Digital elevation model of the Naples Bay and adjacent areas (Eastern Tyrrhenian Sea)

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ABSTRACT

An extensive, high-resolution bathymetric survey has recently been carried out, portraying the continental shelf-slope system of the Campania Region, in southern Italy (Eastern Tyrrhenian Sea). The relative bathymetric data were acquired between 1997 and 2002, using multibeam systems with an average vertical resolution of $\leq$ 0.25 % water depth and a position accuracy of $\leq$ 10 m. The survey data were successively merged with a Digital Terrain Model (DTM) created from topographic maps of the onshore coastal area and islands of theNaples Bay, to produce a Digital Elevation Model (DEM) based on a homogeneous grid with cell-spacing of 20 m.

The shaded-relief, colour scale map of the Naples Bay presented in this study provides new, detailed information on the morphology of the coastal Campania Region. This continental margin displays evidence of the interplay between tectonics and volcanism and their interference with sedimentary processes during the latest Neogene and Quaternary.

The major morphological features revealed by the 3D digital maps are: 1) the system of marine canyons (Dohrn and Magnaghi) that cut the continental slope at a depth between 250 m and 1100 m; 2) the funnel-shaped marine slope system of the Ischia volcanic structure; 3) the onshore-offshore volcanic field of the Campi Flegrei; 4) the rugged seafloor area (of a diameter of ca 2 km) off the town of Naples (Banco della Montagna), caused by active uplift of small-scale volcaniclastic diapirs (pyroclastic lumps); and 5) the debris-flow/avalanche deposits on the inner continental shelf of the Eastern Bay of Naples, that evolved from the pyroclastic products of the Vesuvius.

AIMS

This study is part of a long-term project focused on the extensive bathymetric survey of selected segments of the Tyrrhenian continental shelf. On-going research activities include the acquisition of digital earth and seafloor surface elevation data in order to obtain high-resolution digital models and maps of the Campania continental margin and adjacent areas. This is a heavily populated segment of the Italian coastal zone that is subject to severe environmental threat due to intense anthropical activity.

The aims of the research program include:

- Acquisition of high-resolution, digital, bathymetric data on the Italian economic zone (continental shelf-slope system) of the Eastern Tyrrhenian Sea and digital topography of the coastal zone.
- Study of morphostructural features and related geological processes along the Eastern Tyrrhenian continental margin.
- Creation of merged, 3D, digital maps of onshore topography and offshore bathymetry imaged as a unique habitat, to be adopted as a tool for a Geographic Information System (GIS)-based study or application.
- Use of accurate marine DEMs for numerical modelling of oceanographic processes and sediment and pollutant transport, geological mapping, assessment of submarine slide potential, location of the surface expression of active faults and identification of offshore disposal sites, as well as monitoring of biological processes and benthic habitats.

KEY WORDS

Tyrrhenian Sea, multibeam bathymetry, digital elevation model, continental margin, submarine canyon, debris avalanche, pyroclastic diapir.

RIASSUNTO

Negli ultimi anni è stato realizzato un esteso rilievo batimetrico di alta risoluzione è stato realizzato recentemente in corrispondenza del sistema piattaforma-scarpata del margine continentale campano nel Tirreno orientale. I dati batimetrici sono stati acquisiti tra il 1997 ed il 2002 utilizzando ecoscandagli multifascio (sistemi multibeam) con risoluzione verticale $\leq$0.25 % della profondità d'acqua e posizionamento con errore inferiore a 10 m. I dati raccolti sono stati utilizzati per la realizzazione di una griglia di dati batimetrici con maglia di 20 m. Il grid batimetrico è stato poi integrato con dati digitali di terreno (DEM), di eguale risoluzione, derivati da carte topografiche dell'area costiera e delle isole campane.

La carta batimetrica digitale con rilievo a luci ed ombre ed il modello 3D qui illustrati forniscono nuove informazioni sulla morfologia di dettaglio del margine continentale della Campania che mostra nel suo complesso una chiara evidenza dell'interazione tra processi tettonici, vulcanici e sedimentari durante il Neogene superiore - Quaternario. Gli elementi morfologici principali evidenziati dai dati batimetrici sono: 1) i sistemi di canyon sottomarini (Dohrn and Magnaghi) che dissecano la scarpata continentale tra circa 250 m e 1000 m di profondità; 2) la scarpata continentale dell'apparato vulcanico dell' Isola di Ischia; 3) una serie di banchi vulcanici al largo del distretto vulcanico dei Campi Flegrei (ad es. Ischia, Miseno, Penta Palummo, Nisida); 4) un'area dal rilievo irregolare, del diametro in pianta di circa 2 km, al largo della città di Napoli (Banco della Montagna), legata alla emergenza al fondo mare di piccole strutture diapiriche in depositi vulcanoclastici pomicei; 5) accumuli sottomarini da debris-flow/avalanche di masse piroclastiche vesuviane parzialmente inserite nel margine orientale del Golfo di Napoli.

DEM OF THE NAPLES BAY

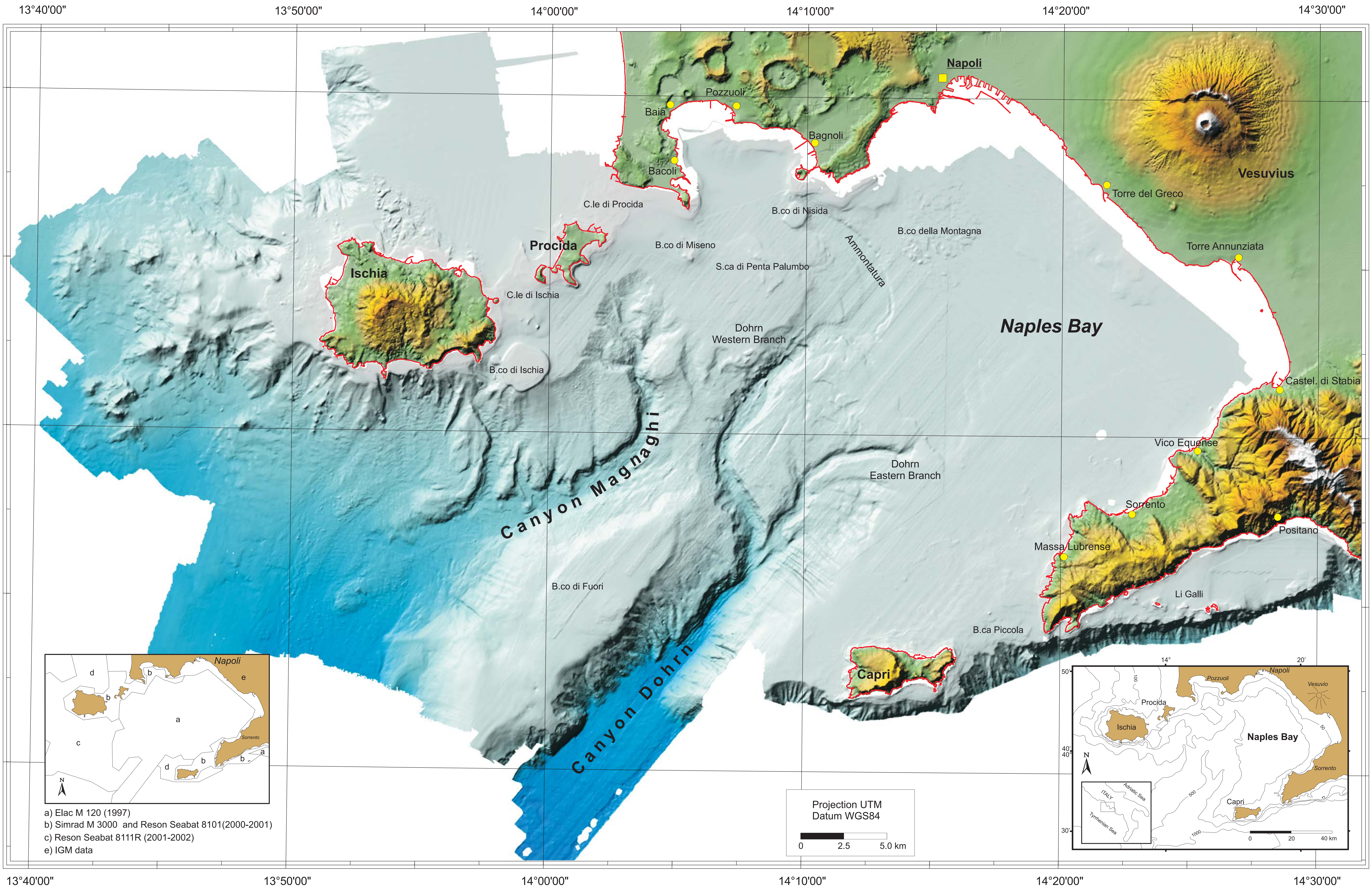

Fig. 1 - *Colour shaded relief map of the Naples Bay and adjacent areas based on digital elevation data.*

TOOLS AND METHODOLOGY

Today, swath or "multibeam" bathymetry is recognized as one of the most effective tools for marine surveying. This methodology provides almost full sea-floor coverage over relatively short acquisition times and does not imply extensive interpolation of data like the classic single-beam echo-sounders. An advantage of this method is the possibility of generating a Digital Elevation (or Terrain) Model (DEM) of the real bathymetry with a resolution that is dependent both on the intrinsic characteristics of the echo-sounder and on water depth.

Unlike topographic surveys on land, the compilation of a marine DEM normally requires a longer process, during both the acquisition and processing phases. There are three main sources of error and noise systematically associated with multibeam datasets: those related to the monitoring of the vessel and echo-sounder motion (navigation, pitch, roll, heave, yaw); those related to a poor acoustic signal (especially on lateral beams); and those due to oceanographic factors (water sound velocity, tides, swell). In the Mediterranean, some of these disturbance factors, such as tides and oceanic swell, are negligible, unless very high resolution is required, as is the case for detailed surveys (scale > 1:10,000) and in very shallow water. Echo-sounders are normally suited for a given bathymetric range with a transducer frequency varying from hundreds of kHz (shallow water surveys) to tens of kHz (full oceanic depth). While vertical resolution depends on the transducer's frequency and water sound velocity only, horizontal resolution is typically depth-dependent and referred to as the "footprint", i.e. the seafloor area covered by each acoustic beam. The echo-sounder systems employed during the 1997-2002 surveys off the bay of Naples and their characteristics are listed in Tab. 1. Most marine DEMs are based on regularly-spaced soundings arranged in symmetrical x,y,z matrices called grids. When navigation route patterns are relatively homogeneous, there is no particular need for choosing anything other than symmetrical DEMs. Each grid is characterised by an elementary square cell unit and the adopted cell size must take into account the limits imposed by the average footprint.

The DEM of Fig. 1 is based on a 20x20 m cell and results from the integration of different grids, each characterised by variable cell size ranging from 2.5x2.5 m in the shallow areas (water depth <50 m) to 25x25 m at greater depths. The marine part of the DEM has been merged with a digital terrain model of the coastal area, derived from 1:25,000 topographic maps having the same cell size. Despite the loss of resolution in shallow water areas, the 20x20 m matrix was shown to be adequate in detecting the most prominent (larger than a few tens of meters) topographic and bathymetric features of the coastal zone.

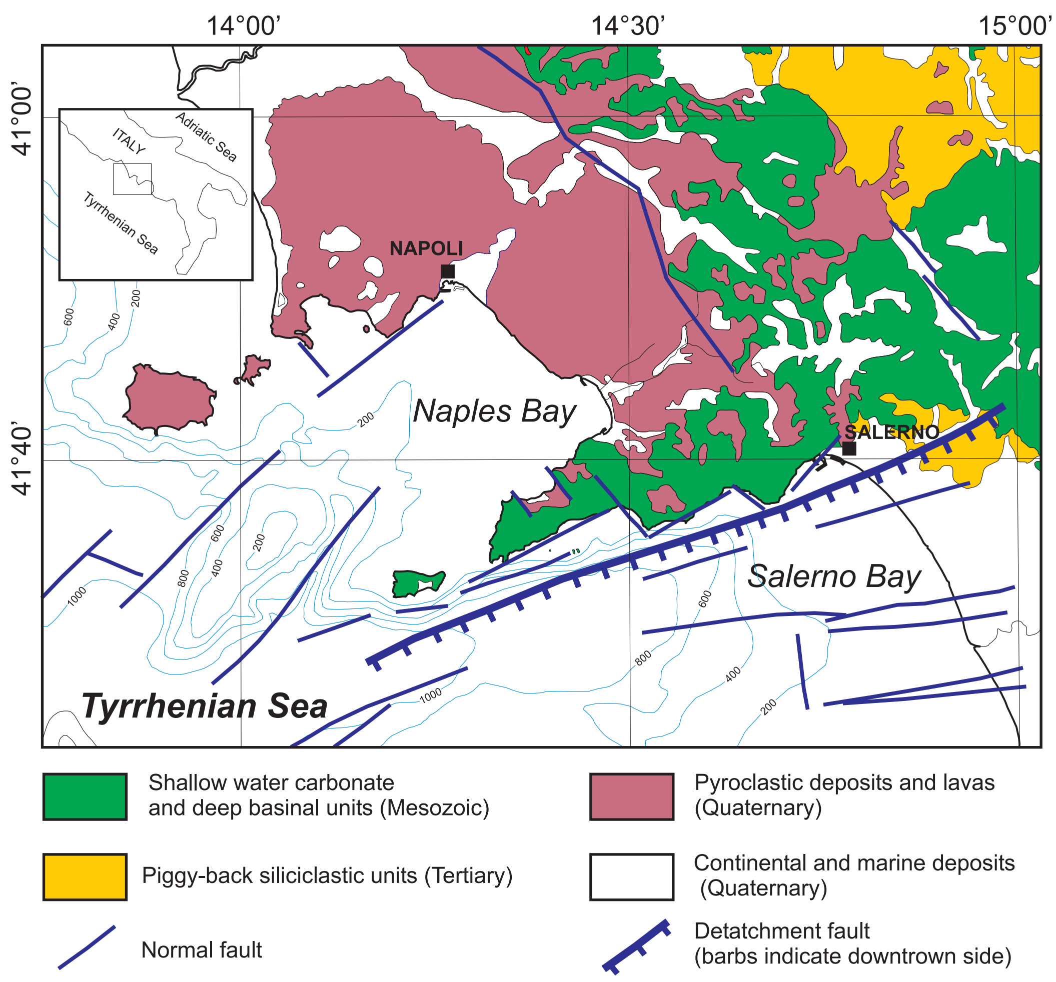

Fig. 2 - *Tectonic sketch-map of western Campania Apennines.*

Echo-sounder	Simrad EM 3000	Reson SeaBat 8101	Reson SeaBat 8111	Elac Bottomchart MkII
frequency	300 kHz	240 kHz	100 kHz	50 kHz
Swath sector	130°	150°	150°	150°
N° of beams/ping	127	101	101	126
Vertical resolution at 1500 m/sec	0.5 cm	0.6 cm	1.5 cm	3 cm
Footprint diameters at 10/100/1000/3000 m depths	0.17/1.7	0.26/2.6	0.26/2.6/26	0.2/2/20/62
Coverage	Up to 10 times water depth	1.8 to 7.4 times water depth	1.8 to 7.4 times water depth	2 to 8 times water depth

Tab. 1 - *Characteristics of the echo-sounder systems employed for the bathymetric survey of the Naples Bay.*

GEOLOGICAL SETTING

The eastern margin of the Tyrrhenian Sea is characterised by a number of basins that evolved during the latest Neogene - Quaternary across the structural boundary between the Apennine fold and thrust belt and the Tyrrhenian back-arc extensional area (Fig. 2). These basins, which include the present-day Naples Bay, formed in response to large-scale orogen-parallel extension and associated transtensional tectonics that accompanied the anti-clockwise rotation of the Apennine belt and lithospheric stretching in the central Tyrrhenian basin (Sacchi *et alii*, 1994; Ferranti *et alii*, 1997).

Therefore, the Campania segment of the peri-Tyrrhenian structural belt displays the characteristics of a passive continental margin, where Quaternary orogen-parallel extension caused the formation of half-Graben systems (e.g. Volturno Bay, Naples Bay, Salerno Bay) and intervening structural highs (e.g. Sorrento Peninsula, Mt. Massico) that trend perpendicularly to the main axis of the Apennine thrust belt (Mariani & Prato, 1988; Sacchi *et alii*, 1994; Milia & Torrente, 1999). In turn, the Quaternary extension along the Campania segment of the Southern Apennine - Eastern Tyrrhenian hinge zone caused the onset of intense volcanism. Major volcanic centres are the Somma-Vesuvius, Ischia Island and the district of the Campi Flegrei, with its numerous vents both onshore and offshore in the Naples Bay. The recent morphological evolution of the Naples Bay has been significantly controlled by sea-level changes and consequent base-level fluctuation during the last glacio-eustatic cycles (Milia, 1999).

THE DOHRN CANYON: A FOSSIL DRAINAGE SYSTEM IN AN ACTIVE VOLCANIC AREA

The Dohrn and Magnaghi canyons originate from the shelf break of the Naples Bay off the Phlegrean Fields volcanic complex, located along a 140 m isobath. The course of the Dohrn canyon lower section is likely to be controlled by morphostructural lineaments, i.e. the Banco di Fuori and Capri structural highs. Both the Magnaghi canyon and the Dohrn western branch display morphological evidence of retreating canyon heads (Figs. 1 and 3). The upper Dohrn canyon section consists of two major curved branches. The western branch cuts deep into the shelf through a channel which is 1.5 km wide and 20-40 m deep (Ammontatura), characterised by flat thalweg and asymmetrical levees. The Ammontatura channel is probably an incised valley subsequently filled by younger deposits, and predates the onset of the most recent volcanic edifices in the Pozzuoli Bay, as suggested by its abrupt termination towards the Nisida submarine vent. The width of the canyons ranges from a few hundred meters to more than 1 km; their depth ranges from 250 m at the shelf edge to some 1300 m at the junction with the bathyal plain; the slope of canyon walls attains some 35° in the steepest sectors. The Dohrn eastern branch (DEB) shows a meandering trend and develops from the shelf break of the Sorrento Peninsula, located along the 120 m isobath. The Dohrn western branch (DWB) is broader and deeper than the eastern branch. The two do not join, as the eastern branch is suspended over the western (Figs. 4 and 5).

Canyon morphology

In general, V-shaped erosional profiles characterize the upper section of the Dohrn canyon, while U-shaped profiles develop in the lower, rectilinear section. V-shaped profiles prevail in the retreating head of the DW, and

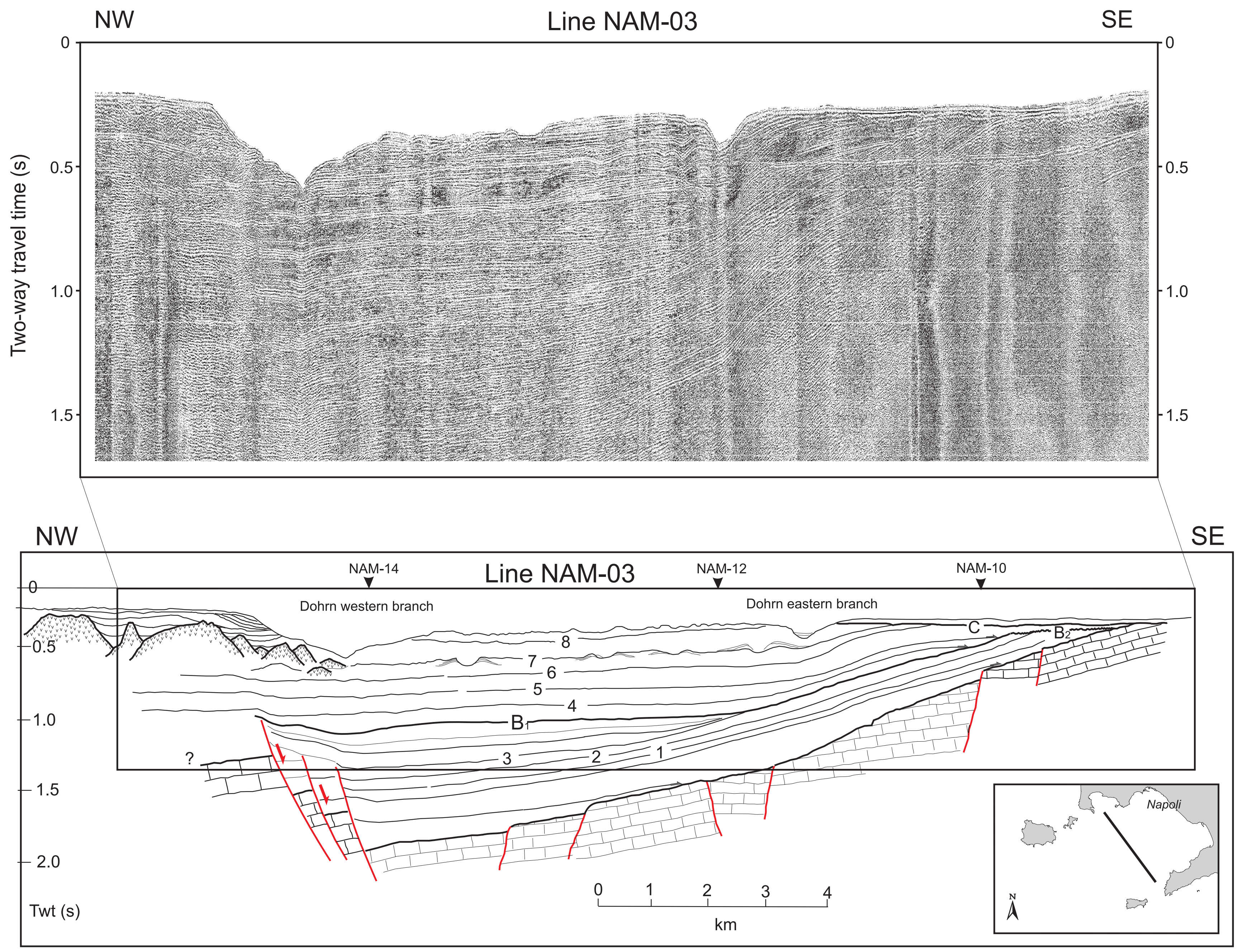

Fig. 3 - *Line drawing of the NAM3 seismic profile that crosses the Naples Bay from the Ischia and Procida islands to the Sorrento Peninsula showing the stratigraphic relationships between the seismic sequences. Units 1-3 are interprete as a wide, relic prograding wedge with eroded topsets and preserved clinoforms, probably Early Pleistocene in age. Units 4-8 are interpreted as to Upper Pleistocene prograding wedge fed by the palaeo-Sarno River mouth.*

rapidly evolve into U-shaped profiles towards the meandering sector of the canyon. V-shaped profiles may be again detected in the sector of the DWB, close to the confluence between the two branches (Fig. 5). Large round-shaped morphologies at the bottom of the DWB and in the confluence area, close to the present-day thalweg of the canyon system, are likely to represent remnants of the eroded substrate rather than slide blocks.

The geological scenario of the Dohrn canyon seems typical of a "mature" morphology, as suggested also by the occurrence of at least three phases of incision and terracing that predate the developmentof the present-day thalweg. Section D3 shows terrace rims respectively located at 300 m and 340 m of water depth. These morphological evidences suggest at least two phases of activity and the retreat of the canyon's head. Several well-developed terrace rims (at least five) were identified on bathymetric profiles (Fig. 5). Recent phases of canyon filling are testified by U-shaped morphologies in the meandering sector of the DWB and in the terminal sector of the canyon.

Drainage system

A dense network of previously unknown tributary channels, controlling sediment transport towards the surrounding areas of the continental slope, feeds the canyons.

Two main tributary channels develop from the shelf break of the Phlegrean volcanic banks (located along the 140 m isobath) across the continental slope between the Dohrn and Magnaghi canyons. Some of these channels trend NW-SE and seem to be fault-controlled (CHIOCCI *et alii*, 1998).

Inactive tributary channels, suspended over the main branches of the canyon, testify to phases of rapid re-incision, when the feeding from lateral sources was cut off, thus forming suspended valleys (AIELLO *et alii*, 2000).

Gravitative instability processes

Several submarine slides and scars are evident on the canyon walls, especially along the western flank of the DWB as well as on the continental slope. Factors known to control submarine slides include loading of under-consolidated deposits due to rapid burial, slope oversteepening consequent to deep linear erosion, earthquakes and sea-level changes (SAXOV & NIEUWENHUIS, 1982; O'LEARY & DOBSON, 1992). This appears to be a significant issue to be addressed, due to the potential risk of anomalous waves originated by submarine instability on the coastal zone. Most slide scars involving the Dohrn canyon appear to be concentrated along the right flank of the Dohrn western branch. However, the Dohrn eastern branch does not appear to be involved in extensive gravitative instability like the western branch. Moreover, slide scars are made evident by bathymetric profiles also

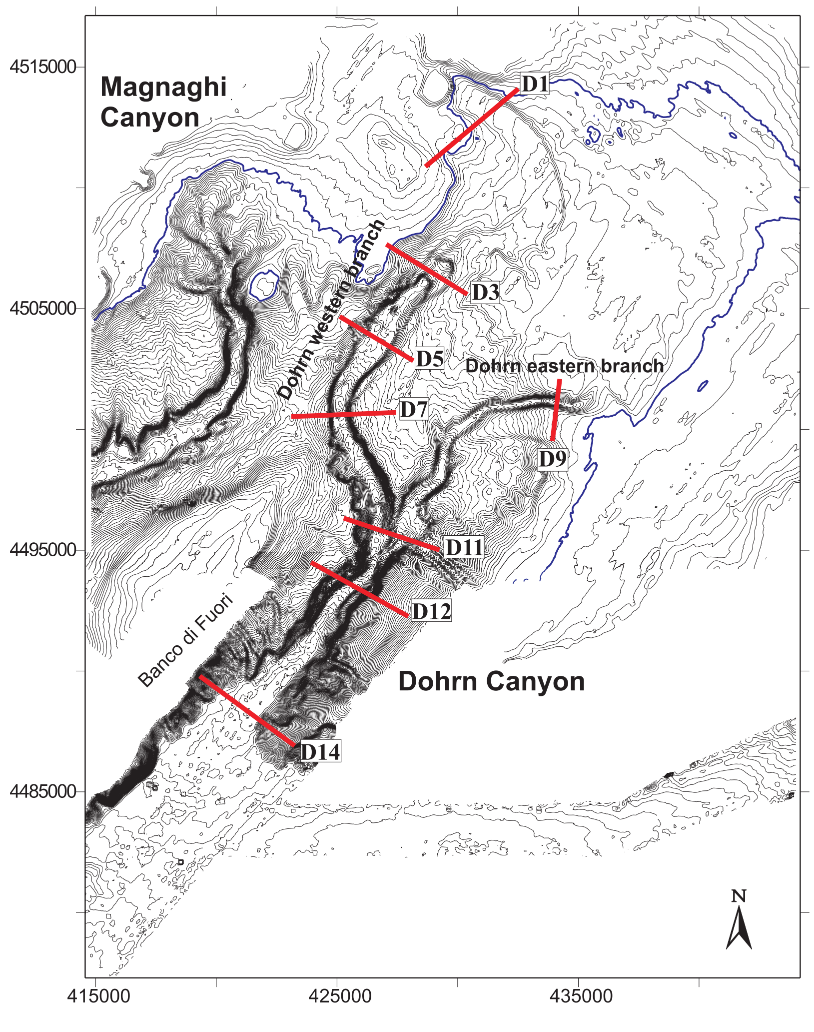

Fig. 4 - *Simplified map of the central sector of the Naples Bay with location of bathymetric profiles illustrated in Fig. 5.*

in the proximity of the present-day thalweg of the canyon.

Late Pleistocene-Holocene seismic stratigraphy
Hundreds of meters of a Middle-Upper Pleistocene prograding wedge are along the walls of the Dohrn canyon, formed by clastic and volcaniclastic sediments and genetically related to the palaeo-Sarno fluvial system. A major morphostructural high (Banco di Fuori) separates the Dohrn canyon from the Magnaghi canyon (Fig. 1). This consists of a Mesozoic carbonate block resulting from regional uplift and tilting of the acoustic basement, cropping out in the structural highs of the Sorrento Peninsula and Capri Island (Fusi *et alii*, 1991; Milia & Torrente, 1999; Aiello *et alii*, 2001). The location of the Dohrn eastern branch and evidence from seismic stratigraphy suggest a genetic link between the activity of the Dohrn canyon and the Sarno palaeo-delta during sea level lowstands. The deltaic system of the palaeo-Sarno River directly fed the continental slope areas during the lowstand phases of Middle-Late Pleistocene, giving rise to a wide prograding wedge, deeply incised by the Dohrn canyon. This is also suggested by the occurrence of two non-volcanic highs located near the heads of the Dohrn canyon. Seismic stratigraphy reveals that they consist of deltaic sediments characterized by clinoform patterns and related to the distal part of a prograding wedge fed by the palaeo-Sarno River mouth. These highs, having an elevation with respect to the surrounding depth in the order of 20-30 m, represent relic morphologies of the Middle-Late Pleistocene continental shelf (Aiello *et alii*, 2001). Seismic evidence suggests that this erosional phase predates the onset of the Campania Ignimbrite (> 35 ka) (Cinque *et alii*, 1997; Milia, 1998, 2000).

Evolution of the submarine canyon
Morphobathymetric and seismostratigraphic evidences are important towards understanding submarine canyon formation, as, according to recent models on submarine canyon evolution, it appears that sediment flows may repeatedly trigger retrogressive failures (Pratson & Coakley, 1996). The canyon's formation may be interpreted by reconciling morphological evidences of head-ward canyon erosion by mass wasting with stratigraphic evidence of canyon inception by downslope-eroding sediment flows. As already suggested, the canyon's evolution may be seen as a transition from "youthful" to "mature" morphology (Farre *et alii*, 1983). The youthful stage begins with extensive slope failures. Retrogressive mass wasting of continental slope sediments along the failure headwall leads to the formation and upslope extension of a relatively straight, steep-walled chute. If this head-ward migrating chute breaches the shelf break, the canyon taps into a new sediment source of outer shelf sands and enters into a mature phase of evolution. Failure of shelf sediments in the vicinity of the canyon head initiates coarse-grained turbidity currents, which become an important agent of erosion by down-cutting the canyon and creating a sinuous thalweg (Twichell & Roberts, 1982; Farre *et alii*, 1983; Pratson & Coakley, 1986; Talling, 1998).

IMAGING AND SAMPLING OF THE ISCHIA MARINE DEBRIS AVALANCHE

One of the most destructive forms of volcanic behaviour has only recently received scientific

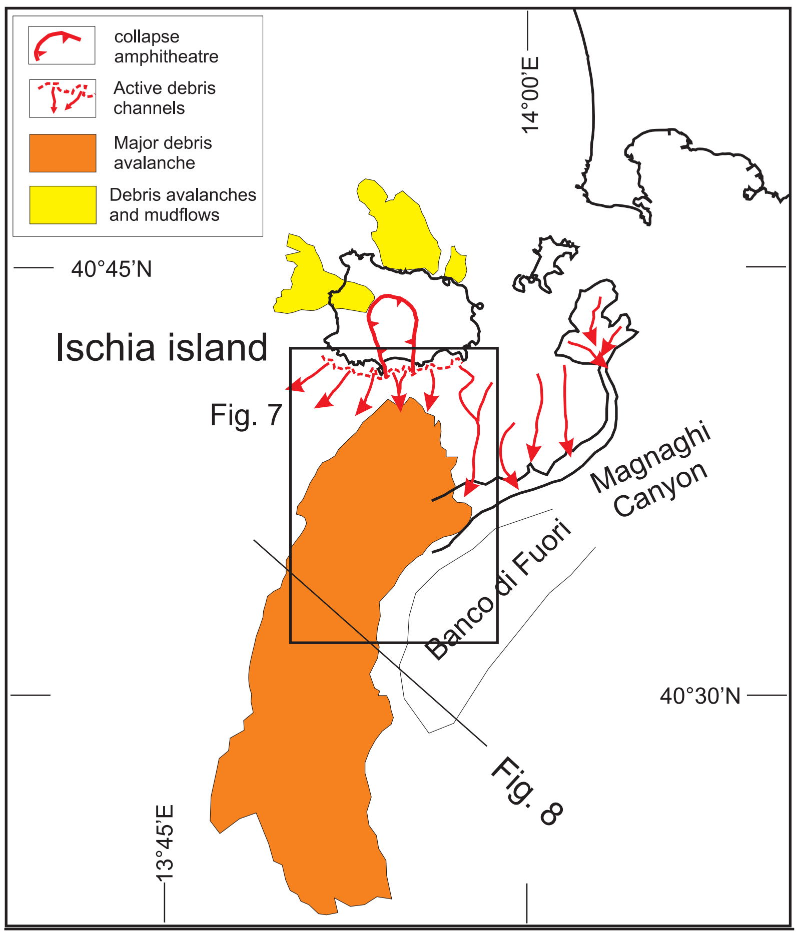

Fig. 6 - *Morphologic sketch-map of the continental slope south of the Ischia Island with indication of the debris avalanche deposits.*

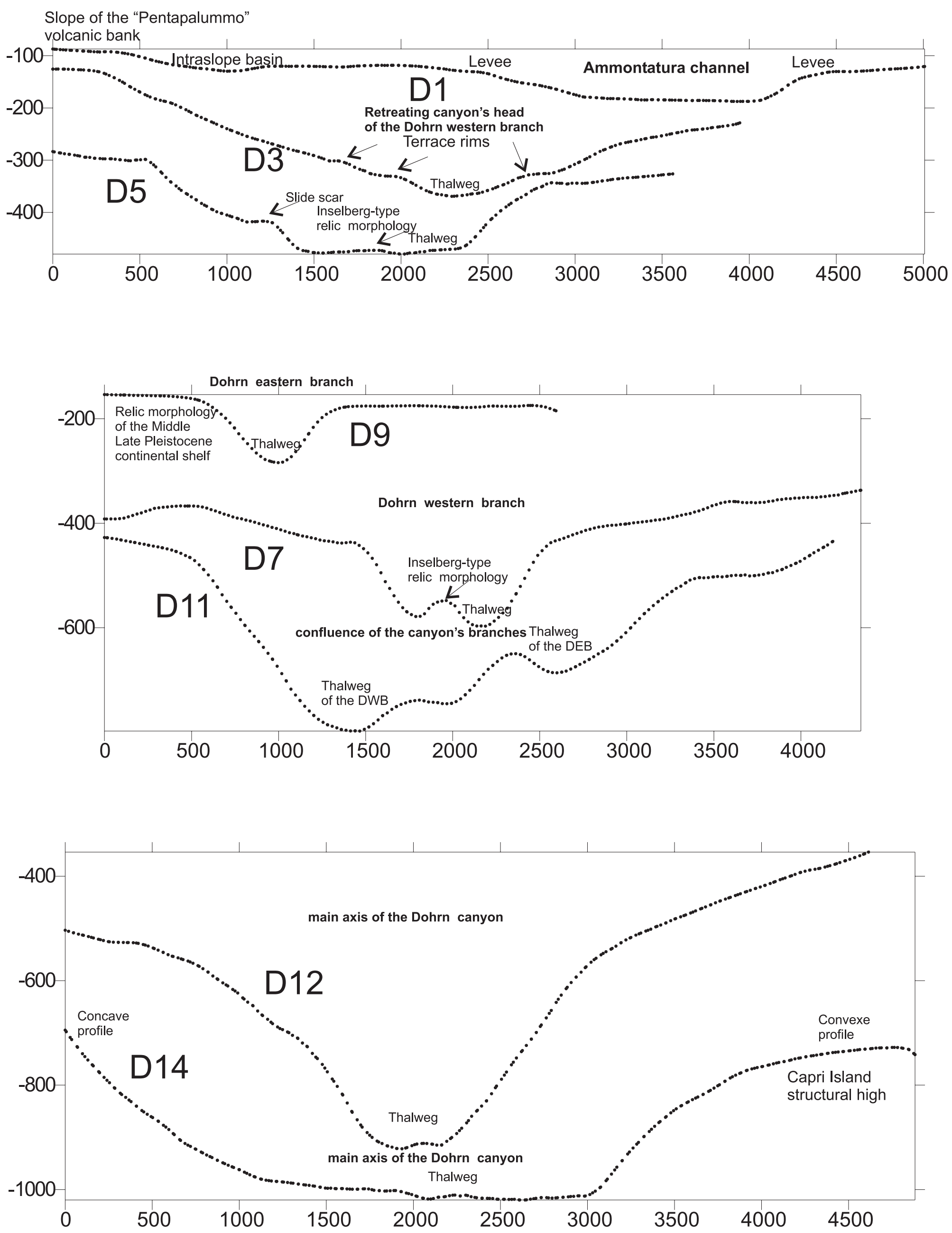

Fig. 5 - *Serial bathymetric profiles across Dohrn canyon. See Fig. 4 for location.*

Fig. 7 - *Side Scan Sonar* (TOBI) *image showing the rugged seafloor morphology of the Ischia debris avalanche. See Fig. 6 for location.*

attention. This involves the catastrophic, sudden collapse of a sector of the volcanic edifice that generates debris-avalanche deposits and leaves amphitheatre-like craters. Generally speaking, subaerial collapses (such as that of Mt. St. Helen, USA, in 1980) are one order of magnitude smaller than those occurring over large volcanic islands in the ocean, such as the as Hawaii or Canary islands (MOORE *et alii*, 1994; MASSON *et alii*, 2002).

The island of Ischia is only the emerged top (about 30%) of a major, E-W trending volcanic ridge that separates two sectors of the continental shelf: the Gulf of Gaeta to the north-west and the Naples Bay to the south-east, which has a deeper and rough sea-floor topography (ALESSIO *et alii*, 1996; BRUNO *et alii*, 2002). Ischia consists of alcali-trachitic lavas and pyroclastites dating back to 150 ka (RITTMANN, 1930; GILLOT *et alii*, 1982). The southern offshore of the island is characterised by extremely narrow shelf areas, followed by a very steep upper slope carved by several active canyons (MARSELLA *et alii*, 2001; DE ALTERIIS & TOSCANO, 2003; BUDILLON *et alii*, 2003a).

The hypothesis that the Ischia volcano might have undergone subaerial and/or submarine sector collapse during its history (LUONGO *et alii*, 1991) has been recently reproposed on the basis of a deep-tow survey (TOBI instrument, Southampton Oceanography Centre, UK) carried out over the southern offshore in the 300-1100 bathymetric range (TIVOLI CRUISE, CHIOCCI *et alii*, 1998). The acoustic data collected during that cruise revealed a debris avalanche extending some 50 km in the southern offshore, down to the 1000-1100 m isobath (Figs. 6 and 7). Further surveys, carried out in 2000 and 2002 showed "hummocky" topography in the western and northern offshore in the 0-150 bathymetric range (BUDILLON *et alii*, 2003b).

Side-Scan-Sonar records over the southern Ischia debris avalanche have shown that the blocks are mostly located on the lower slope (between 500 and 1100 m water depth). Block size ranges from a few meters to more than 100-200 m with large boulders raising 25-40 m above the sea-floor (DE ALTERIIS *et alii*, 2001; CHIOCCI *et alii*, 2002) .

On the basis of seismic profiles, and due to high-energy backscatter over the hummocky topography, as of now being only a tentative appraisal of the Ischia debris can be proposed. On the other hand, seismic techniques clearly show that the eastern edge of the debris avalanche has been confined by the Banco di Fuori morpho-structural high (Fig. 8). Sampling of the Ischia debris avalanche from about twenty coring and dredging stations recovered: a) post-avalanche 0.5-1 m thick hemipelagic mud, in turn incorporating some air-fall tephra layers; b) DA matrix, consisting of slightly consolidated sandy groundmass, at times still plastic, including heterogeneous lithic assemblages; c) small (submetric) blocks consisting of both volcano-sedimentary siltstones, at times with typical jigsaw cracks, and more or less altered trachytic lava, scoriae and welded tuffs and d) debris flow consisting of a mud-supported deposit including extremely heterogeneous volcanic and sedimentary clasts and representing the heteropic, distal facies of the DA matrix.

The Ischia southern collapse may be regarded as < 10 ky on the basis of thickness of the post-avalanche hemipelagic drape, and the average sedimentary rate in turn calibrated on well known tephra layers in the offshore.

THE MORPHOLOGY OFFSHORE VESUVIUS VOLCANO

A hummocky seafloor morphology has been documented at a water depth of 30 and 100 m on the continental shelf, offshore the Somma-Vesuvius volcano. Sub-bottom (CHIRP) profiles acquired parallel to the coast show this morphology draped landward by younger sediments (Figs. 9 and 10).

The seaward termination of this surface in the multibeam bathymetry displays an irregular pattern characterised by elongated lobes that lie perpendicularly to the coast (MILIA *et alii*, 1998, 2003).

Seismic sections across this area display a seismic unit (DA1) characterised by chaotic facies that terminate seawards with a steep, 60 m-high scarp. This unit lies above an erosional unconformity on top of the Campania Ignimbrite (35 ka BP). The top of unit DA1

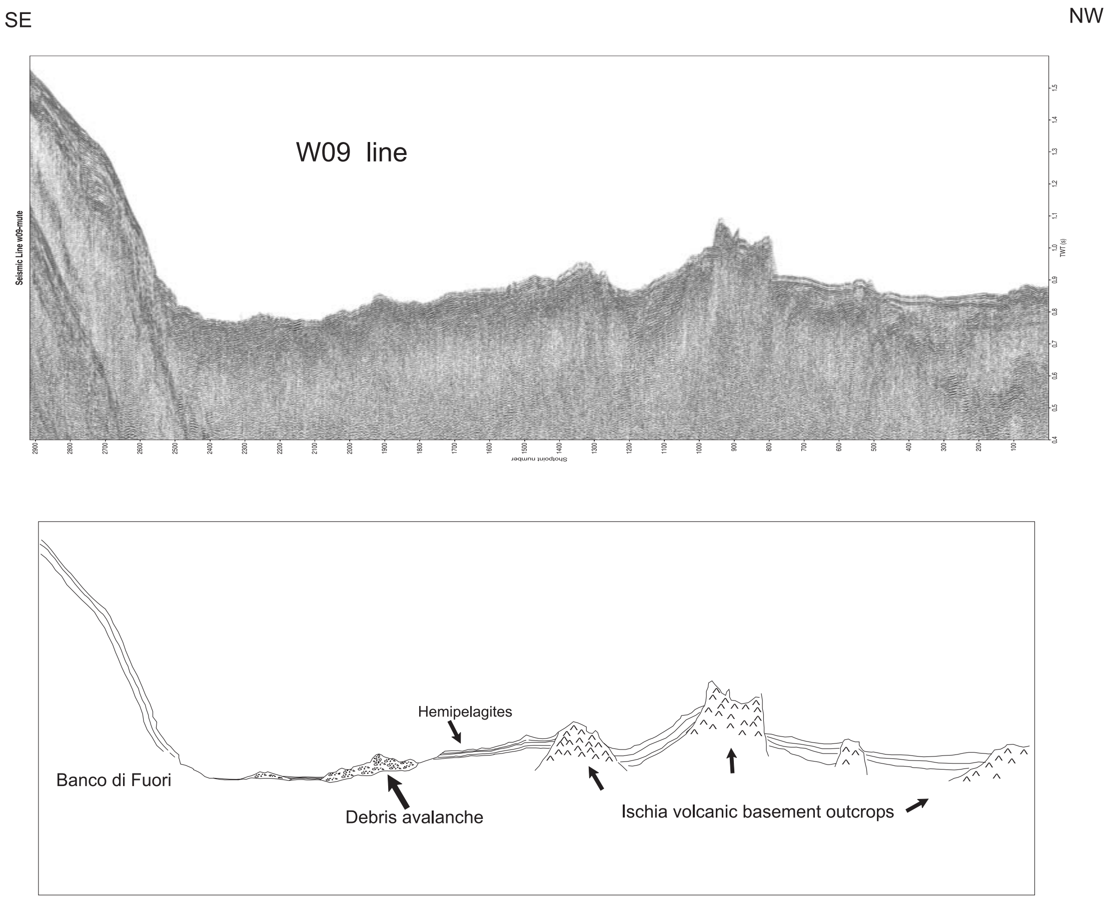

Fig. 8 - W09 *subbottom profile across the Ischia debris avalanche and relative interpretation. See Fig. 6 for location.*

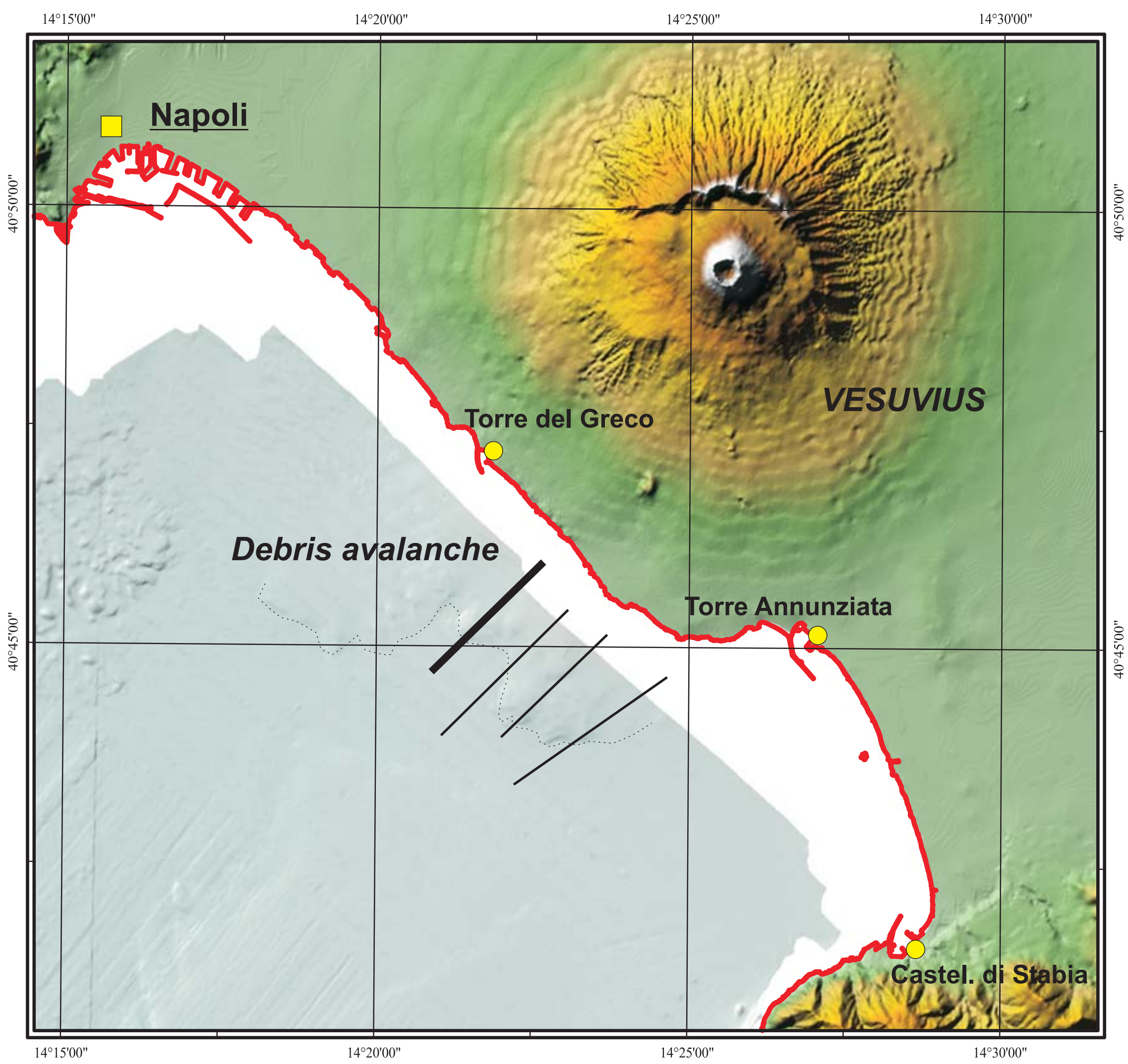

Fig. 9 - *Shaded relief map of the Vesuvius area with indication of the debris avalanche offshore Torre del Greco and Torre Annunziata, with location of the interpreted sparker profile shown in Fig. 10 (thick line) and subbottom* (CHIRP) *profiles shown in Fig. 11 (thin lines).*

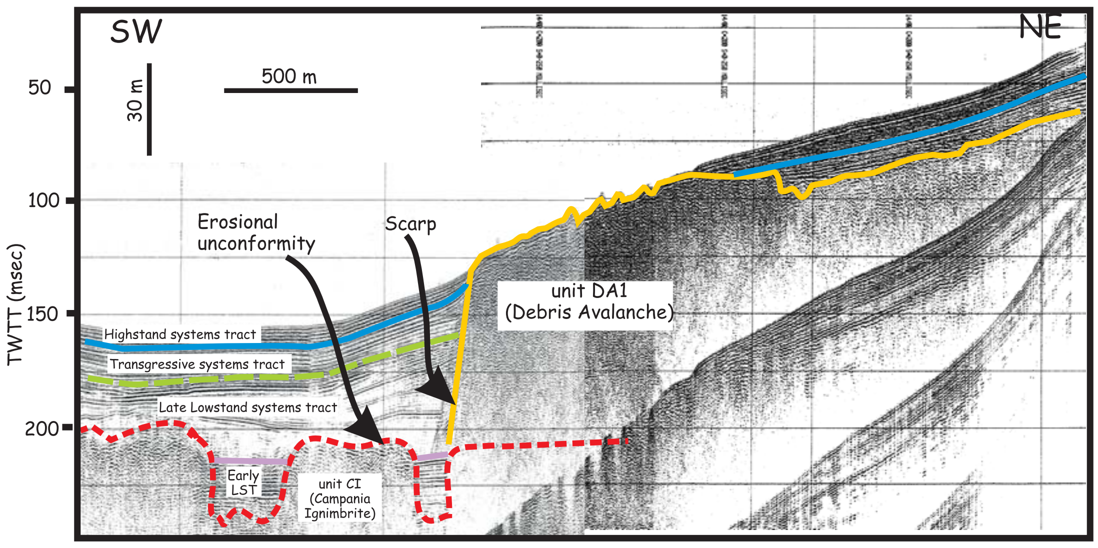

Fig. 10 - *Geologic interpretation of a sparker seisimic profile offshore the Vesuvius. See Fig. 9 for location.*

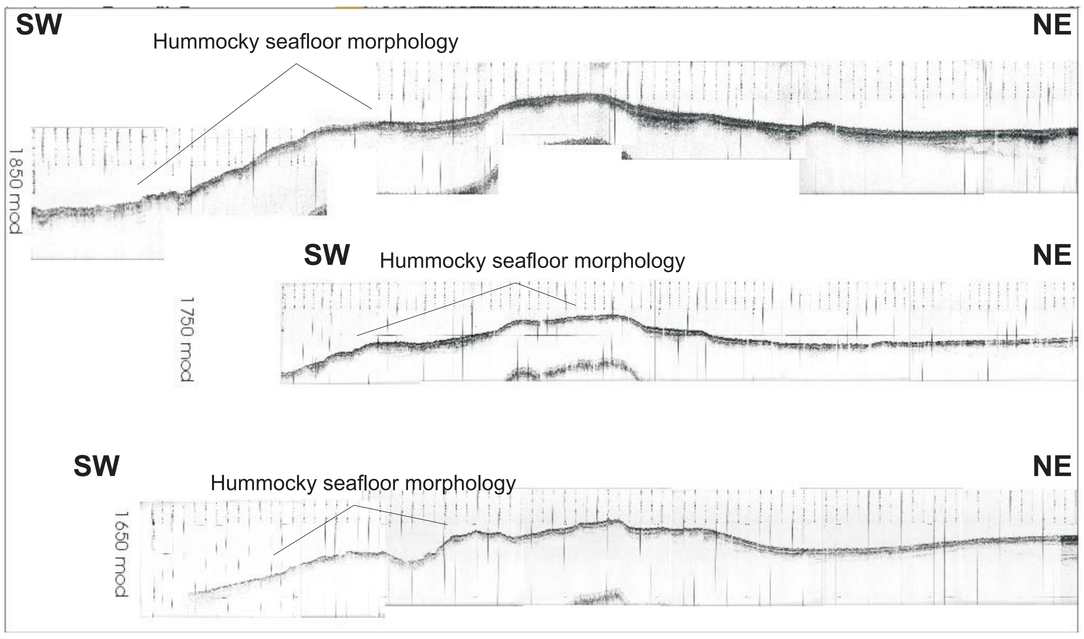

Fig. 11 - *Subbottom* (CHIRP) *profiles showing hummoky seafloor morphology off the Vesuvius debris avalanche. The location of profiles is shown in Fig. 9.*

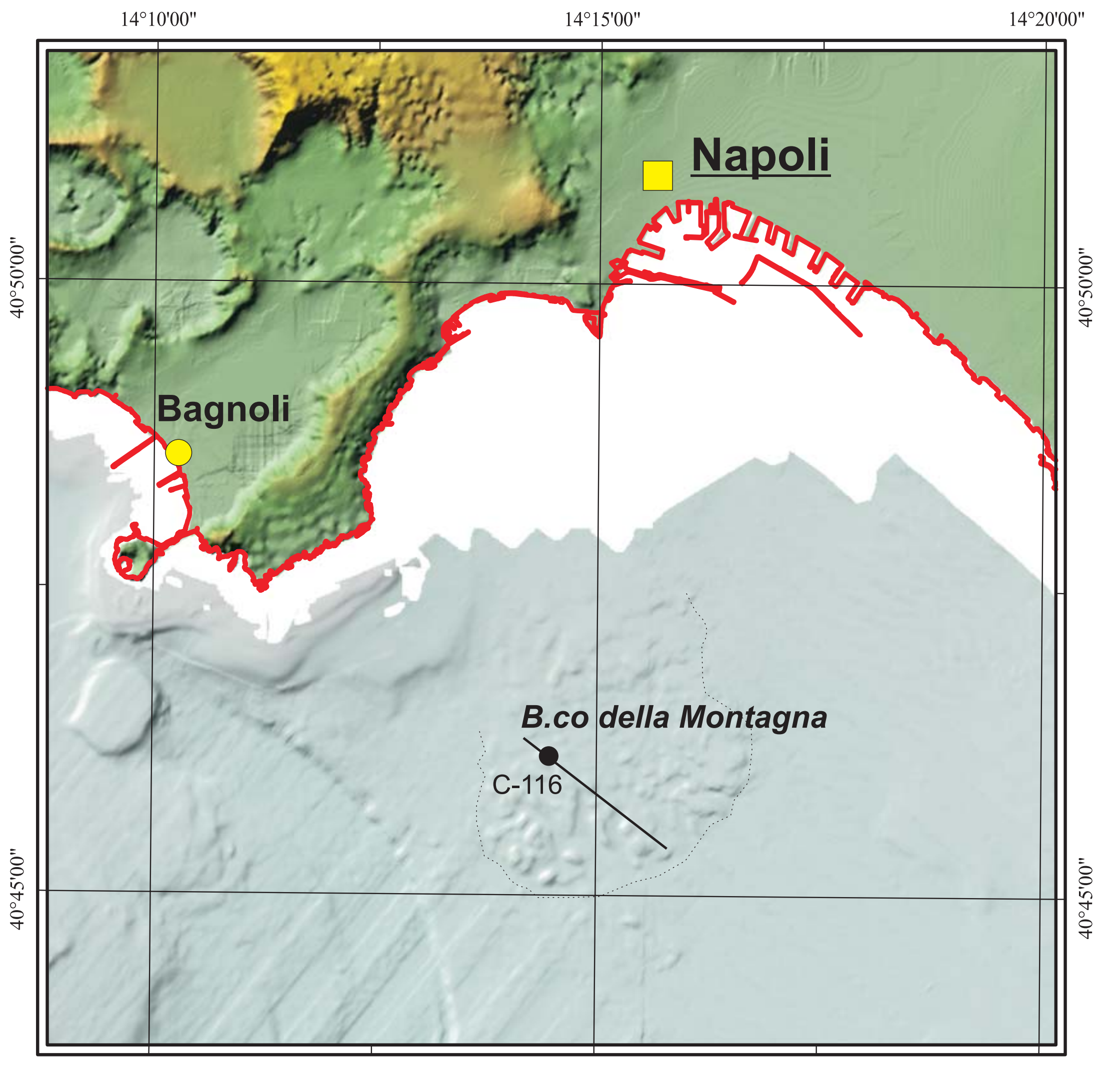

Fig. 12 - *Shaded relief map of the continental shelf-slope offshore Naples. The rugged seafloor morphology of the Banco della Montagna area is due to the recent uplift of diapiric structures that developed at depth within uppermost Quaternary pumiceous deposits.*

features a staircase morphology with flat surfaces overlain by marine sediments.
At its seaward margin, unit DA1 is covered by a progradational seismic unit characterised by a toplap surface dipping seaward, with depths of 130-145 m. Because the toplap surface marks the sea level position at the time of its deposition, and the sea level reached a depth of approximately 130 m during the last glacial maximum that occurred at 18 ka BP (BARD *et alii*, 1996), the DA1 unit is here considered as emplaced at 18 ka in a subaerial environment. Its stratigraphic position is confined above the unconformity overlying unit CI and below the wedge that formed during the sea level lowstand. The DA1 unit is therefore interpreted as the debris avalanche that led to the collapse of Monte Somma at 18 ka, shortly before the "Pomici di Base" eruption (Fig. 11).

PYROCLASTIC DIAPIRS

Diapiric structures consisting of massive volcaniclastic deposits have been recently discovered beneath the sea floor a few kilometres offshore the town of Naples (Eastern Tyrrhenian Sea). High-resolution (sparker 1.5-4 kJ) and very high-resolution (sub-bottom CHIRP), single-channel seismic reflection profiles show these pyroclastic diapirs (pyroclastic lumps) rising through the uppermost Pleistocene - Holocene deposits and dramatically deforming the sea floor over a quasi-circular area of ca 2 km in diameter (Figs. 12 and 13) (SACCHI *et alii*, 2000; AIELLO *et alii*, 2001).
The pyroclastic lumps of the Naples Bay are rooted in the uppermost layers of a large volcanic unit, several tens of meters beneath the sea floor. The chemical analysis and 40Ar/39Ar dating of the pumice collected from gravity core samples proves that the pyroclastic deposits forming the diapirs derive from the products of widespread eruptions during the Latest Pleistocene-earliest Holocene, mostly including the "Neapolitan Yellow Tuff"(15 ka BP) (INSINGA *et alii*, 2000; INSINGA, 2003) (Fig. 14).
The key factors controlling the dynamic system include:
1) the viscosity of the ascending pyroclastic material;
2) the density of the overlying deposits;
3) the density contrast between these structures and the overlying sediments;
4) the initial width of the individual diapiric structures.
The modelled rates of uplift of pyroclastic lumps are in the order of several mm/yr (SACCHI *et alii*, 2000).

CONCLUSIONS

The Naples Bay and adjacent areas comprise a highly mobile segment of the hinge zone between the Southern Apennines fold and thrust belt and the Tyrrhenian basin.
This area was characterised by intense tectonic and volcanic activity during the Quaternary and represents an outstanding natural laboratory for the study of recent and active morphologic and sedimentary processes and their relation to the geodynamic evolution of the region.

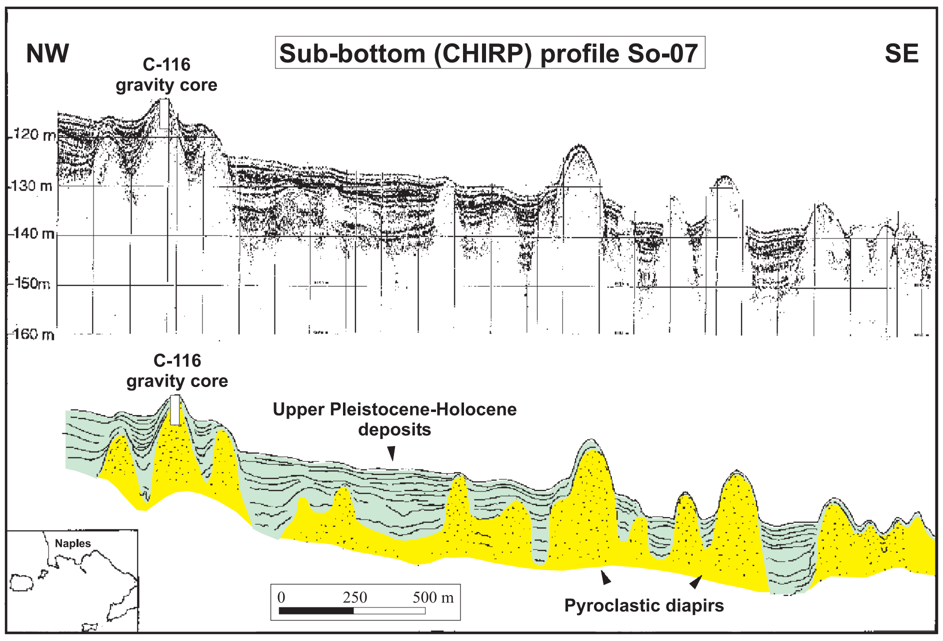

Fig. 13 - *Sub-bottom* (CHIRP) *profile across the pyroclastic diapirs of the Banco della Montagna, and location of the* C-116 *gravity core used for the calibration of sesimic data. The location of the profile is shown in Fig. 12.*

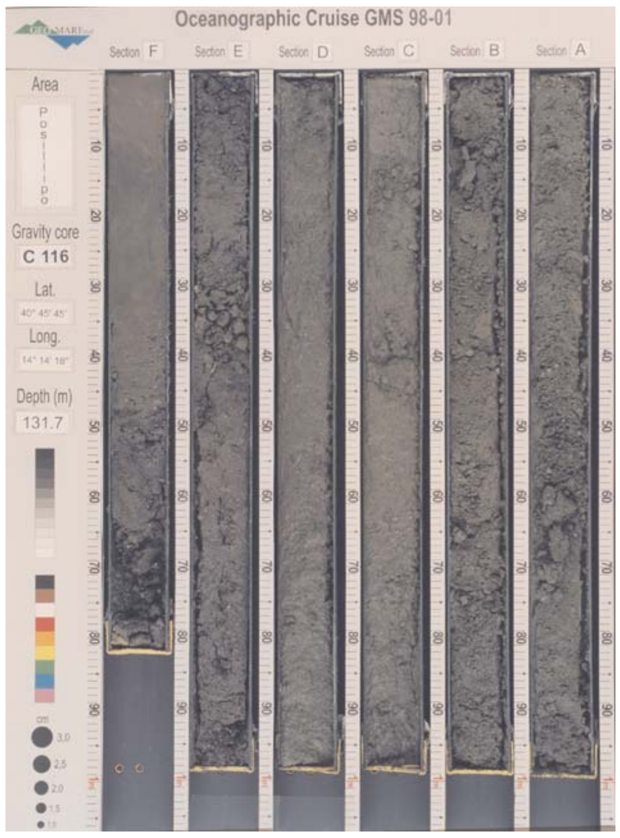

Fig. 14 - *The* C-116 *gravity core sampled a succession of sand-sized marine deposits interbedded or chaotically mixed with pumice layers. See Fig. 12 for location.*

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