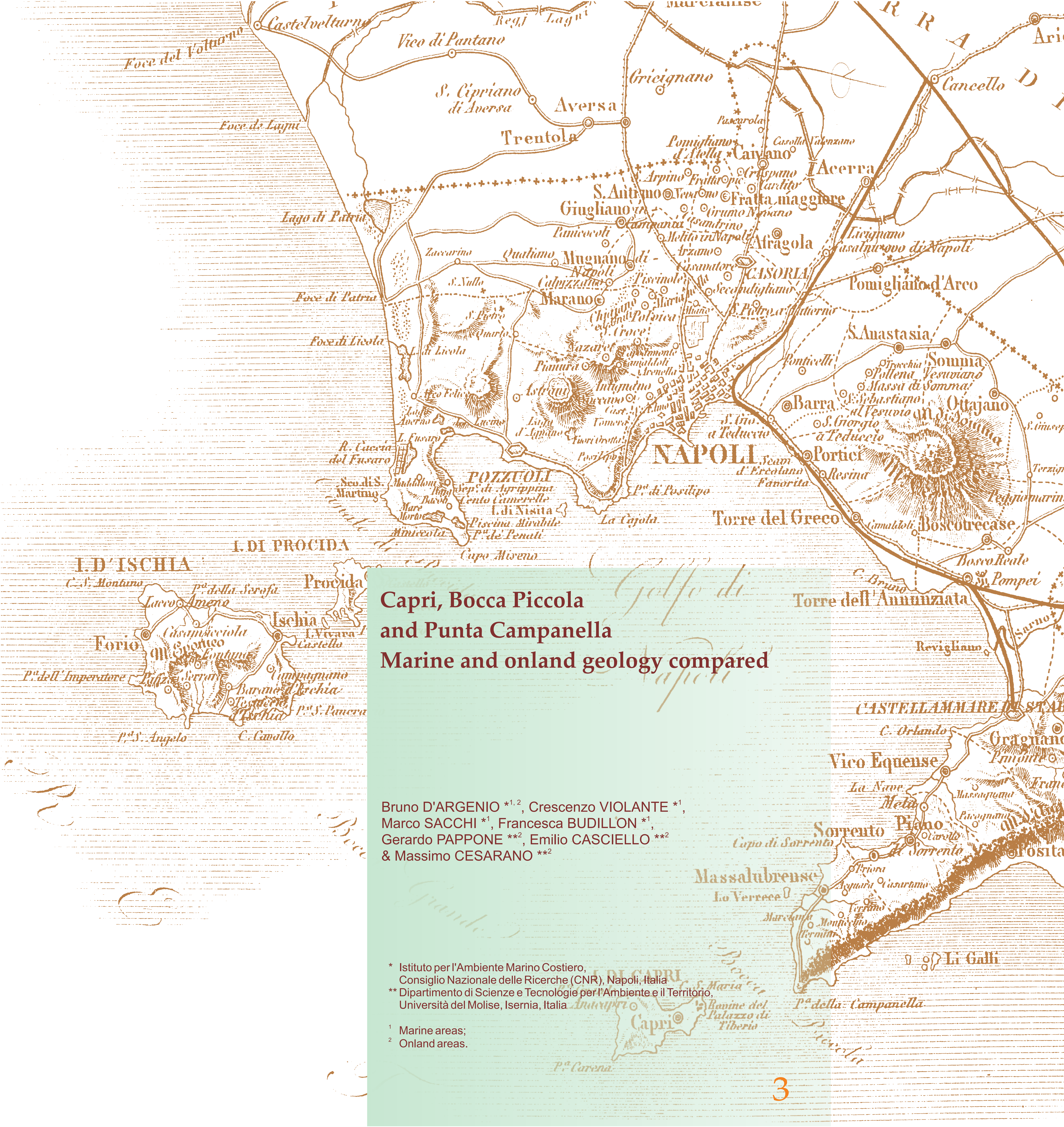

Capri, Bocca Piccola and Punta Campanella Marine and onland geology compared

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[1] Marine areas;
[2] Onland areas.

ABSTRACT

This map portrays both the onland geology of the complex and discontinuously emerging rim of the of the internal Apenninic structures (Capri Island and Punta Campanella, the tip of Sorrento-Amalfi Peninsula), spanning from the Lower Liassic (Late Triassic?) to the Recent, and the Late Pleistocene-Recent sedimentary and geomorphologic features of the intermediate submerged threshold (Bocca Piccola). The high resolution mapping on land and at sea (CARG, Sheet n° 484, Isola di Capri), integrated with data sets from multidisciplinary studies on Marine Protected Areas, has allowed to present the contrasting aspects of an area that was almost totally emerging at ca 15-18 ka BP, and that was subsequently covered by seawater and marine sediments by the later eustatic sea level rise.
While the emerging sides contain a limited record of the contemporaneous continental Quaternary deposits, in the Bocca Piccola area the distribution and features of marine sediments are well preserved. Interpretation of accurate seafloor base maps aided by collection of seafloor samples, has led to establish geologic criteria for very detailed scale marine surveys. Both biological and anthropic activities have been recognized and mapped, providing a picture of the present and past processes that shaped the seafloor morphology and affected the texture and composition of the sediments.

AIMS

The main purposes of this map are:
- to analyze and to interpret the seafloor geology between Capri and Punta Campanella with particular reference to lithofacies associations - depositional environments within the upper Quaternary depositional sequence;
- to illustrate the relationships between the onland geology of Capri Island and Punta Campanella, and the the adjacent marine areas;
- to present a case history of a marine survey based on high resolution multibeam, sidescan sonar and seismic investigations;
- to describe procedures and methods used for accurate seafloor investigations in the study area; and
- to illustrate the importance of the information provided by accurate seafloor base maps and their role in marine geological survey.

KEY WORDS

Naples Bay; marine geological mapping; multibeam bathymetry; backscatter data; organogenic deposition; marine depositional environments.

RIASSUNTO

Questa carta illustra la geologia del complesso e discontinuo margine interno della Catena Appenninica (l'Isola di Capri e la Punta Campanella, all'estremità occidentali della Penisola Sorrentina) di età compresa tra il Liassico inferiore (Triassico sup.?) e l'Attuale, e descrive i caratteri sedimentari e geomorfologici della interposta area sommersa di Bocca Piccola. Il rilevamento di aree marine e terrestri effettuato nell'abito del progetto CARG (Foglio n° 484) e integrato con dati provenienti da studi interdisciplinari per l'istituzione di Aree Marine Protette, ha consentito la realizzazione di questa carta, che mostra i diversi aspetti di un area quasi del tutto emersa circa 15-18 mila anni fa, e successivamente ricoperta dal mare e dai suoi sedimenti.
A differenza delle aree emerse che preservano solo in parte i depositi attuali e recenti, nell'area di Bocca Piccola è possibile osservare nel dettaglio i caratteri e la distribuzione degli ambienti sedimentari marini. L'interpretazione di carte di base di elevata risoluzione calibrate tramite prelievi di fondo, ha consentito di stabilire dei criteri di rilevamento a scala di dettaglio. Sono state cartografate anche le forme di fondo riconducibili ad attività biologica ed antropica, che hanno fornito un quadro integrato dei processi responsabili del modellamento dei fondali investigati.

GEOLOGICAL MAP OF CAPRI, BOCCA PICCOLA AND PUNTA CAMPANELLA

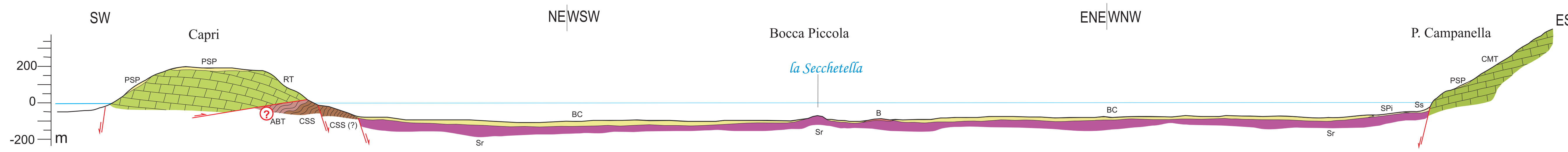
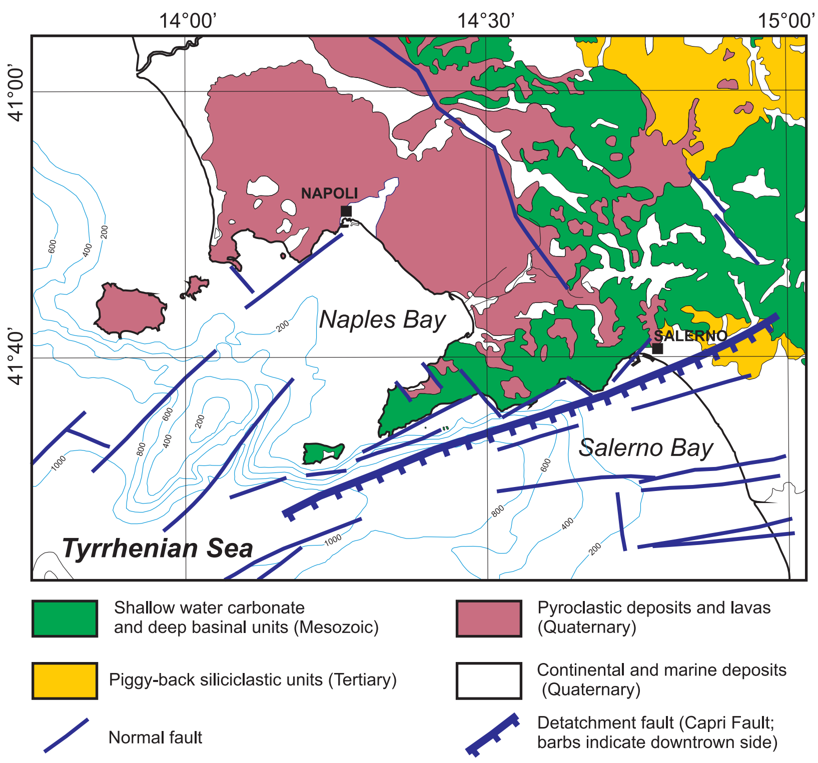


Fig. 1 - *Geological map of Capri, Bocca Piccola and Punta Campanella. "A" is the trace of the geological section of figure 7B. "B" is the trace of the geological section shown at the top of this page. Legend is in the next page.*



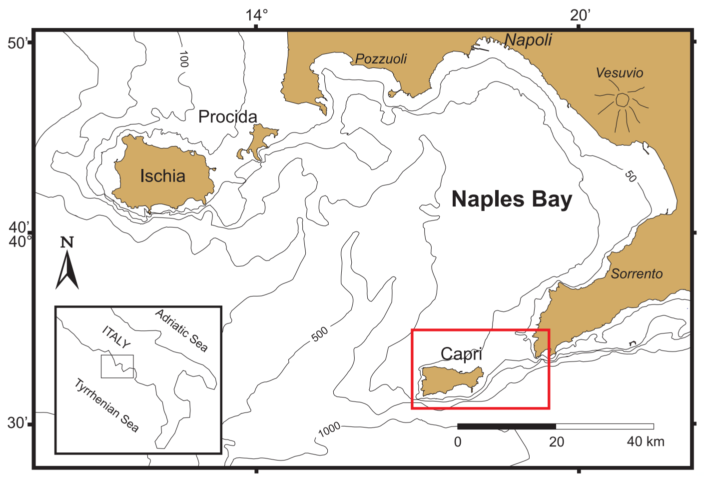
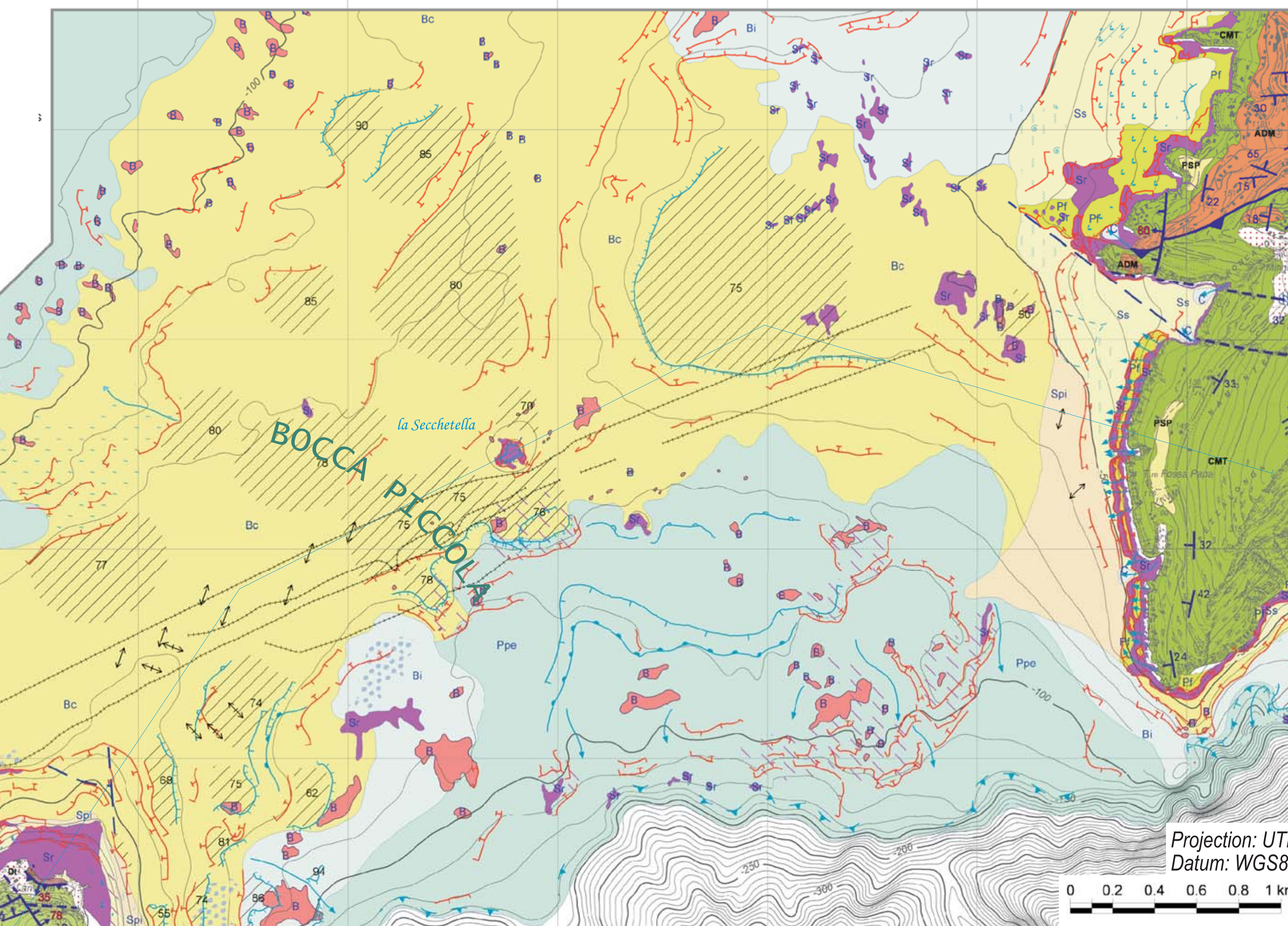
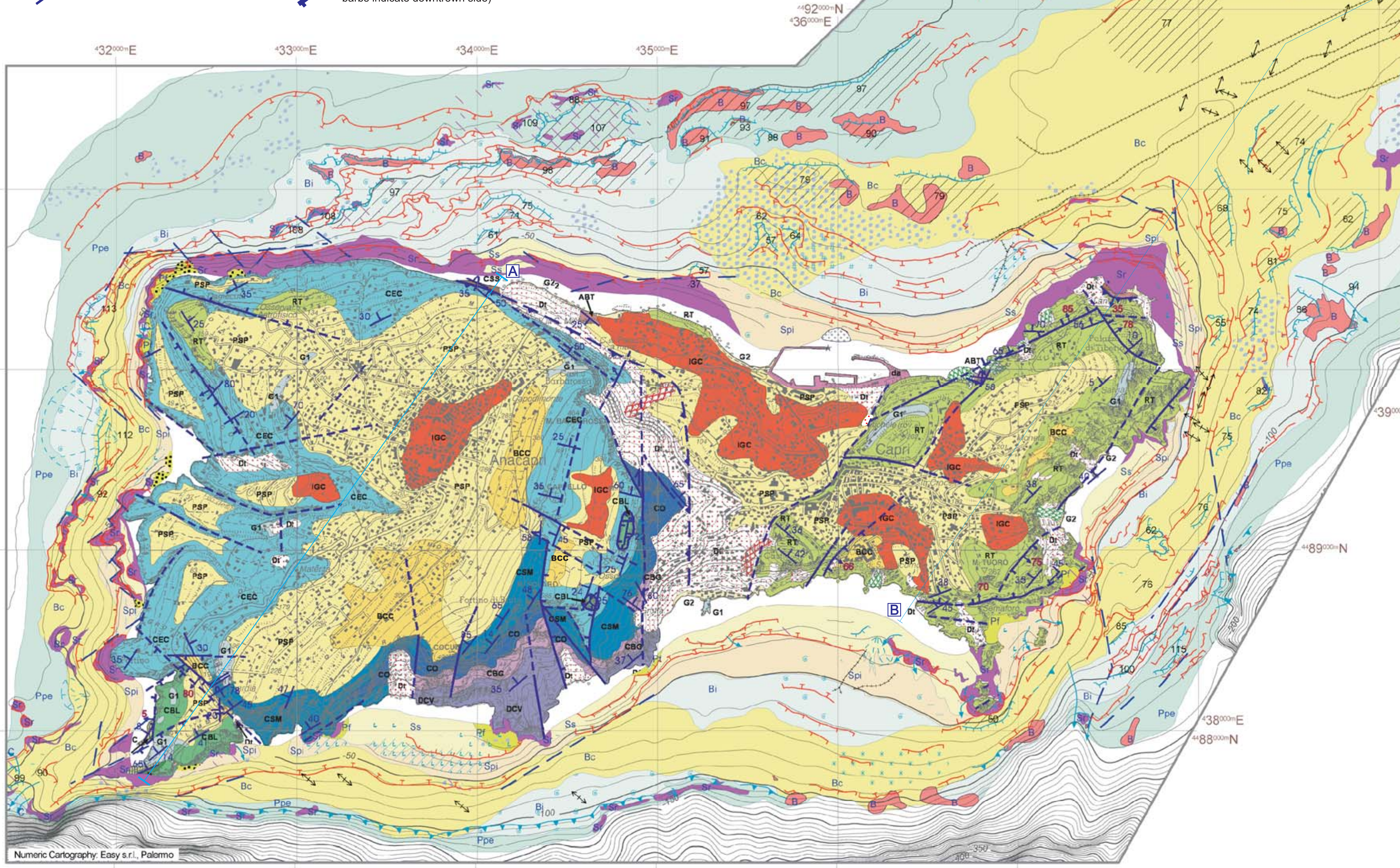


Fig. 2 - *Location of the study area (red box) and tectonic sketch-map of western Campania Apennines.*





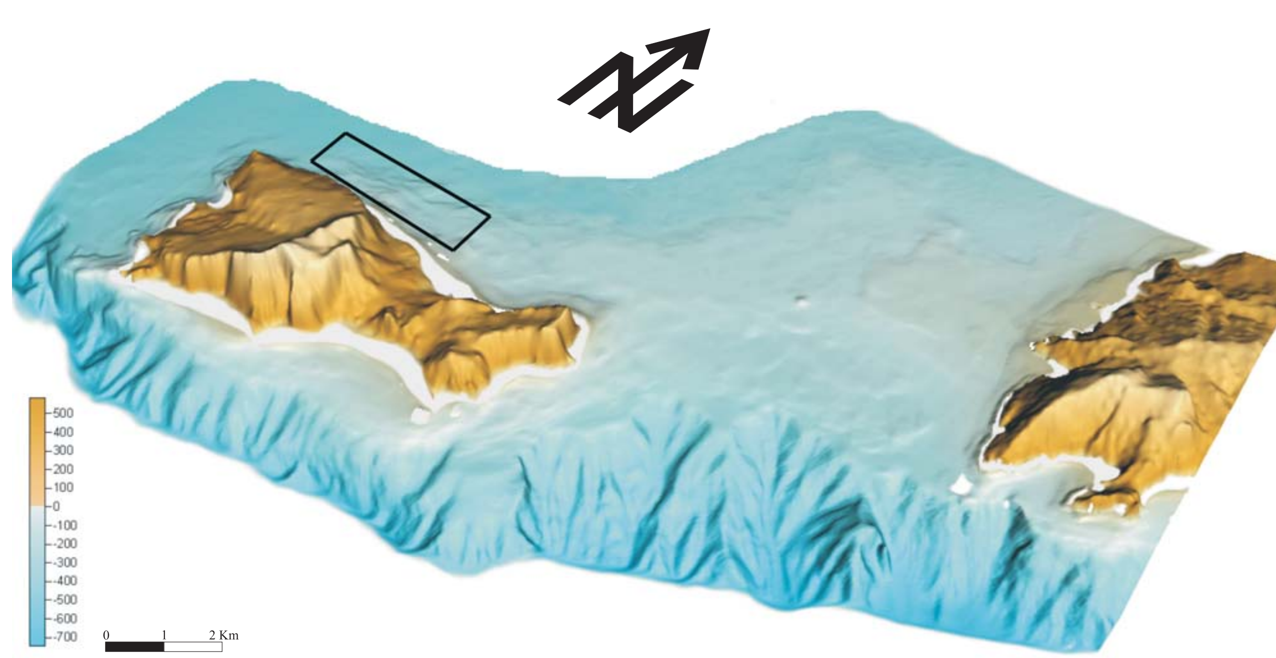


Fig. 3 - *3D surface map of Capri-Punta Campanella and relative marine areas obtained by merging multibeam bathymetric data and terrestrial elevation data. The black box is the location of Fig. 5.*

MATERIALS AND METHODOLOGY

Today, advances in remote sensing allow high-resolution seafloor bathymetry, backscatter and sub-bottom profiling (Fig. 4) data to be collected. By integrating these data sets, large portions of the seafloor can be mapped in detail for geological purposes and hazard assessment. In the study area, multibeam bathymetric data (Figs. 3 and 5) and sidescan imagery (Figs. 6 and 11) were collected during the summers of 2000 and 2001, at depths between -10 and -750 meters (multibeam) and between -15 and -150 m (sidescan), from the RV Thetis (cruises GMS00-4, GMS01-3 and GMS01-4).

Reason SeaBat 8101 and 8111, and Simrad EM-3000 multibeam systems were used, with their tracks positioned in such a way as to insonify 100% of the seafloor with at least a 20% overlap. Sidescan sonar imagery was acquired using an EdgeTech Df 1000 with a range of 167 meters, the tracks being spaced at 250 meters. This allowed a 30% overlap with a 100% coverage of the seafloor. Navigation was via wide-area differential GPS using satellite corrections from the Racal Sky Spot System, integrated with a HYDRO Trimble Navigation software package.

High-resolution seismic profiles (Fig. 9) were acquired during the summer of 1995 from aboard the RV Urania (cruise GMS95-02). The seismic profiling system was equipped with an implosive acoustic source (15 in^3 water gun) and signals were received by an array of equally spaced hydrophones. Data were saved to magnetic disk and printed on thermic paper. The water gun operated at 0.5 m below sea level.

Multibeam data were edited to eliminate spurious bathymetric and navigation points and processed using PDS 1000 and PDS 2000 software from Thales Geosolutions and Mermaid and Neptune software from Simrad. Subsequently, the processed data were used to, generate maps and digital terrain models (DTM) of an accuracy meeting the requirements of the International Hydrographic Organization (IHO, 1997). Backscatter data were edited for navigational and slant range corrections, and processed using an ISIS-TEI software package. The processed acoustic imagery was mosaiked to generate maps depicting backscatter features (Figs. 6 and 11).

Seafloor samples collected by grab (Fig. 10), box-corer and dredge (Fig. 8) constrained the interpretation of backscatter features in terms of texture and composition (Blonder & Murton, 1997), allowing the identification of sediment distribution (Fig. 1). At the same time, the integration of high-resolution seismic data with seafloor maps allowed seafloor attributes to be linked to specific subsurface features (Fig. 9).

Both sidescan imagery and multibeam bathymetry are obtained from hull-mounted or towed echo-sounder systems (Fig. 4). The sound pulses transmitted by sidescan sonar are reflected back by the seafloor and the reflection intensity or backscatter (grey levels in Figs. 6 and 11) depends on the acoustic properties of the seafloor. Bathymetry is measured by two-way travel time of sound pulses transmitted as arrays of several simultaneous, downward-looking beams of acoustic energy across the track of the vessel, creating a wide swath of coverage (swath

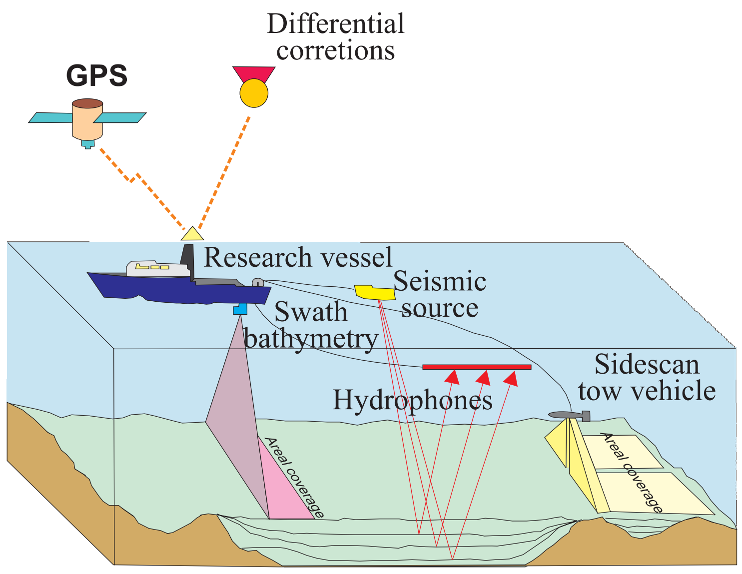


Fig. 4 - *Techniques of sea floor investigation used in the study.*

bathymetry). GPS provides accurate positioning once the resulting data are corrected formotions (pitch, roll and heave).

GEOLOGICAL SETTING

The study area includes the Punta Campanella promontory, the Bocca Piccola sound and the Island of Capri, located at the western end of the Sorrento Peninsula (Fig. 2). The latter is the top of a submerged homocline dipping towards the north-west and bordered southwards by normal faults, with a NE-SW orientation (CINQUE & PUTIGNANO 1992; BRANCACCIO *et alii*, 1995), and separating the Bay of Naples to the north from the Bay of Salerno to the south. Both these bays are half-Graben systems that evolved during the Late Neogene-Quaternary and were formed in response to large-scale extension parallel to the Southern Apennines (SACCHI *et alii*, 1994; MILIA & TORRENTE, 1999). Extensional tectonics also caused the formation of major volcanic centres, represented by the Somma-Vesuvio and Campi Flegrei district, at present bordering the bay of Naples to the NE (Fig. 2).

The Punta Campanella promontory and the Island of Capri are mainly composed of Mesozoic limestone, tectonically uplifted since the Lower Pleistocene and discontinuously covered by Miocene siliciclastic deposits and Quaternary volcaniclastic and alluvial deposits. A shallow rocky substrate, mostly mantled by organogenic deposits, also forms the subsurface structure of the Bocca Piccola sound (section B in Fig. 1), while a high rate of subsidence has allowed the accumulation of volcanic and siliciclastic successions up to 1500 m and 2000 m in thickness in the two bays of Naples and Salerno respectively (BRANCACCIO *et alii*, 1991; see also D'ARGENIO *et alii*, this volume).

ONLAND AREAS

Capri island is the westward extension of the Punta Campanella promontory, now isolated from the mainland by the Bocca Piccola sound, a marine area about 5 km wide and averaging 70 m in water depth. Nevertheless, the two areas are characterised by different Mesozoic and Tertiary rocks and tectonic patterns; the island is formed by a carbonate succession with scarp-to-basin facies showing complex tectonic relationships and related to the western margin of the Apennines, while only structurally higher units outcrop at Punta Campanella (Fig. 1; D'ARGENIO *et alii*, 1973; BARATTOLO & PUGLIESE, 1987; CASTELLUCCIO & NAPOLITANO, 1989).

The morpho-structural setting of Capri island is related to two Mesozoic carbonate slabs, the Anacapri and the Capri blocks, which tectonically overlie Oligocene and Miocene deposits and are separated by a structural low (Fig. 1). Evidence of thrust geometries characterised by folding and sub-vertical bedding occurs along the northern coastline, at Bagno di Tiberio and Punta Sbruffo (Fig. 7). Here the Anacapri tectonic unit, made of Jurassic limestone, is tectonically superimposed -with a north-eastern direction of tectonic transport- on the Oligocene and Miocene deposits. The eastern side of this block is marked by right lateral-strike slip faults, approximately N-S-trending, which probably represent part of a lateral ramp related to the Punta Sbruffo thrust. Another overthrust contact is present at Punta del Capo in the north-eastern corner of the Island of Capri. Here the Oligocene and Miocene deposits rest below the Cretaceous limestone forming the Capri tectonic unit (section B in Fig. 1).

The relationships between the Capri and Anacapri structural blocks are mostly hidden below the Pleistocene and Holocene deposits that crop out in a structural low corresponding to a N-S depression, where the major harbours of Marina Grande and Marina Piccola are located (Figs. 1 and 7). Nevertheless, the presence of the Rudite di Tiberio (RT) between

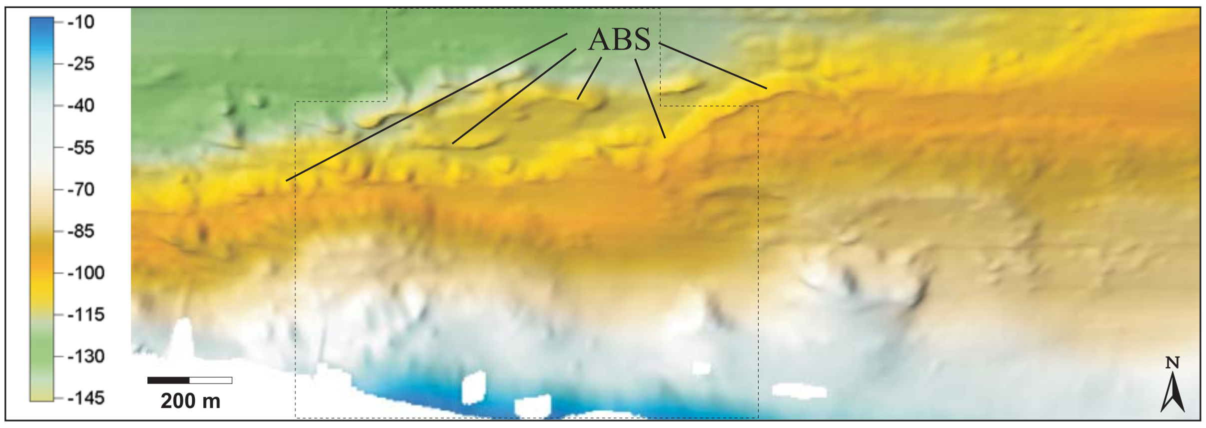


Fig. 5 - *3D surface map of the seafloor area contoured in black in Fig. 3.* (ABS) *aligned bioconstructions. The dashed black box is the location of Fig. 6.*

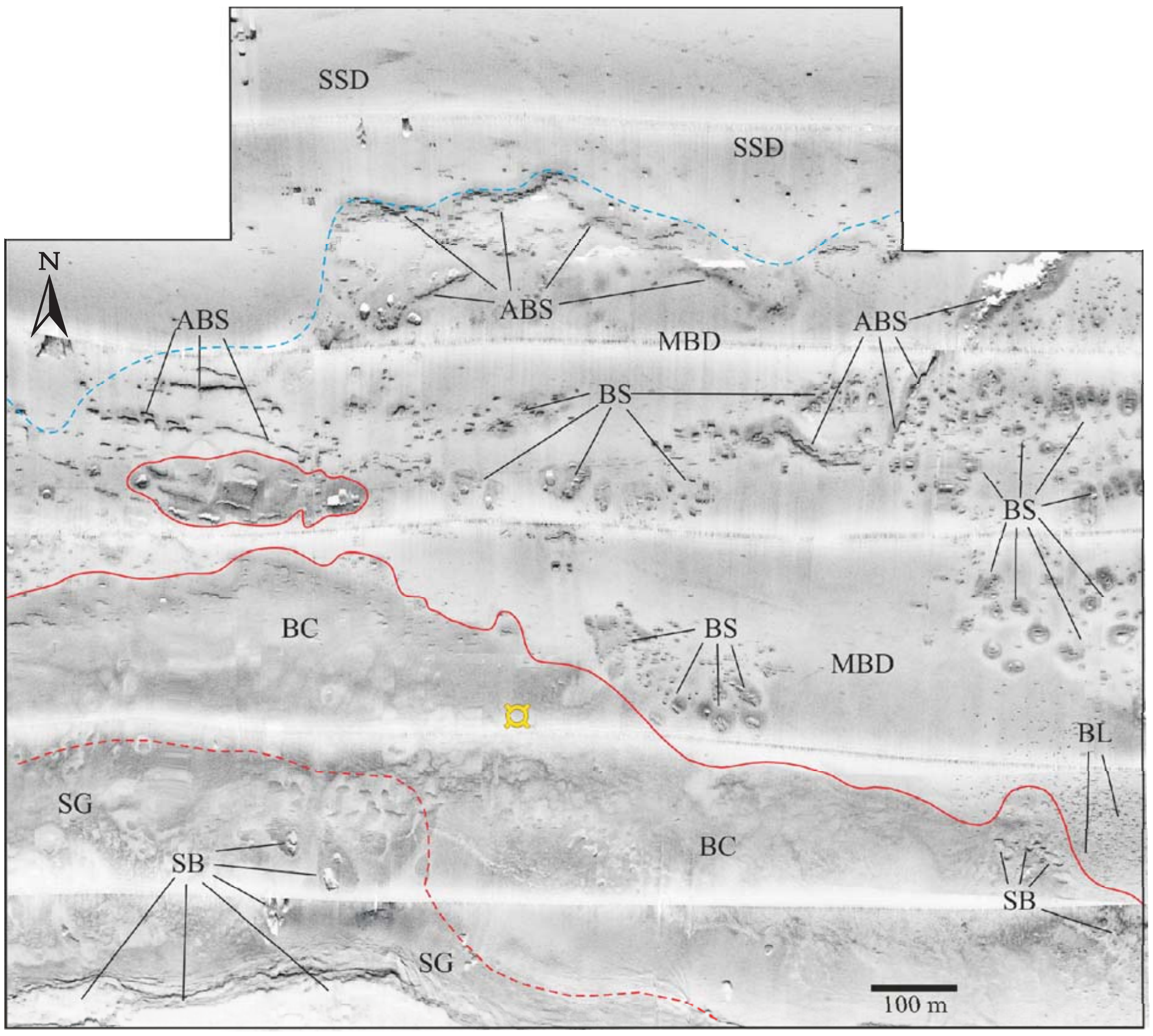


Fig. 6 - *Interpreted sidescan sonar mosaiked imagery of the seafloor area reported in Fig. 5.* (BL) *sparse boulders;* (SB) *rocky substrate;* (SG) *coarse sand and gravel;* (BC) *bioclastic sand;* (MBD) *muddy bioclastic deposits;* (SSD) *silt-size deposits;* (BS) *bioconstructions;* (ABS) *aligned bioconstructions; dashed red line is boundary between* (SG) *and* (BC); *red line is boundary between* (BC) *and* (MBD); *dashed blue line is boundary between* (MBD) *and* (SSD); (○) *location of the seafloor sample reported in Fig. 10 (3).* BC, MBD *and bioconstructed structures form the Middle Shelf environment reported in Fig. 1. Light tones represent low backscatter. See also Fig. 11.*

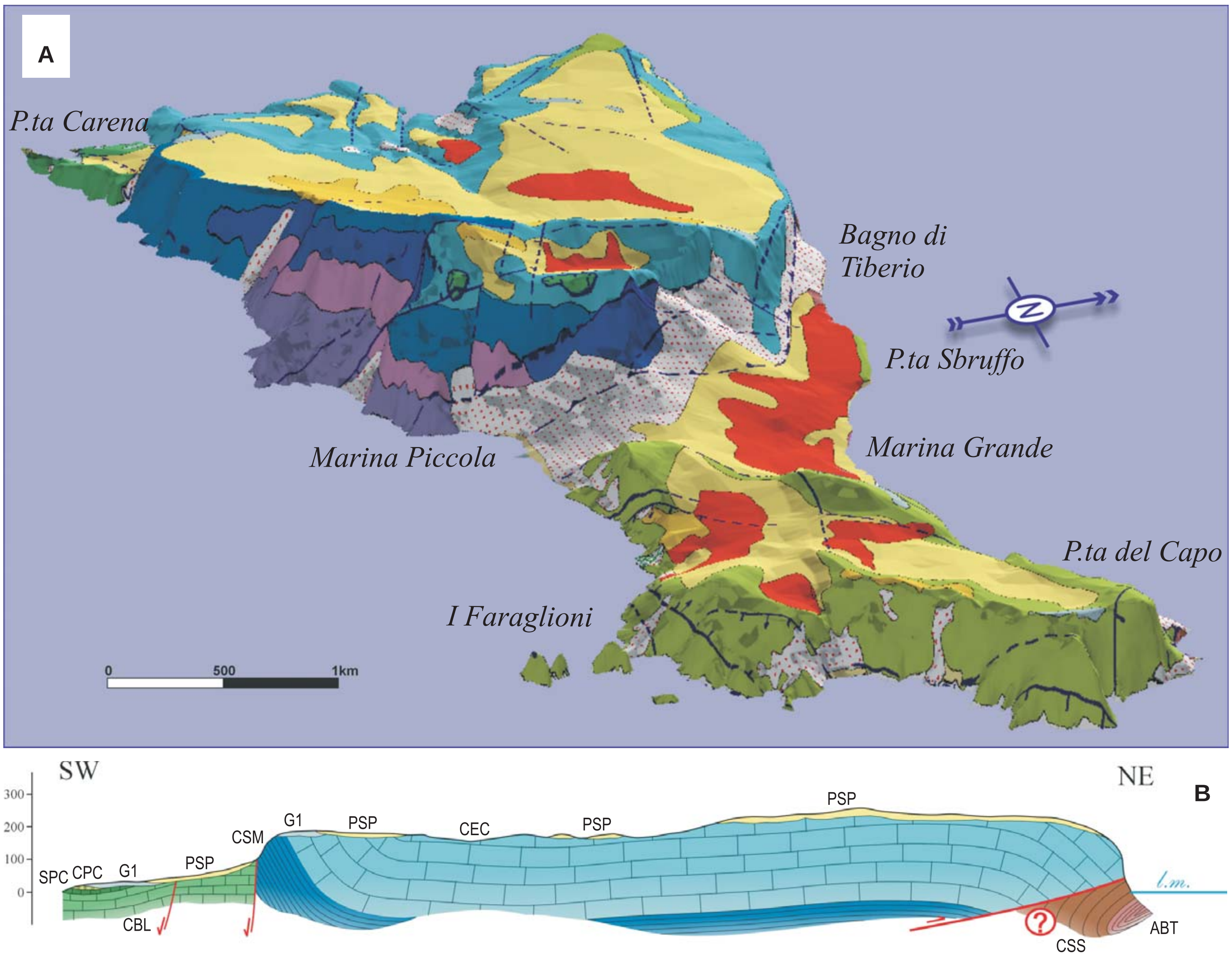


Fig. 7 - *3D geological map of Capri Island* **A** *and cross-section trough Anacapri* **B** *(see Fig. 1 for location) showing the gross lithostratigraphy and onland structures. For legend see Fig. 1.*

the Marina Grande and Bagno di Tiberio suggests that the Anacapri block is tectonically superimposed on the Capri block, and that both of them are tectonic slabs stacked with a north-eastern vergence. Contractional structures are displaced by high-angle normal faults which trend NE-SW -and, subordinately, NW-SE in the Capri structural unit- and by NW-SE faults in the Anacapri unit. Recent tectonic activity controlled the current physiography of the island (BARATTOLO *et alii*, 1996), characterised by steep coastal cliffs deeply affected by instability phenomena (rock-fall).

Overthrust features have also been found at Mt. San Costanzo, in the northern sector of Punta Campanella (Fig. 1). At this location, upper Cretaceous carbonate platform deposits tectonically overlay Miocene siliciclastic deposits.

MARINE AREAS

Heterogeneous textural and morphological features characterise the investigated seafloor. Sedimentary structures due to current and wave action, and seafloor sediment distribution reflect both the reduced hydrologic pattern and the geology of the adjacent continental areas (Fig. 1). In particular, the main carbonate composition of Capri Island - Punta Campanella still persisting as shallow rocky substrate in the marine areas. Along with scarce sediment supply, favour starved conditions/ amalgamation with high sediment production by in situ biologic activity. Bioconstructions of different size

Fig. 8 - *Floatstone composed of lithoclasts and bioclasts, dredged from the substrate in the Bocca Piccola area. Clasts of very different shape, size and composition are embedded in a reddish calcareous matrix. Scattered black dots correspond to iron-manganese concentrations. Diffuse perforations are due to biologic activity (bioerosion).*

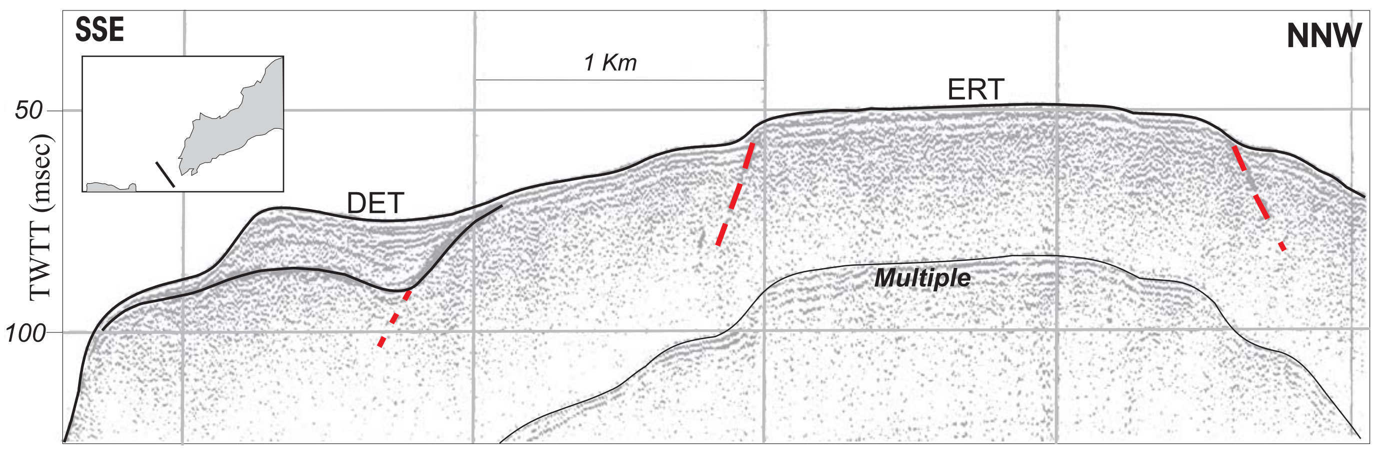


Fig. 9 - *Seismic profile (near trace) across the Bocca Piccola sound (see inset map for location). In this area, a very shallow rocky substrate (see also Fig. 8) covered by thin bioclastic deposits is flattened locally by erosional terraces* **ERT**. *Small prograding sedimentary wedges (depositional terraces;* **DET**), *tilted locally by tectonic activity, also occur.*

characterize the study area at depths ranging from -40 to -95 m. These occur as both isolated and grouped mounds, surrounded by strong-backscatter areas related to coarse organogenic deposits (Fig. 6). In the northern Capri offshore, bioconstructional mounds develop along the edges of erosional terraces, resulting in a pool-like morphology of the seafloor (Fig. 5). Nevertheless, the general decrease in sand-grain size and the increase in mud content with water depth present a significant inversion related to the occurrence of coarse organogenic sediment (Fig. 10.3) at depths ranging from -45 to -90 meters (Fig. 1; middle shelf facies).

In the Bocca Piccola area, a rocky substrate is levelled by several erosional terraces (Figs. 1 and 9), and outcrops locally as small shoals at the seafloor (section B in Fig. 1). The substrate is limited upward by a heavily bored surface composed of breccia deposits (Fig. 8), passing into a veneer of bioclastic and organogenic sediments. This area was mostly emerged during the last glacial (15-18 ka) to form an E-W-oriented land bridge, connecting Capri to Punta Campanella.

The rocky substrate gently deepens away, leaving accommodation space for local prograding wedges (depositional terraces; Fig. 9) with internal organization controlled by post-Tyrrhenian glacio-eustatic oscillations (BUDILLON *et alii*, in press). Shallow rocky substrate also occurs in the upper offshore - foreshore area surrounding Capri, up to a depth of about -90 m.

A steep fault scarp (the Capri scarp) bounds Capri, Bocca Piccola and Punta Campanella to the south, resulting in a very narrow continental shelf with erosional shelf break (Figs. 1 and 2). In particular, canyon catchment areas, characterised by significant failure scarps, develop offshore the Faraglioni area and Punta Carena, directly connecting the above coastal cliffs with the continental slope (Fig. 3).

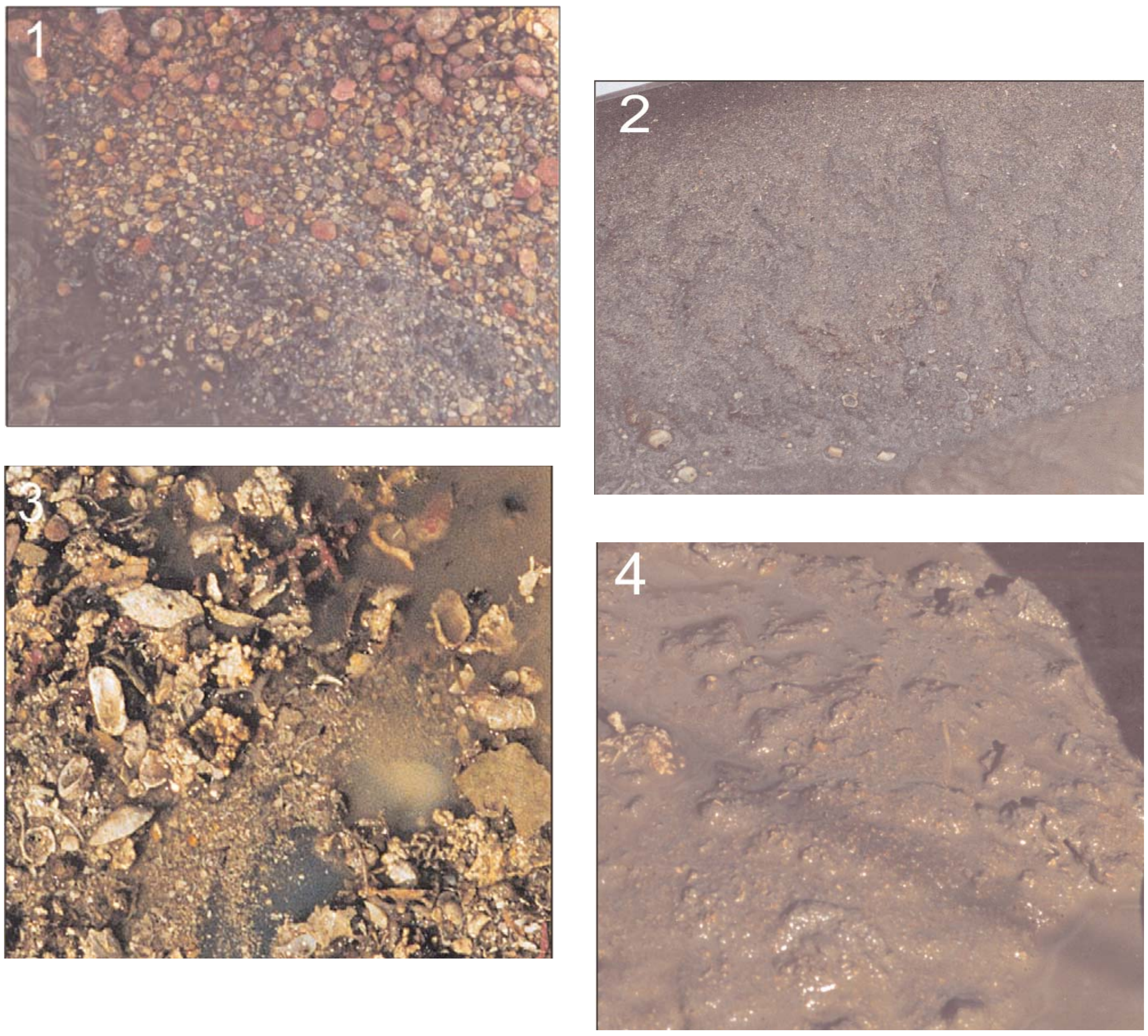
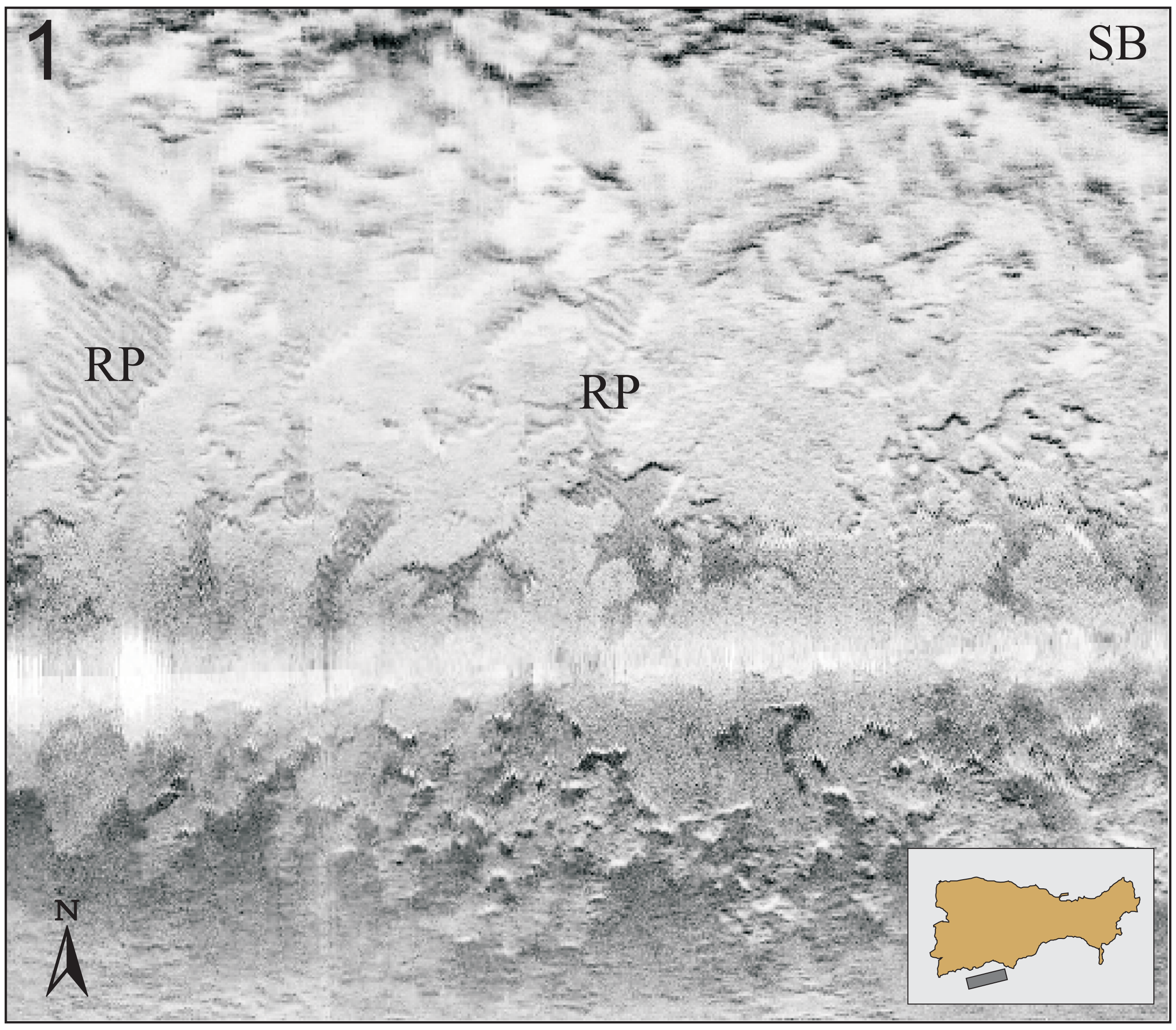


Fig. 10 - *Seafloor samples characterizing the main sedimentary environments recognized in the study area.* (1) *Well-sorted sand and gravel deposits (SG in Figs. 6 and 11.2) mainly composed of pre-Quaternary carbonate lithoclasts, encrusted locally by red algae (nearshore breaker zone).* (2) *Sand-size and silt deposits composed of pre-Quaternary carbonate rock fragments, volcaniclasts and rare bioclast (inner shelf - upper offshore).* (3) *Bioclastic deposits* (BC *in Fig. 6) composed of mollusc fragments, red (rhodolites) and green algae and bryozoans. Calcareous algae also occur. The red colour is due to biologic pigmentation (middle shelf).* (4) *Muddy bioclastic deposits* (MBD *in Fig. 6) composed of algae, mollusc and echinid fragments, embedded in a silt/ sand-size matrix. Red algae (middle left in the photograph) also occur (middle shelf). See also Figs. 6 and 11.*

SEAFLOOR GEOLOGICAL MAPPING

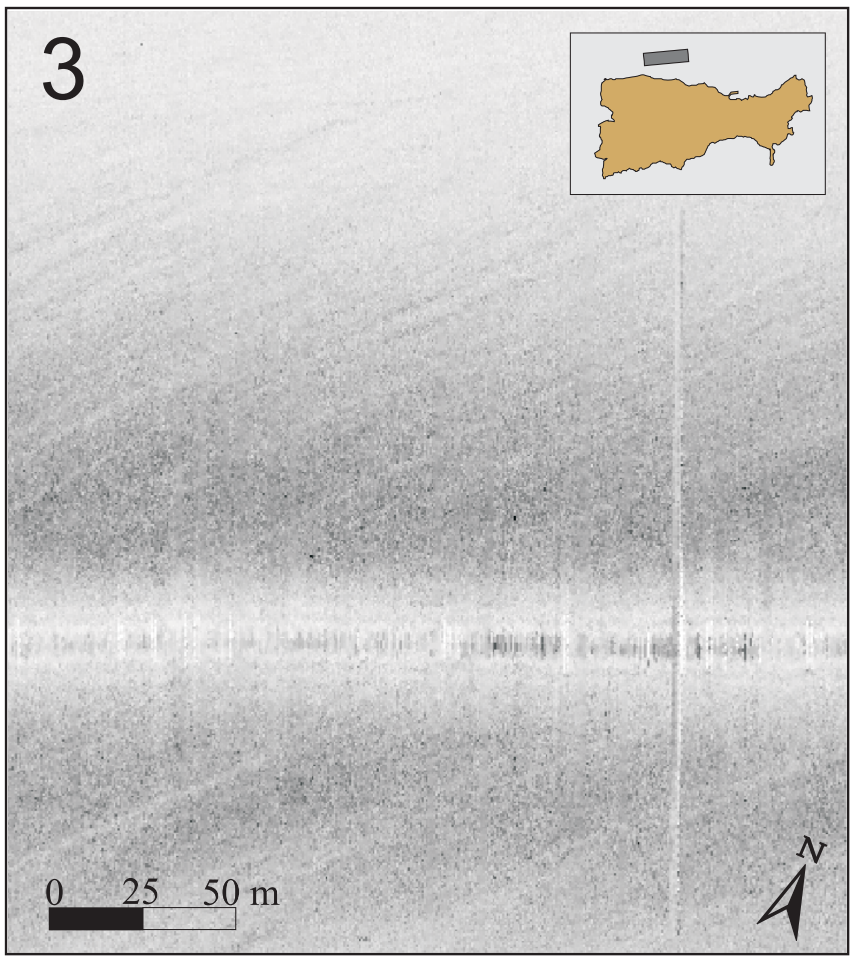
Bathymetric features and backscatter patterns reveal the geological complexity of the Capri offshore and highlight the issues of marine geological cartography. In this context, geological and geomorphological information provided by multibeam data and sidescan sonar imagery show a significant overlap, except for low-relief sedimentary structures (ripples, sand ribbons, patchy sediment distribution), anthropic structures (trawl tracks and anchoring tracks) and sediment distribution, their definition being related to backscatter features (Figs. 6 and 11). Indeed, these latter have primary significance for environmental purposes in terms of acoustic facies interpretation, as they lead to map distribution and lateral variation of lithofacies association-depositional elements within the Upper Quaternary depositional sequence. In the study area, these include foreshore-shoreface [cliff talus, fan delta, and breaker zone coarse-sandy facies; Figs. 10(1), 11(1) and 11(2)], inner shelf [upper offshore fine-sandy facies; Fig. 10(2), middle shelf (organogenic facies and mound; Figs. 10(3), 10(4) and 11(2)] and outer shelf [lower offshore silt-sandy facies; Fig. 11(3)], each of them characterised by specific



sedimentary structure and grain size distribution and composition (VIOLANTE *et alii*, 2003).
The characterization of the sedimentary environments of Capri and Punta Campanella offshore has strongly benefited from identification of seafloor texture and composition through extrapolation of punctual sedimentologic data over seafloor areas with a specific backscatter.

MARINE AND ONLAND GEOLOGY COMPARED

The geological structure of Capri island shares an overall NW dip with the Punta Campanella promontory, also documented in the offshore by reflection seismic data (FINETTI & MORELLI, 1974; FUSI *et alii*, 1991; AIELLO *et alii*, 1999). Steep fault scarps are present southwards, both along the shoreline and at the shelf break (Capri fault, Figs. 1 and 2), resulting in an asymmetrical bathymetric profile, with the northern Capri offshore gently sloping towards the Bay of Naples and the southern seafloor suddenly and precipitously reaching bathyal depths (Fig. 3).
Nevertheless, onland geological investigations depict a very different stratigraphic organization of Capri Island with respect to that of the Punta Campanella promontory, pointing to complex tectonic relationships occurring in the intervening Bocca Piccola sound. Actually, the regional facies analysis would place the Capri structures as originally belonging to more internal (western) domains (mostly scarp-to-basin facies) with respect to the Mt. S. Costanzo-Punta Campanella domains, considered as originally forming a shallow ramp carbonate platform (BARATTOLO & PUGLIESE, 1987; D'ARGENIO, 1988; ZAPPATERRA, 1994; CARANNANTE *et alii*, 2000). Unfortunately, due to a high reflectivity of carbonate deposits, multi-channel seismic investigations (FINETTI & MORELLI, 1974; BERTOTTI *et alii*, 1999) failed to trace a structural framework of the Bocca Piccola area. Therefore, in accordance with the regional geological framework, it may be hypothesized that the Capri structures form a thrust unit overriding at depth the westward extension of the Sorrento Peninsula structures.



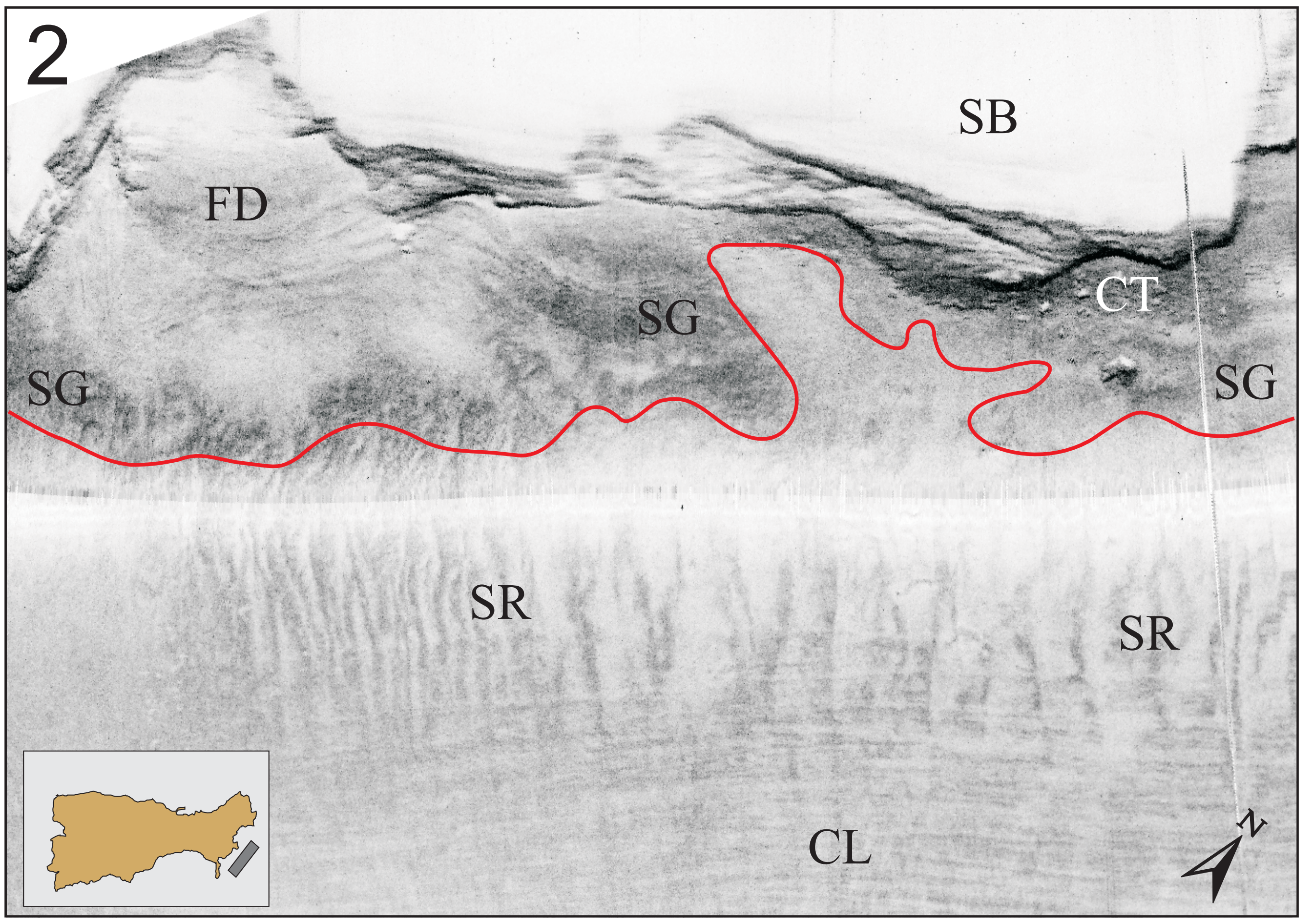


Fig. 11 - *Sidescan sonar imagery depicting the main acoustic features of the investigated seafloor area.*
(1) Posidonia meadow developing on a coarse-sandy seafloor, with ripples (RP) locally occurring in intra-matte areas. The thin leaves of the Posidonia oceanica interfere with high frequency acoustic waves, causing a fuzzy appearance of the image in the far range. Breaker zone. (SB) rocky substrate.
(2) Cliff talus (CT), sand and gravel deposits (SG) and fan delta (FD) (foreshore-nearshore zone) laterally passing into (red line) bioclastic and organogenic deposits with sediment waves (SR) and current lineations (CL) (middle shelf zone).
(3) Silt-size deposits with current lineations. See inset maps for location. Same scale for (1), (2) and (3).

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