-175.
- Scarpa, R., Tronca, F., Bianco, F. & Del Pezzo, E. (2002). High resolution velocity structure beneath Mount Vesuvius from seismic array data. *Geophysical Research Letters*, Vol.29, pp.204-219.
- Scarpati, C., Cole, P. & Perrotta, A. (1993). The Neapolitan Yellow Tuff - A large volume multiphase eruption from Campi Flegrei, Southern Italy. *Bulletin of Volcanology*, Vol.55, pp.343-356.
- Secomandi, M., Paoletti, V., Aiello, G., Fedi, M., Marsella, E, Ruggieri, S., D'Argenio, B., Rapolla, A. (2003). Analysis of the magnetic anomaly field of the volcanic district of the Naples Bay. *Marine Geophysical Researches*, 24, 207-221.
- Sheridan, M.F., Barberi, F., Rosi, M. & Santacroce, R. (1981). A model for Plinian eruption of Vesuvius. *Nature*, Vol.289, pp. 282-285.

- Sheridan, M.F. (1982) Application of computer assisted mapping to volcanic hazard evaluation of surge eruptions: Vulcano, Lipari and Vesuvius. *Journal of Volcanology and Geothermal Research*, Vol.17, pp. 187-202.
- Sigurdsson, H., Cashdollar, S. & Sparks, S.R.J. (1982). The eruption of Vesuvius in AD79: reconstruction from historical and volcanological evidence. *American Journal of Archaeology*, Vol.86, pp.39-51.
- Tesson, M., Allen G.P. & Ravenne, C. (1993). Late Pleistocene shelf perched lowstand wedges on the Rhone continental shelf. In: *Sequence Stratigraphy and Facies Associations*, H.W. Posamentier, C.P. Summerhayes, B.U. Haq & G.P. Allen (Eds.), IAS Special Publication, No18.
- Todesco, M., Neri, A., Esposti Ongaro, T., Papale, P., Macedonio, G. & Santacroce, R. (2002) Pyroclastic flow hazard at Vesuvius from numerical modelling I. Large scale dynamics. *Bulletin of Volcanology*, Vol.64, pp. 155-177.
- Tramontana, M., Colantoni, P. & Fanucci, F. (1995). Risultati preliminari delle indagini morfologico-sedimentologiche condotte nell'ambito del progetto EOCUMM94. In: *Caratterizzazione ambientale marina del sistema Eolie e dei bacini limitrofi di Cefalù e di Gioia*, F.M. Faranda (Ed.), Data Report, 1995, pp. 331-338.
- Trincardi, F. & Field, M.E. (1991). Geometry, lateral variation and preservation of downlapping regressive shelf deposits: Eastern Tyrrhenian sea margin, Italy. *Journal of Sedimentary Petrology*, Vol.61, pp.775-790.
- Trincardi, F. & Normark, W.R. (1988). Sediment waves on the Tiber prodelta slope: interaction of deltaic sedimentation and currents along shelf. *Geomarine Letters*, Vol.8, pp. 149-157.
- Trincardi, F., Correggiari, A. & Roveri, M. (1994). Late Quaternary transgressive erosion and deposition in a modern continental shelf: the Adriatic semienclosed basin. *Geomarine Letters*, Vol.14, pp.41-51.
- Trincardi, F., Cattaneo, A. & Correggiari, A. (2003). Growth of the modern Po delta and prodelta system. *COMDELTA Conference*, Aix En Provence, France, p. 141.
- Vail, P.R., Mitchum, R.M. & Thompson, S. (1977) Seismic stratigraphy and global changes of sea level, Part 3, relative changes in sea level from coastal onlap, In: *Seismic Stratigraphy - Applications to Hydrocarbon Exploration*, C.E. Payton (Ed.), AAPG Mem. 26, pp.63-81.
- Vail, P.R., Hardenbol J. & Todd, R.G. (1984) Jurassic unconformities, chronostratigraphy and sea level changes from seismic stratigraphy and biostratigraphy, In: *Interregional unconformities and hydrocarbon accumulation*, AAPG Mem. 36, 129-144.
- Vezzoli, L. (1988). Island of Ischia. *Quaderni De La Ricerca Scientifica*, CNR., Roma.
- Zollo, A., Gasparini, P., Biella, G., De Franco, R., Buonocore, B., Mirabile, L., De Natale, G., Milano, G., Pingue, F., Vilaro, G., Bruno, P.P.G., De Matteis, R., Le Meur, H., Iannaccone, G., Deschamps, A., Virieux, J., Nardi, A., Frepoli, A., Hunstad, I., Guerra, I. (1996) 2D seismic tomography of Somma-Vesuvius: description of the experiment and preliminary results. *Annals of Geophysics*, Vol.39, pp. 471-486.
- Zollo, A., Gasparini, P., Virieux, J., Biella, G., Boschi, E., Capuano, P., De Franco, R., Dell'Aversana, P., De Matteis, R., De Natale, G., Iannaccone, G., Guerra, H., Le Meur H. & Mirabile, L. (1998). An image of Mt. Vesuvius obtained by 2D seismic tomography. *Journal of Volcanology and Geothermal Research*, Vol.82, pp.161-173.

Zollo, A., Gasparini, P., Virieux, J., Biella, G., Boschi, E., Capuano, P., De Franco, R., Dell'Aversana, P., De Matteis, R., De Natale, G., Iannaccone, G., Guerra, H., Le Meur H. & Mirabile, L. (2003). An image of Mt. Vesuvius obtained by 2D seismic tomography, In: *The Internal Structure of Mt. Vesuvius*, P. Capuano, P. Gasparini, A. Zollo, J. Virieux, R. Casale & M. Yeroyanni (Eds.), Liguori Editore, Napoli, pp, 75-104.