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THE GEOMORPHOLOGY OF NAPLES BAY CONTINENTAL SHELF (ITALY)

ABSTRACT: MILIA A., *The geomorphology of Naples Bay continental shelf (Italy).* (IT ISSN, 0391-9838, 1999).

Naples Bay is a peri-Tyrrhenian basin that covers an area of about 1000 km^2 and is characterized by active tectonics and volcanism. High resolution seismic reflection data were used to study the geomorphology of the continental shelf that displays erosional, depositional and volcanic features. In particular, three sectors were distinguished on the shelf that present different morphologic characters. The southern shelf, close to the Sorrento Peninsula, is characterized by erosional surfaces affecting the Meso-Cenozoic carbonate rocks, Middle Pleistocene prograding units, and the pyroclastic deposits of the Campanian Ignimbrite (35 ka BP). The central shelf displays depositional surfaces corresponding to the upper boundary of marine deposits which overlay the Campanian Ignimbrite. The northern shelf, close to the Phlegrean Fields, shows the more complex physiographic pattern because, in addition to the erosional and depositional surfaces, there are forms due to Late Quaternary tectonics and volcanism.

KEY WORDS: Geomorphology, Late Quaternary, Continental Shelf, Bay of Naples, Italy.

RIASSUNTO: MILIA A., *La geomorfologia della piattaforma continentale del Golfo di Napoli.* (IT ISSN, 0391-9838, 1999).

Il Golfo di Napoli è un bacino peritirrenico che copre un'area di circa 1000 km^2 ed è caratterizzato da tettonica e vulcanismo attivi. Profili sismici a riflessione ad alta risoluzione sono stati utilizzati per studiare la geomorfologia della piattaforma continentale che mostra forme erosive, deposizionali e vulcaniche. In particolare, sono stati identificati tre settori della piattaforma che mostrano differenti caratteristiche morfologiche. La piattaforma meridionale, contigua alla Penisola Sorrentina, presenta superfici di erosione intagliate sulle rocce carbonatiche meso-cenozoiche, sulle unità progradanti medio-pleistoceniche e sui depositi piroclastici dell'Ignimbrite Campana (35 ka BP). La piattaforma centrale mostra superfici deposizionali che corrispondono al tetto dei depositi marini soprastanti l'Ignimbrite Campana. La piattaforma settentrionale, contigua ai Campi Flegrei, mostra la configurazione fisiografica più complessa. Oltre alle superfici erosionali e deposizionali sono, infatti, presenti forme associate alla tettonica e all'attività vulcanica di età tardo quaternaria.

TERMINI CHIAVE: Geomorfologia, Tardo-Quaternario, Piattaforma continentale, Golfo di Napoli, Italia.

INTRODUCTION

The geomorphology of the continental margins results from the interplay between global and local processes. During the Late Quaternary the eustatic sea level oscillation ranged between +8 and –130 m of depth in respect to the present sea level. The shape of the eustatic curve is asymmetrical displaying a slow sea level fall, occurring between the Isotopic Stages 5 and 2, with a rapid sea level rise occurring between the Isotopic Stages 2 and 1 (Chappell & Shackleton, 1986; Martinson & *alii,* 1987). The sea level fall produced a wide erosional surface and at the same time deposition below a depth of –130m (Chiocci, 1994, Tesson & *alii*, 1994). The main local factors influencing the physiography are volcanism and tectonics. Volcanism following large eruptions builds reliefs and instantaneously modifies the landscape. Tectonics gives rise to structural reliefs and scarps. Recent studies confirm that the architecture of a sedimentary basin is strictly controlled by tectonic structures, contemporaneously producing fault scarps, uplifting and subsiding sectors (Leeder & Gawthorpe, 1987; Ravnås & Steel, 1998).

Only few scientific studies have dealt with the geomorphology of Naples Bay. Segre (1972), De Pippo & *alii* (1984) and Pescatore & *alii* (1984) reported the results of a study of a limited area (corresponding to Pozzuoli Bay) of the Naples Bay shelf. This study focuses on the geomorphology of the Naples Bay continental shelf by analysing the relationship between its forms and Late Quaternary sea level oscillations, tectonics and volcanism (fig. 1).

SEISMIC DATA AND METODOLOGY

This work is based on the interpretation of 3500 km high resolution seismic reflection profiles (fig. 1). Continuous seismic reflection were made, using a 16-kJ Multispot Extended Array Sparker system, along grid lines that had a total length of more than 2500 km (fig. 1). LORAN C was used to determine the ship's position. In addition a survey of about 1000 km of line was conducted in relati-

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vely shallow water using 1-kJ Surfboom system. During the latter survey ship positioning was determined by using a MICRO-FIX RACAL system, which has a positioning accuracy of 1 m. All seismic sections data were recorded graphically on continuous paper sheets. Vertical recording scales varied from 0.25 to 0.5 sec for Surfboom data and from 1 to 2 sec for Sparker data. The best vertical resolution of a seismic unit was about 1 m for Surfboom and about 6 m for Sparker data.

GEOLOGIC FRAMEWORK

The Bay of Naples is located in the Eastern Tyrrhenian Sea margin (fig. 1). The latter is characterized by crustal thinning and severe rifting processes that affect the Neogene Southern Apennines thrust belt (Lavecchia, 1988; Doglioni, 1991). The Quaternary struttural pattern of the Bay of Naples is characterized by NW-SE trending normal and trascurrent faults, E-W trending transcurrent faults and NE-SW trending normal faults (fig. 1). The latter, generated in the Early-Middle Pleistocene boundary, are responsible for the development of the Bay of Naples half-graben and the Sorrento Peninsula emergent crest of the fault block (Milia, 1996; Milia & Torrente, 1997; Milia, 1999). The Meso-Cenozoic carbonatic substrate, outcropping in Sorrento Peninsula, dips 7°-10° towards the NW and is overlain by Quaternary sediments and volcanic products (Finetti & Morelli, 1974; Fusi & *alii*, 1991). The stratigraphic succession is made up of several seismo-stratigraphic units (Milia, 1999). The older one corresponds to an unconformity-bounded unit covered by six Middle Pleistocene prograding sedimentary units. Successively, during the Late-Quaternary thick volcanic units were interlayered with the marine sediments. Many volcanic units overlay the Middle Pleistocene deposits in the northern bay, offshore Campi Flegrei (Milia, 1998a). The latter is a volcanic complex formed by many monogenic volcanoes (Rosi & Sbrana, 1987). The oldest volcanic unit (about 150 ka old) makes up the Penta Palummo, Gaia and Miseno submerged banks. In the central continental shelf pyroclastic deposits attributed to 35 ka-old Campanian Ignimbrite were recognized (Fusi & *alii*, 1991, Milia & *alii*, 1998 a). More recent volcanic deposits correspond to the Neapolitan Yellow Tuff (12 ka old) located off the Posillipo hill that separate lowstand deposits from transgressive an highstand deposits (Milia, 1996; Milia & *alii*, 1998a; Milia, 1998b). A north-south alignment of tuff cones corresponds to the Nisida complex (10-8 ka) (Colantoni & *alii*, 1972; Milia, 1998a). Finally, recent magmatic intrusions are present in the area off Vesuvius volcano, Pozzuoli Bay and Naples Harbour (Milia & *alii*, 1998a; 1998c).

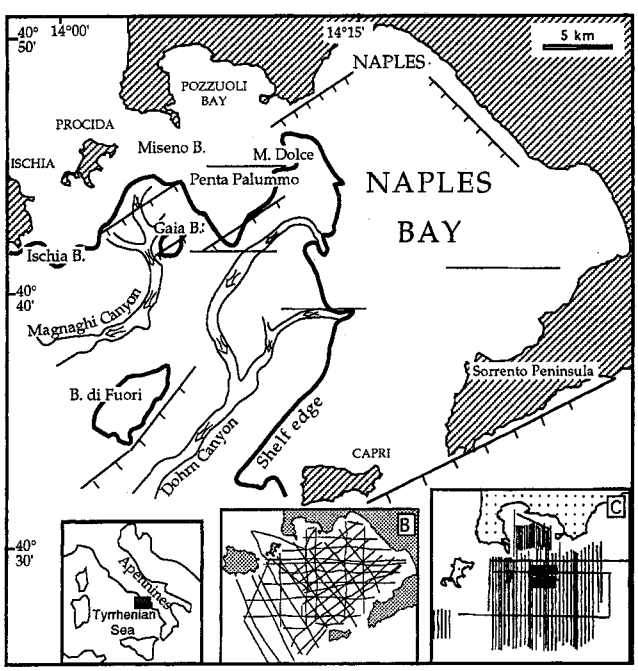

FIG. 1 - Tectonic and physiographic map of Naples Bay. Insets B and C respectively show the Sparker and Surfboom high-resolution seismic lines.

PHYSIOGRAPHY

The Naples Bay continental shelf extends to water depths of between 100 and 180 m. Shelf width varies from a maximum of about 20 km in the central bay to about 2.5 km off the islands of Capri and Procida (fig. 1). The northern sector features an irregular continental shelf as it is part of an extensive system of volcanic banks (Gaia Bank (GB), Penta Palummo (PP), Miseno Bank (MB), Ischia Bank (IB)) (figs. 1, 2). Its shelf edge lies at a depth of about 140 m and displays an irregular slope with a gradient of up to 45°. The southern sector, to the west of Capri, has a narrow continental shelf, a shelf edge at a depth of about 165-150 m, and an upper slope with an average gradient of 6° dipping towards the NW (fig. 2). In the central sector the continental shelf is 20 km wide (fig. 1) and has a shelf edge at a depth of 165 m in the soutern part and 180 m in the northwest, whereas the upper slope has an average gradient of 3° and dips towards the W-NW. An intraslope basin dipping about 1.5° is present seaward of the upper slope (fig. 2). In the middle of Naples Bay, between Capri and Ischia, a NE-trending structural high is present. It is known as Banco di Fuori (BF), and has a minimum depth of about 130 m. This high forms an asymmetrical ridge displaying a southeastern slope steeper than the northwestern one (fig. 2).

The continental slope is cut by two canyons: the Magnaghi Canyon (MC) and the Dohrn Canyon (DC) (fig. 2). The Magnaghi Canyon begins at the northern shelf on the edge of the volcanic banks. It runs for 15 km, first in a souterly, and then in a westerly direction, passing between Ischia and the Banco di Fuori (BF) and terminating in the Tyrrhenian basin (figs. 1, 2). The Dohrn Canyon is S shaped and is composed of a northern and soutern branch (fig. 2). It is 25 km long and runs from the shelf edge to the deep basin west of Capri.

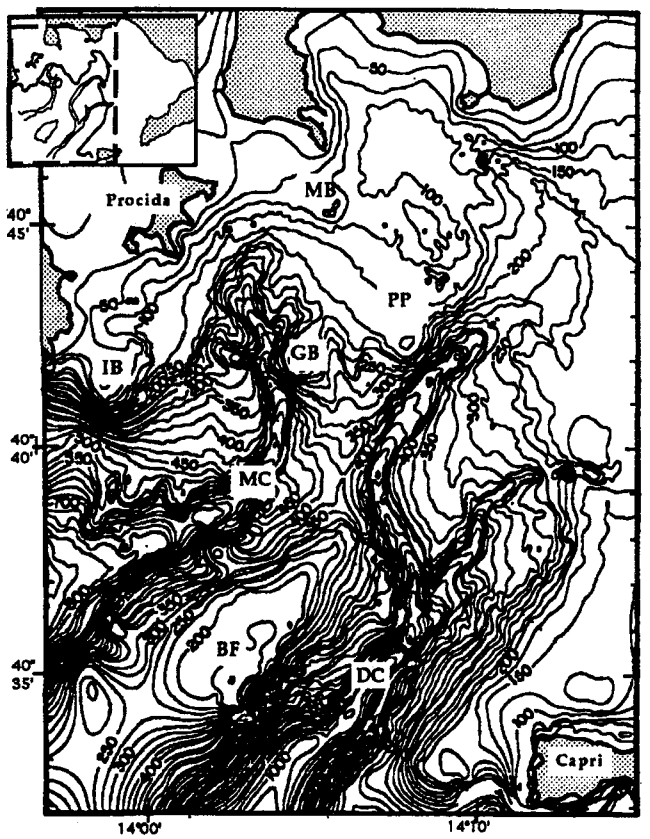

FIG. 2 - Bathymetric map of Naples Bay slope surveyed with a Sea-Beam system. BF = Banco di Fuori; DC = Dohrn Canyon; MC = Magnaghi Canyon; GB = Gaia Bank; PP = Penta Palummo Bank; MB = Miseno Bank; IB = Ischia Bank. Modified from Crane & *alii* (1985).

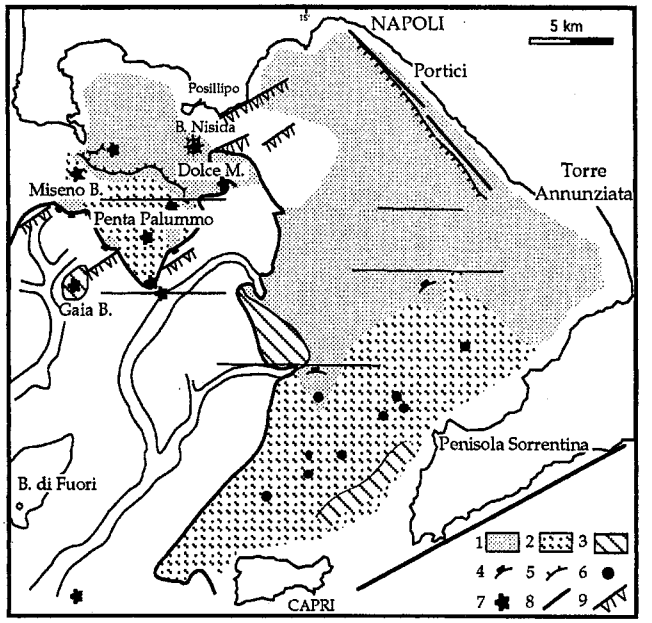

FIG. 3 - Geomorphologic map of the Bay of Naples shelf. Legend: 1) depositional area, 2) erosional surface, 3) erosional terrace, 4) depositional terrace edge at a depth of –130 m, 5) depositional terrace edge at a depth of –60/–80 m, 6) pinnacle reef, 7) volcanic vent, 8) fault, 9) fault scarp and fault-line scarp.

EROSIONAL, DEPOSITIONAL AND VOLCANIC FEATURES OF THE CONTINENTAL SHELF

Erosional, depositional, structural and volcanic forms were detected and mapped in the continental shelf of Naples Bay (fig. 3). Erosional surfaces were discovered present in the southern and northern shelf. They cut the Meso-Cenozoic substrate (MC in fig. 4), Middle Pleistocene deposits (P in fig. 4) and the Campanian Ignimbrite pyroclastic deposits (see figure 3 in Milia, 1998b). Erosional terraces affecting the carbonatic substrate located in the southern shelf between the Sorrento Peninsula and Capri (Cinque & Putignano, 1992) were also detected.

At depths of –110 m and –120 m the erosional surface is overlain by pinnacles that can be interpreted as erosional relicts, reefs or beach rocks. The different nature of the rocks and sediment that constitute the substrate of the pinnacles, Meso-Cenozoic carbonatic substrate, Middle Pleistocene clastic deposits and the Campanian Ignimbrite pyroclastic deposits permitted us to exclude them as being interpreted as erosional relicts. At a depth of -130 m pro-

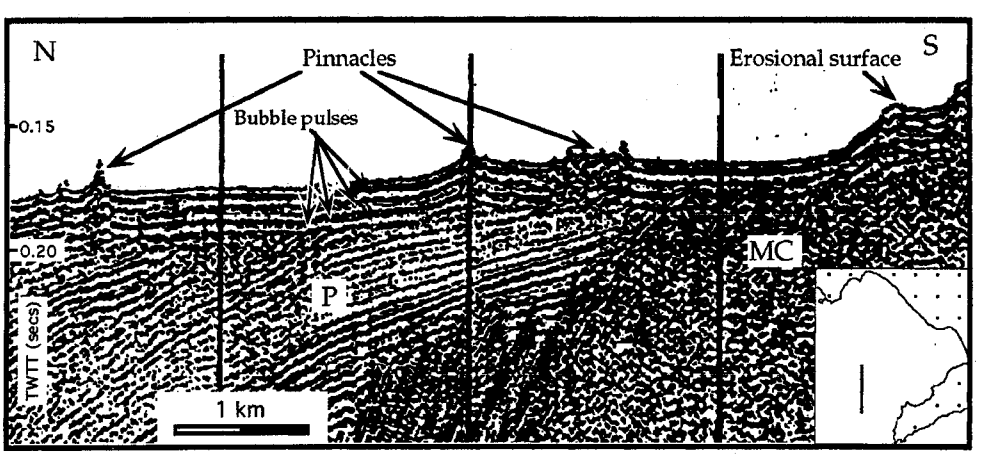

FIG. 4 - Sparker seismic reflection profile located in the southern shelf sector. The upward reflector termination of Middle Pleistocene unit (P) is an erosional truncation. Pinnacles are present above the erosional surface. Landward there are erosional terraces cutting the Meso-Cenozoic substrate (MC). Note that the four reflectors parallel to the sea floor are bubble pulses. From Milia (1996).

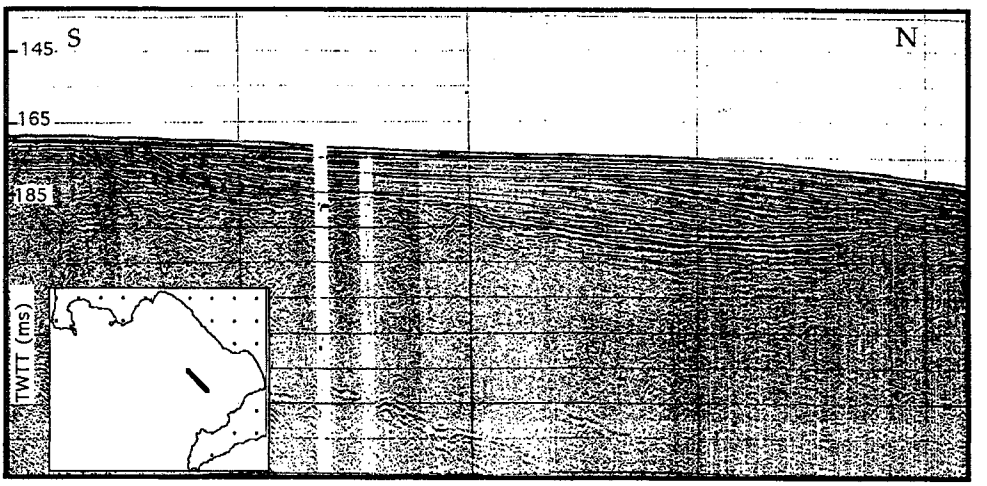

FIG. 5 - Surfboom seismic reflection profile showing a prograding seismic unit located at the edge of the erosional surface of the southern continental shelf. From Milia (1996).

gradational depositional units form in the southern shelf at the edge of the erosional surface (fig. 5). In the central shelf Late Quaternary distal deposits (D2 in fig. 6) resting above the Campanian Ignimbrite (Milia, 1996; 1999) form a depositional surface deeper than –130 m. Close to the coast the Late Quaternary deposits present a progradational unit the top of which forms a depositional terrace at a depth of approximately 75 m (fig. 4, 6). The foresets of this unit dip less than 1° and pass seaward in the central shelf to a wide sub-horizontal surface locally deformed and uplifted by magmatic cryptodomes (fig. 6; Milia & *alii*, 1998a, 1998c). In the outer shelf an erosional surface affects the Middle Pleistocene deposits (P in fig. 6).

The northern sector of the bay corresponds to the offshore counterpart of the Campi Flegrei and is made up of numerous volcanic units (Milia, 1998a; Milia & *alii*, 1998b). Above the older volcanic banks an erosional surface occurs. In places the latter is overlain by Late Quaternary deposits (fig. 4, 7) that form two principal depositional terraces at depths of -130/-140 m and –60/–80 m (Segre, 1972; Latmiral & *alii*, 1971; Pescatore & *alii*, 1984). The latter depositional terraces overlie the Neapolitan Yellow Tuff and the Nisida Bank (Segre, 1972; Milia & *alii*, 1998b). The volcanic forms of the northern sector are monogenic volcanoes, small calderas, tuff cones and lava extrusions. For example, the Gaia Bank is a monogenic volcano built above a normal fault down throwing the Middle Pleistocene deposits (P) towards the south (fig. 8A). The size of this volcano, 2.25 km wide and 150 m high, is comparable to that of the Monte Nuovo volcano that formed in 1531 A.D. During the last Campi Flegrei eruption. The Miseno Bank features a steep northern slope that is interpreted as a caldera wall successively filled by Late Quaternary deposits (fig. 8B). The Nisida volcanic complex displays volcanoes smaller than Gaia Bank and features well defined internal and external mound geometries (fig. 8C). These seismic features suggest that these volcanoes correspond to tuff cones such as the Nisida volcano. Finally some uprising volcanic bodies reach the sea floor locally (Milia & *alii*, 1998a; Milia & *alii*, 1998b). In particular, Mount Dolce rises 40 m from the sea bed (fig 8D).

A Late Quaternary complex fault pattern is present in Naples Bay (fig. 3): NE-SW trending normal faults dipping mainly southeastwards affected the northern sector, E-W trending trascurrent faults affected the whole bay, and NW-SE trending normal faults are located close to the eastern coast of the bay (fig. 4; Milia, 1996; 1997; 1998b; Milia & *alii*, 1998c). The NE-SW trending normal faults give rise to fault and fault line scarps in the northern sector (see fig. 7 in Milia, 1998b), whereas cliffs are associated to the NW-SE and NE-SW trending faults close to the Posillipo hill coast.

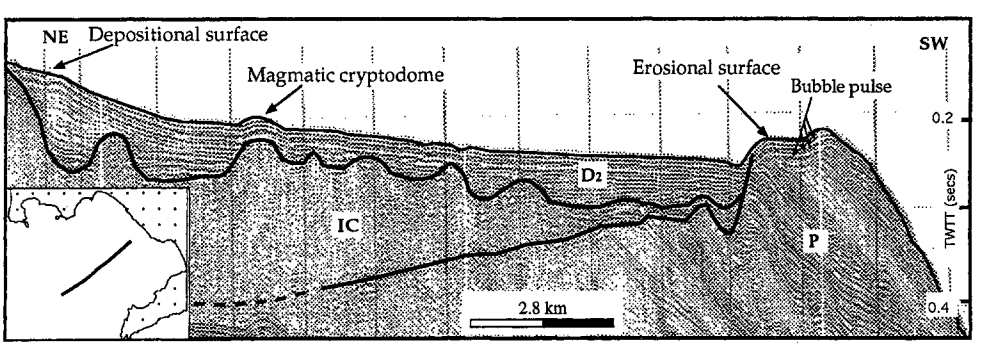

FIG. 6 - Sparker seismic reflection profile located in the central shelf sector corresponding to a depositional area. The outer shelf displays an erosional surface overlying Middle Pleistocene progradational units. Legend: P = Middle Pleistocene progradational deposits; IC = Campanian Ignimbrite; D2 = Late Quaternary marine sediments. Note that the four reflectors parallel to the sea floor correspond to bubble pulses. Modified from Milia (1996).

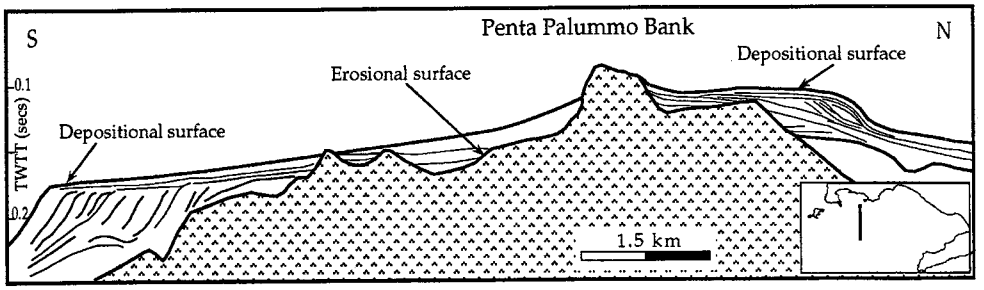

FIG. 7 - Line drawing of a Surfboom seismic reflection profile along the northern shelf sector. This section shows erosional and depositional forms overlaying volcanic banks. Two depositional terraces at a depth of –130 m and –60/–80 m occur. From Milia (1998a).

DISCUSSION AND CONCLUSIONS

The geomorphology of Naples Bay is characterized by erosional, depositional, volcanic and tectonic forms. The main erosional surface extends over a wide area in the southern and northern shelf up to a depth of –130 m. Because the younger volcanic deposits affected by this erosional surface are that of the Campanian Ignimbrite (35 ka B.P.) one can argue that the origin of this surface is related to: (a) shoreface erosion during the sea level fall, that reached its maximum depth about 20 ka B.P.; (b) subaerial erosion during the emersion of the area; and (c) erosion and reworking of the sediment during the last sea level rise.

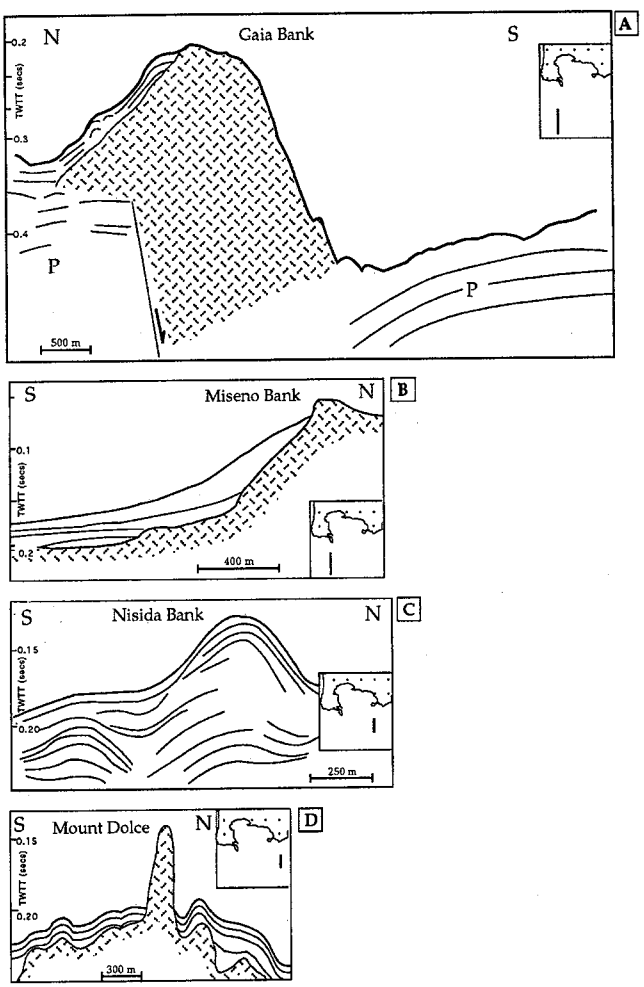

FIG. 8 - Line-drawings of Surfboom seismic reflection profiles displaying the volcanic forms of the northern shelf sector. 8A) Banco Gaia volcano overlies Middle Pleistocene deposits (P) and was emplaced along a normal fault. 8B) Banco Miseno caldera and overlying deposits. 8C) Tuff cones of the Nisida Complex. 8D) Mount Dolce extrusion rising 40 m from the sea floor.

Two principal depositional surfaces, located at different depths, were recognized in the shelf. The first one is present at a depth higher than or equal to –130 m at the margin of the erosional surface; the second one is at a depth of –60/–80 m. The deeper surface represents the top of marine sediments deposited during the sea level fall and lowstand. The shallower surface corresponds to depositional terraces located at the top of a prograding unit that formed during a sea level stillstand (*sensu* Mitchum & *alii*, 1977). On the basis of the age of the volcanic deposits underlying the prograding units of Neapolitan Yellow Tuff (12 ka B.P.) and Nisida bank (10-8 ka B.P.), it is possible to attribute this depositional surface to the Younger Dryas cold event that occurred during the sea level rise. The sedimentary response to this event was also recognized in the Adriatic Sea by means of interpreting seismic reflection profiles and core logging (Trincardi & *alii*, 1996).

There are numerous Late Quaternary tectonic features localized in the northern sector of the bay. Among the faults the NE-SW trending normal faults are characterized by large displacements. The map distribution of the volcanic vents suggests that these faults control volcanic activity. Asymmetrical extensional block faulting produces steep fault scarps, subsidence (depositional areas) in the belt parallel and close to the faults and uplift or tectonic stability (erosional areas) in the distal areas (Gawthorpe & *alii*, 1994; Leeder & Gawthorpe, 1987; Ravnas & Steel, 1998). The tectonic evolution of Naples Bay, a half graben with master faults trending NE-SW (Milia, 1999), is in agreement whith the map distribution of the erosional and depositional features (fig. 3). In the southern continental shelf, up to a depth of –130 m, an important NE-SW trending erosional surface is present. In the central shelf it passes to a depositional area (figs. 3, 9).

The recognized forms of the Naples Bay continental shelf are the results of global and local phenomena, eustatic sea level oscillations, tectonics and volcanisms. This study shows that the depths at which erosional and depositional surfaces of the bay are associated whith sea level fluctuations whilst their spatial distribution is a result of

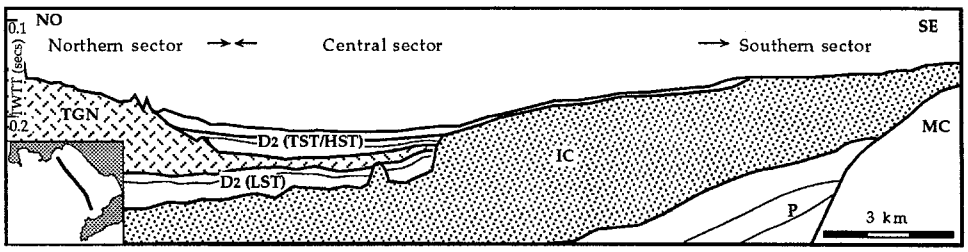

FIG. 9 - Line-drawing of a Sparker seismic reflection profile displaying the main physiographic features of the Naples Bay continental shelf. The southern sector is basically an erosional area, the central sector corresponds to a depression filled by sediments and the northern sector displays forms due to the occurence of the Neapolitan Yellow Tuff.

Legend: MC = Meso-Cenozoic rocks; IC = Campanian Ignimbrite; D2 (LST) = Late quaternary sediments deposited during the sea level lowstand; D2 (TST/HST) = Late quaternary sediments deposited during the sea level rise and highstand; TGN = Neapolitan Yellow Tuff. Modified from Milia & *alii* (1998a).

tectonics. In fact erosional surfaces occurring up to a depth of –130 m and depositional surfaces below –130 m are associated with a lowering of the sea level until the last glacial maximum (Isotopic Stage 2). Depositional surfaces found above –60/–80 m are associated with a stillstand during the general sea level rise. The tectonics affecting the uplifted and subsiding areas during the activity of the NE-SW faults influenced the erosive-depositional architecture of the Naples Bay continental shelf. Futhermore, the distribution of the volcanic edifices present in the northern sector of the shelf and following a NE-SW alignement are directly associated with there faults.

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