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Marine geological maps of the campania region (southern tyrrhenian sea, italy): considerations and contributions to a different scale of geological survey

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ABSTRACT

Marine geological maps of the Campania region have been constructed both to 1:25.000 and to a 1:10.000 scales in the frame of research projects financed by the Italian National Geological Survey, focusing, in particular, on the Gulf of Naples (Southern Tyrrhenian sea), a complex volcanic area where volcanic and sedimentary processes strongly interacted during the Late Quaternary and on the Cilento Promontory offshore. In this paper the examples of the geological sheets n. 464 "Isola di Ischia" and n. 502 "Agropoli" have been studied. The integration of the geological maps with the seismo-stratigraphic setting of the study areas has also been performed based on the realization of interpreted seismic profiles, providing interesting data on the geological setting of the subsurface. The coastal geological sedimentationhas been studied in detail in the Ischia and Agropoli offshore. The mapped geological units are represented by:i)the rocky units of the acoustic basement (volcanic and/or sedimentary), ii) the deposits of the littoral environment, including the deposits of submerged beach and the deposits of toe of coastal cliff, iii) the deposits of the inner shelf environment, including the inner shelf deposits and the bioclastic deposits, iv) the deposits of the outer shelf environment, including the clastic deposits and the bioclastic deposits, v) the Lowstand System Tract, vi) the Pleistocene relict marine units, vii) different volcanic units, Pleistocene in age. The seismo-stratigraphic data, coupled with the sedimentological and environmental data provided by the geological maps, allow to give new insights on the geologic evolution of this area during the Late

Quaternary.

Keywords: marine geological maps; geological survey; coastal and marine environments; seismo-stratigraphic units; Campania offshore; Southern Tyrrhenian sea.

1. Introduction

One main aim of this paper is to discuss selected examples of marine geological maps of the Campania offshore (Southern Tyrrhenian sea, Italy) both to 1:25.000 and to 1:10.000 scales, focusing on selected examples in the geological sheets n. 464 "Isola di Ischia" and n. 502 "Agropoli". These geological maps have been produced during two research projects aimed at the geological mapping of the Campania region, carried out at the Geomare Sud CNR research institute of Naples, Italy, now Institute of Marine and Coastal Environment (IAMC) of Naples (National Research Council of Italy). Firstly, a research program on Naples and Salerno Gulfs has been carried out, aimed at constructing, from 1998 to 2000, geological and thematic maps of selected coastal and marine areas at the 1:25.000 scale. In this context, marine geological maps pertaining to the geological sheets n. 465 "Isola di Procida", n. 466 "Sorrento" and n. 467 "Salerno" have been constructed and are published in the ISPRA (National Geological Survey of Italy) website. The survey activities have included the use of cartographic software (Global Mapper) aimed at carrying out the geologic interpretation and the geologic mapping of morpho-structural lineaments and faults, the definition of cartographic areas representative of the distribution of the sediments cropping out at the sea bottom and of the Late Quaternary depositional sequence. The interpretation and the informatics graphic realization of stratigraphic sketches and interpreted seismic sections, representing integrant elements of the geological maps has been realized.

The second research project on the marine geological survey of the Campania region to a 1:10.000 scale was promoted and financed by the Region Campania. The sea bottoms surrounding the coast may be considered as the natural geologic and morphologic prosecution of the emerged coastal belt. In this framework they show morpho-structural and lithologic analogies with the surrounding coastal sectors. The geological reconstruction of the evolution of the submerged sectors represents an important ring of junction with the geological history of the sectors of the coastal belt now emerged and an adjoining element with the deeper marine sectors.

The flooding of significant parts of the Italian coasts gave rise during the Post-Glacial, perhaps only in some areas, for instance in the Campania region, with repeated phases of subaerial exposure, which have been controlled by tectonic and volcanic processes. A comparative reading of these three sectors (emerged coastal belt, submerged coastal belt and marine coastal belt) has shown the more recent stages relative to the sea level rises and the significant role of the Quaternary tectonics involving the Southern Apennines (Cello and Mazzoli, 1998; Critelli, 1999; Schiattarella et al., 2003; Catalano et al., 2004; Rosenbaum and Lister, 2004; Ferranti and Oldow, 2005; Caiazzo et al., 2006).

The geological survey of the Campania offshore at the 1:10.000 scale is not a cartographic product derived from the national cartography (the first research project), but is the basic geologic map, where the whole geologic and geomorphological data recorded at both the 1:10.000 and 1:5000 scales have been reported. These data, opportunely generalized, have been plotted in the national geological maps at the 1:50.000 scale.

In the geological maps this change in scale has imposed a revision of the methods of data acquisition and cartographic criteria to use for the geological survey to a detailed scale of cartographic representation of the geological structures and Quaternary deposits. It has also created an opportunity of both an interchange of the obtained information and of active participation to the construction and to the phases of elaboration of the national cartography.

Some scientific results have been previously obtained, mainly regarding the morpho-bathymetry, the geology and the sedimentology of the coastal and marine environments in the Phlegrean island of Ischia, Procida and Vivara (de Alteriis and Toscano, 2003; Budillon et al., 2003a; 2003b; Ferraro and Molisso, 2003; Aiello et al., 2009; Putignano and Schiattarella, 2010; Fedele et al., 2011; Sbrana et al., 2011; Aiello et al., 2012; 2015a; 2015b; 2018). Many other geological studies have been produced on the marine geology of the Naples and Pozzuoli Bays, including the Ischia island. As a general rule, the Naples Bay is composed from three main volcanic and physiographic domains: the Somma-Vesuvius volcano and its offshore, the Phlegrean Fields and the Gulf of Pozzuoli and the Island of Ischia and Procida (Aiello and Marsella, 2016).The Somma-Vesuvius volcano has been deeply studied regarding the eruptive events, the recent seismicity, the geochemistry, the ground movements of the volcano and the volcanic hazard (Cassano and La Torre, 1987; Santacroce, 1987; Castellano et al., 2002; Esposti Ongaro et al., 2002; Saccorotti et al., 2002; Scarpa et al., 2002). The Phlegrean Fields and the Gulf of Pozzuoli, i.e. the submerged border of the Phlegrean caldera, have also been studied by many authors and are continuously monitored by the National Institute of Geophysics and Volcanology (INGV).

2. Materials and Methods

The geological maps of the Campania region to the scale 1:10.000 have been realized through detailed bathymetric bases. Regarding the coastline, the coastline of the region Campania has been digitized based on the most recent aerial photographs (Volo 2004). The acquisition surveys of the bathymetric data have been realized using the GPS differential system. The maps have been geo-referenced using the datum WGS84, while the used projection was the Universal Transverse Mercator. While the distance between the isobaths is of 1 m, their representation in the maps is every 5 m.

The criteria for the realization of the geological maps are quite different for the submerged coastal be, hlt from 0 to 30 m of water depth and for the continental shelf /upper slope from 30 m to 200 m of water depth. These criteria are herein described in the two bathymetric and morpho-depositional domains.

2.1 Submerged coastal belt from 0 to 30 m of water depth

For the sea bottoms having depths lower than 5 m the interpretation of the geophysical data has been carried out using high resolution bathymetric data recorded through the Multibeam Reson SeaBat 8125, 455 kHz, elaborated in a

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morpho-bathymetric key and in a backscattering photomosaic (Side option). The geological mapping of wide areas has been supported by ecographic data to a lateral scanning Sidescan Sonar Edgetech DF1000 and Klein2000 (100-500 kHz). The interpretative hypotheses on the morpho-structural setting have been supported by high resolution single-channel Sparker data.

During a next working phase the dives have been planned based on the preliminary observation of the geophysical data following three main objectives, the first one consisting of the calibration of the interpretative keys, the second one represented by the acquisition of direct data (structural, stratigraphic and sedimentologic) and the third one composed of the sampling of the loose sediments and the rocky sea bottom.

The criteria for the construction of the keys for the 1:10.000 geological maps have included the lithostratigraphic units, the Quaternary deposits, the symbols, the archeological structures and the main biological associations. One of the most important lithostratigraphic units was represented by the Cretaceous limestones with Radiolitids, cropping out in the Sorrento Peninsula. The peri-coastal sea bottoms may be considered as the natural geologic and geomorphologic prosecution of the emerged coastal belt.

2.2 Continental shelf /upper slope from 30 m to 200 m of water depth

The acquisition of the geophysical and geological data has been carried out with enough detail to ensure an accuracy compatible with the adopted survey scale. These data are morpho-acoustic, morpho-bathymetric and geologic (box-corers, cores and dredges). The elaboration of the data has allowed, during a first work phase, the cartographic restitution of the bathymetric data collected by the Multibeam echosounder as bathymetric maps with isobaths and shaded relief maps for the geologic interpretation of the main morpho-structural lineaments. During a next work phase grain-size analyses have been carried out on previously sampled sediments at the sea bottom, classified according to Folk (1954).

The geologic interpretation is based on the recognition of the acoustic facies, carried out through the integrated interpretation of Multibeam and Sidescan Sonar data calibrated in terms of their lithology through the results obtained from the grain-size analyses of the samples at the sea bottom.

The interpretation of the high resolution seismic profiles has been a valid support for the reconstruction of the stratigraphic and structural setting of the continental shelf and slope successions. The seismo-stratigraphic analysis has allowed to distinguish the volcanic and sedimentary seismic units, separated by regional unconformities, controlled by both the tectonics and the eustasy. In the Naples Bay the Dohrn canyon represents an important morpho-structural lineament, which separates the sedimentary units, occurring on the eastern slope of the Gulf from the volcanic units, occurring on the western shelf and in correspondence to the Ischia and Procida islands. Then, the seismic units have been interpreted in terms of the occurrence of Type 1 or Type 2 sequence boundaries or classified in terms of local unconformities, mainly at the top of relict volcanic edifices or at the top of volcanic seismic units.

The geological map realized in this way shows the distribution of the different lithostratigraphic units cropping out at the sea bottom and of the different morphological lineaments, accordingly to the CARG guidelines to the 1:50.000 and 1:25.000 scales (Catalano et al., 1996; Gruppo di lavoro per la Geologia Marina del Servizio Geologico Nazionale n. 3; 2002). The main stratigraphic units, so individuated through the analysis of the sediments at the sea bottom, belong to the Late Quaternary depositional sequence. The different criteria of subdivision of the Holocene deposits occurring at the sea bottom at the passage from the geological maps at a 1:50.000 scale to the geological maps at a 1:10.000 scale have been outlined. In particular, the Holocene deposits cropping out at the sea bottom in the continental shelf areas have been framed in the depositional elements and represent the final phases (Highstand System Tract) of the Late Quaternary depositional sequence (Late Pleistocene-Holocene). The space and time geologic evolution and the lateral and vertical migration of the depositional environments from marine and coastal environments, continental shelf and slope during the Late Pleistocene-Holocene time interval have been recognized in this sequence.

The stratigraphic succession investigated through the marine geological survey has recorded the variations of the accommodation space of the Late Quaternary deposits during the last 4^{th} order cycle, ranging between 128 ky B.P. (Tyrrhenian stage) and actual times (isotopic stage 5e; Catalano et al., 1996). One of the main aims was the cartographic representation of the lithofacies associations, which have been grouped in depositional elements (representing portions of system tracts), in relationships to the morpho-structural elements recognized through the geologic interpretation of the geophysical data and the geologic evolution of the sedimentary environments. An integration between the classical stratigraphic approach, the sequence stratigraphic approach and the characterization of the depositional systems and elements has been realized. The prevalent volcanic activity which has controlled the stratigraphic architecture of the Naples Bay (Aiello et al., 2001; D'Argenio et al., 2004; Aiello et al., 2005; 2012a; 2012b; Aiello and Marsella, 2015; 2016; Passaro et al., 2016; Aiello et al., 2017; Aiello, 2018; Passaro et al., 2018) has disallowed for a classical stratigraphic approach in the geological mapping, which has been realized taking into account for the associations of depositional systems and the interlayered volcanic and volcaniclastic bodies.

Being bounded below and above by temporal surfaces,the system tracts of the Late Quaternary depositional sequence may be considered as the equivalent to the Unconformity Bounded Stratigraphic Units (UBSU; Chang, 1975; Mitchum et al., 1977; Nummendal and Swift, 1987; Galloway, 1989; Sacchi et al., 1999; Catuneanu, 2006; Rossi et al., 2009;Tibaldi, 2010; Catuneanu et al., 2010; Zecchin and Catuneanu, 2013). Perhaps, they can be considered as the basic units in the cartographic representation. The so-defined stratigraphic units are groups of strata bounded by mainly synchronous surfaces or by related stratigraphic intervals, whose inner part may be characterized through cores or sea bottom samples. The textural classes have been determined from the interpretation of the geophysical data coupled with direct sampling at the sea bottom, in such a way to carry out a further differentiation of the mapped depositional elements.

As it has been stated in the guidelines to the geological survey of the Italian seas (Fabbri et al., 2002), the purposed stratigraphic subdivision derives from the types of data used in marine geology (mainly the reflection seismic data calibrated through cores) and from the methods of geologic interpretation (high resolution sequence stratigraphy). The geological bodies which have been represented are the system tracts of the Late Quaternary depositional sequence, which refer respectively to: 1) the phase of sea-level fall (Falling Sea Level System Tract; Helland-Hansen and Gjelberg, 1994); 2) the phase of sea level lowstand (Lowstand System Tract) and the related internal subdivisions, as it is possible (Posamentier et al., 1991); 3) the phase of sea level rise (Transgressive System Tract; Posamentier and Allen, 1993; Trincardi et al., 1994); 4) the phase of sea level highstand (Highstand System Tract; Posamentier and Vail, 1988). These system tracts, so defined, have been indicated as FST, LST, TST and HST (Fig. 1).

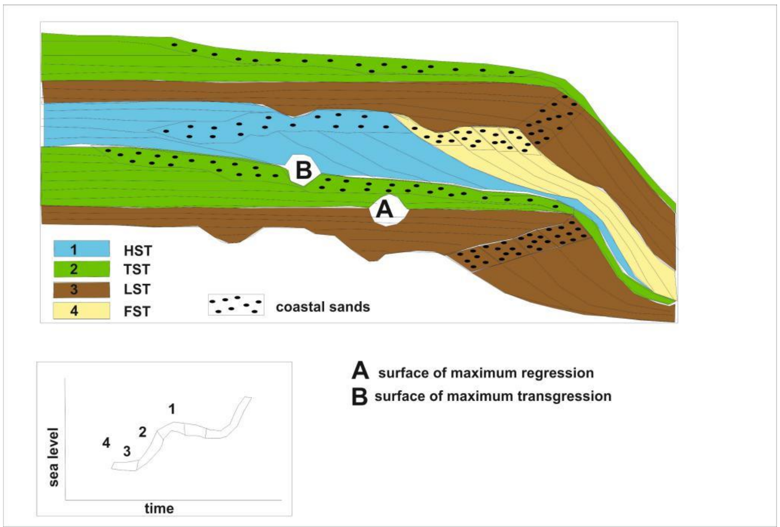

Figure 1. Sketch diagram showing the stacking patterns of system tracts in two ideal depositional sequences. FST: Forced Regression System Tract. LST: Lowstand System Tract. TST: Transgressive System Tract. HST: HighstandSystem Tract.

The choice to represent the system tracts of the Late Quaternary depositional sequence, in particular the HST and the TST, in the geological map of the sea bottom, constitutes a logic starting point and satisfies the following points: 1) to individuate and to map the depositional bodies as three-dimensional objects, referred to their relative stratigraphic location; 2) to give information on the nature of the surface sediments through a high-resolution physical stratigraphic setting tied with samplings and absolute datings of marker horizons. This allows for an indirect characterization of the surface sediments and to give complementary stratigraphic information about the nature of the individuated depositional bodies and about the processes which have controlled their deposition and preservation. The reconstructed depositional systems may be put in relationships with the Late Quaternary sea level fluctuations; 3) to obtain comparable information on all the Italian continental margins without being too influenced by local or particular aspects.

The last Late Quaternary sea level rise, having an excursion of about 120 m and a maximum rate in the order of 10 m/1000 y (Fabbri et al., 2002) has left evidence on the morphologic and stratigraphic setting of all the continental margins of the world. The deposits related to this process are strongly different from area to area as a function of several variables, including the sedimentary supply, the morphologic setting and the oceanographic regime. The mapping of these deposits allows for the correlation of the most significant stratigraphic surfaces (erosional and non-depositional) and for the comparison of the facies, inner geometry and of the deposits, which have recorded the sea level rise in a different way along the continental margins.

3. Results

The characterization of the sea bottom sediments in relationships to the sedimentary structures and to the grain-size of the deposits has allowed to map the different lithologic associations occurring in the sedimentary environments from the littoral to the inner shelf, which have been resumed in Table 1.

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Depositional environment	Deposits	Facies associations
Littoral environment	Submerged beach deposits Toe of coastal cliff deposits	Blocks Gravels Sands
Inner shelf environment	Proximal inner shelf deposits Lithoclastic deposits Bioclastic deposits	Silts and shales

Table 1. Lithologic associations occurring in submerged beach, toe of coastal cliff and inner shelf deposits.

3.1Geological map n. 464 Isola d'Ischia

The example of the geological map of the Island of Ischia is herein discussed (Sbrana et al., 2011). Submerged beach, inner and outer shelf and slope environments have been distinguished, coupled with debris avalanches and debris flows and undifferentiated volcanic deposits. The depositional environments and the corresponding deposits are resumed in Table 2.The geological map 464 section 030 (scale 1:10.000) is shown as an example of geological map in the western Ischia offshore (Fig. 2).

Depositional environment	Deposits	Facies associations
Littoral environment	Submerged beach deposits	Well sorted sands and gravels, composed of lithic elements having a volcanic nature, from rounded to sub-rounded, with a pelitic matrix and scattered bioclasts. The pelitic matrix increases in the sectors protected from the wave motion and towards the outer boundary of the submerged beach.

Inner shelf environment	Inner shelf deposits Bioclastic deposits	Coarse-to-middle-grained sands and fine-grained pelitic sands. Sandy belts aligned along the lines of the sea bottom occur. The western sectors of inner continental shelf are characterized by wide fields of ripples and megaripples. Sands and gravelly sands, mainly bioclastic in scarce pelitic matrix. Subordinately, detrital facies derived from the reworking of organogenic materials on consolidated and lithoid sea bottoms. Middle-grained bioclastic sands in a scarce pelitic matrix located on the morphological highs (Ischia Channel) or to the top of volcanic banks (Forio bank).
Outer shelf environment	Outer shelf deposits Bioclastic deposits	Pelites with variable fractions of middle-fine-grained sands with volcaniclastics and bioclastics and subordinately marine Phanerogams. In the northern and south-eastern sectors of the outer shelf some

		lineaments linked to the occurrence of sea bottom currents occur and are sub-parallel to the isobaths. Detrital bioclastic sands in abundant pelitic matrix characterized by the occurrence of calcareous algae (coastal detritics) whose elements are composed of fragments of Bryozoans, Echinids and algae. The detrital cover is thick up to several decimeters and overlies mainly pelitic sea bottoms.
Slope environment	Slope deposits	Pelites and sandy pelites. The sandy component, more abundant in correspondence to the canyons and the tributary channels is composed of lithoclasts and bioclasts.
Shelf and slope environment	Debris avalanches and debris flows.	Heterometric blocks and accumulations of blocks of tuffs and lavas having dimensions from several hm to dam, interstratified in a detrital matrix, from coarse-to-fine-grained (northern Ischia sector from Lacco Ameno to Casamicciola)

		and western Ischia sector from Punta del Soccorso and Punta Imperatore).
Shelf and slope environment	Undifferentiated volcanic deposits	Volcanic deposits

Table 2. Depositional environments and corresponding deposits at the Island of Ischia.

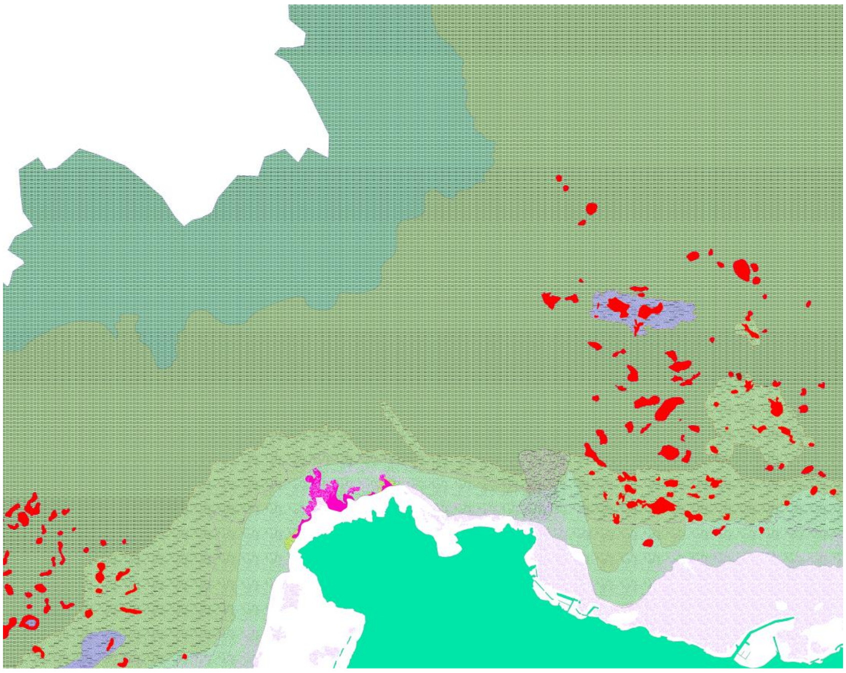

Figure 2. Example of geologic map of north-western Ischia Island offshore (scale 1:10.000). The red circles indicate the debris avalanche deposits occurring in the northern and western Ischia offshore.

The Ischia island lies on a volcanic ridge showing a mainly E-W trend. In the western offshore of the island a strong field of magnetic anomalies has suggested the occurrence of a magmatic system, now inactive. Two main structural trends exist in the E-W trending volcanic ridge of the Island of Ischia: one E-W trending and another ENE-WSW trending, recognized especially in the western offshore of the Island of

Ischia. To a regional scale the comparison between the distribution of magnetic sources and the morpho-structures indicate a poor correlation for the E-W trending morpho-structures and a high correlation for the ENE-WSW (Bruno et al., 2002; Passaro, 2005; Aiello et al., 2012; Aiello and Marsella, 2015a; 2015b; Passaro et al., 2016; 2018; Aiello, 2018).

The seismo-stratigraphic setting of the Island of Ischia has been shown by the geological interpretation of seismic sections located in the northern and western offshore of the island (Sbrana et al., 2011; Aiello, 2017; Fig. 3).Three categories of seismic units have been distinguished, including sedimentary seismic units (Sm1, Sm2; Sm3 and Sm4; Fig. 3), volcanic seismic units (x1, x2, x3, x4 and svi; Fig. 3) and submarine slide units (da,da1, da2, da3, da4; Fig. 3). The sedimentary seismic units are represented by thick relict prograding wedges, probably Late Pleistocene in age, which have been crossed both parallel (seismic line L32 in the lower part of Fig. 3) and perpendicular (seismic lines L27 and L34 in the upper and intermediate part of Fig. 3) to the direction of progradation. On the other side, the volcanic seismic units are represented by thick volcanic deposits, constituting the acoustic substratum (x1 and x2 in the seismic profiles L27 and L32, located in the upper and in the lower part of Fig. 3), sometimes revealing the occurrence of volcanic intrusions (x2 in the seismic profile L32 and svi in the seismic profile L34). Submarine slide deposits appear to be emplaced during different phases, as evidenced by their complex stratigraphic architecture, suggesting at least four phases of emplacement in the western Ischia offshore, evidenced by the corresponding deposits (da1, da2, da3, da4; Fig. 3).

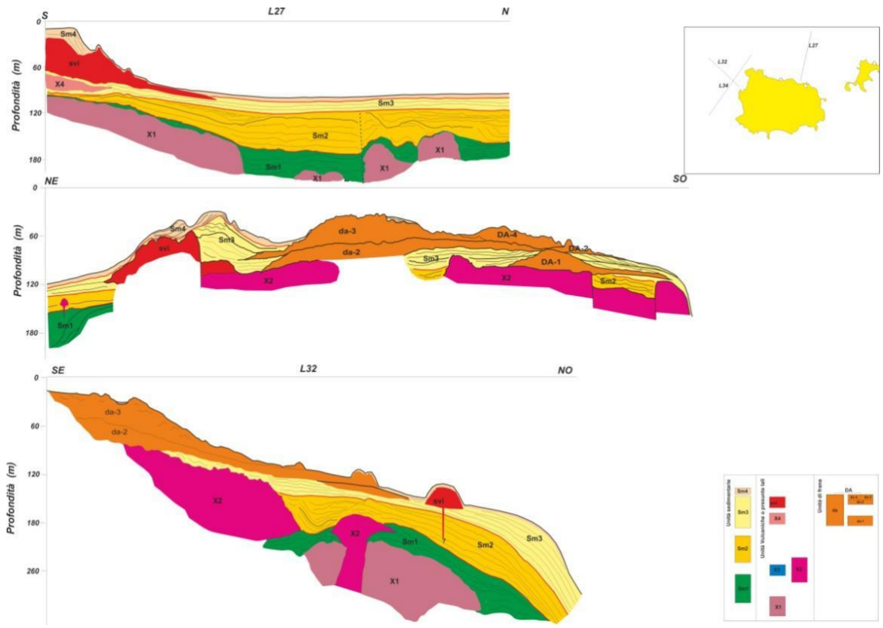

Figure 3. Stratigraphic sketch diagram showing the interpreted seismic sections in the Ischia offshore.

3.2 Geological map n. 502 Agropoli

Significant results have been obtained regarding the geological mapping of the Agropoli continental shelf, located in the Northern Cilento Promontory (geological map n. 502 “Agropoli”). Its morpho-bathymetric setting has been outlined through the construction of four geological maps. One of them is herein shown (Fig. 4). The map has represented a continental shelf deep up to 95 m, having low gradients.In the north-eastern corner of the map the Paestum Plain has been represented and the corresponding offshore sector, characterized by low water depths, up to 35 m. Proceeding southwards, the next physiographic unit is represented by the Agropoli promontory. In the corresponding offshore the isobaths are convex and conditioned from the trending of the rocky shoreline, where the siliciclastic units pertaining to the Cilento Flysch crop out (Bonardi et al., 1992). Another rocky promontory is distinguished between the Tresino Cape and the Pagliarolo Cape. It strongly controls the physiography of the submerged area. High coastlines and convex isobaths

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characterize this area.

The geological units identified through the Agropoli geological map are represented by the rocky units of the substratum and by the Quaternary marine deposits(Fig. 4).

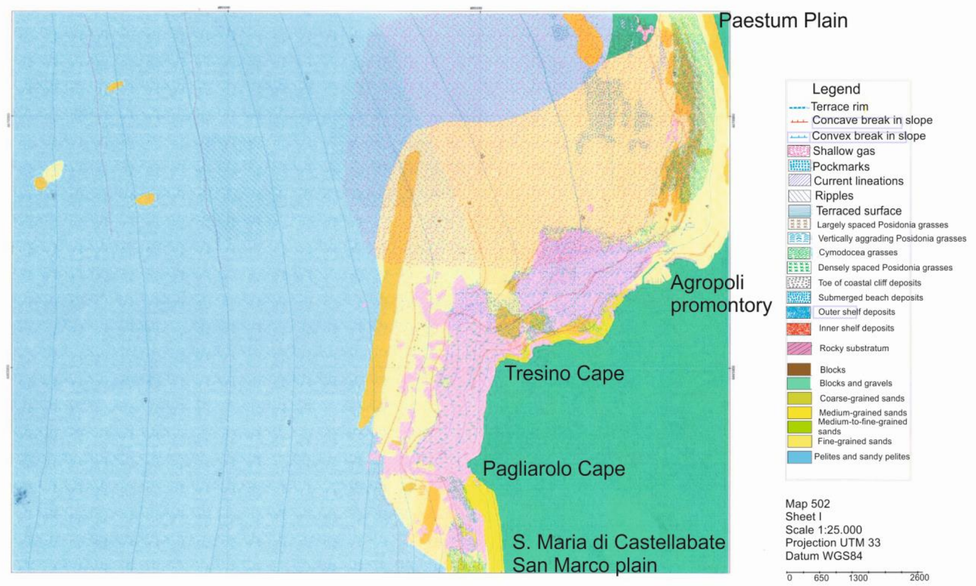

Figure 4. Example of geological map in the Agropoli offshore (southern Campania) to a 1:10.000 scale.

These deposits and the corresponding acoustic substratum have been resumed in the Table 3.

Depositional environments	**Deposits**	**Facies associations**
Rocky units of the substratum	Cenozoic substratum	Siliciclastic deposits of the Cilento Flysch, cropping out at the sea bottom in correspondence with the

		morpho-structural high of the Licosa Cape. Marine terraces at the top of this unit corresponding with polycyclic erosional surfaces. Wide grasses of marine Phanerogams up to water depth of 30 m.
Littoral environment	Submerged beach deposits Toe of coastal cliff deposits	Gravels, sandy gravels and coarse-grained sands, with rounded to sub-rounded pebbles in a middle-to-fine-grained sandy matrix. Coarse-to-middle-grained sands, from rounded to sub-rounded, with gravels, pebbles and blocks. Siliciclastic heterometric blocks, from metric to decametric and siliciclastic heterometric gravels, from centimetric to metric.
Inner shelf environment	Inner shelf deposits Bioclastic deposits	Litho-bioclastic, coarse-grained sands, from well-sorted to poorly-sorted, medium-to-fine-grained litho-bioclastic sands and fine-grained pelitic sands. The sandy fraction is composed of

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		bioclastic fragments. Occurrence of sandy ridges and current lineaments parallel to the isobaths. Heterometric gravels, gravelly sands and bioclastic sands, sometimes in a pelitic matrix, often located at the top of the outcrops of acoustic basement.
Outer shelf environment	Outer shelf deposits Bioclastic deposits	Medium-to-fine-grained sands with lithoclasts and bioclasts and abundant rhyzoms of marine Phanerogams, pelites and sandy pelites rich in small Gastropods, Vermetids and small mollusks. Occurrence of current lineaments. Calcareous sands in an abundant pelitic matrix, overlying the top of outcrops of acoustic basement.
Lowstand system tract	Lowstand deposits	Coarse-grained organogenic sands including abundant shell fragments and fragments of Mollusks, Echinids and Bryozoans, grading upwards into medium-grained sands and pelitic covers. These deposits form coastal wedges overlying

		the shelf margin progradations and represent portions of submerged beach linked to the last sea level lowstand.
Remnants of Pleistocene beach systems	Coarse-to-fine-grained marine deposits of well-sorted sands and gravels with bioclastic fragments and medium-to-fine-grained sands with a pelitic coverage	Pleistocene marine units representing relicts of beach and continental shelf environments.

Table 3. Depositional environments and corresponding deposits in the Agropoli offshore (Cilento Promontory, Campania).

The Cenozoic substratum is composed of Cenozoic siliciclastic rocks, genetically related to the Cilento Flysch. This unit mainly crops out in the inner continental shelf, particularly offshore the Licosa Cape morpho-structural high and is terraced at its top by polycyclic erosional surfaces and covered by wide beds of marine Phanerogams.

The littoral environment is characterized by the submerged beach deposits, including gravels, sandy gravels and coarse-grained sands, with rounded to sub-rounded pebbles in a middle-to-fine-grained sandy matrix, coarse to middle-grained sands, from rounded to sub-rounded, with gravels, pebbles and blocks. Moreover, the toe of coastal cliff deposits, composed of siliciclastic heterometric blocks, occur. The coastal cliffs are incised in the arenaceous-silty successions of the Cilento Flysch (Bonardi et al., 1992).

The inner shelf environment is distinguished from inner shelf deposits and bioclastic deposits. The first ones are composed of coarse-grained litho-bioclastic sands, middle-to-fine-grained litho-bioclastic sands and fine-grained pelitic sands. The second ones are composed of heterometric gravels, gravel sands and bioclastic sands in a pelitic matrix.

The outer shelf environment is characterized by clastic deposits and bioclastic

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deposits. The first ones are composed of middle-fine-grained sands located at the top of wide outcrops of Cenozoic substratum, pelites and sandy pelites. The second ones are composed of bioclastic calcareous sands in a pelitic matrix, organized as sedimentary drapes located at the top of outcrops of Cenozoic acoustic basement.

The lowstand system tract (LST) is characterized by coarse-grained organogenic sands, grading upwards into the middle-grained sands and the pelitic drapes. It is represented by the relict littoral deposits, organized as coastal wedges overlying the shelf margin progradations. Moreover, they represent parts of submerged beaches related to the sea level lowstand and related to the isotopic stage 2.

In conclusion, the Pleistocene relict marine units are represented by coarse-to-fine-grained marine deposits, probably composed of well-sorted sands and gravels with bioclastic sands and by medium-fine-grained sands, with a pelitic cover having a different thickness, but less than 2 m. These units have been mapped in the north-western and south-eastern sectors of the continental shelf and have been interpreted as the remnants of older beach systems, which are genetically related to the isotopic stages 4 and 3.

3.3 Description of the seismic units in the Agropoli offshore

Six seismo-stratigraphic units have been recognized on seismic profiles and are herein described (Units 3, 4, 5 and 6; Fig.5). They are separated by significant seismic reflectors, corresponding to regional unconformities and/or correlative conformities (C; D; E; Fig. 5). These seismo-stratigraphic units are underlain by an acoustically-transparent seismic unit, representing the acoustic basement (S unit;Fig. 5).

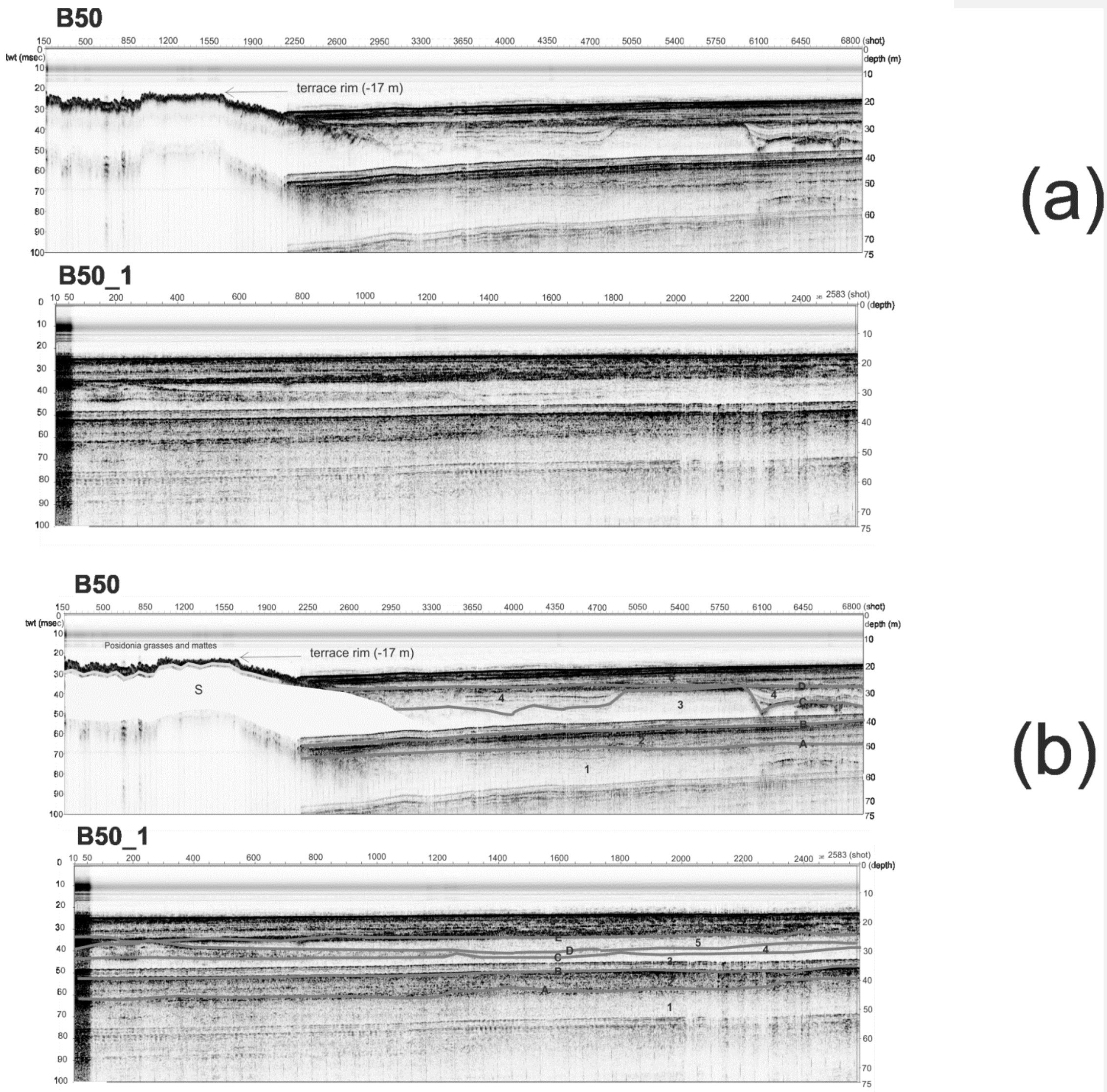

Figure 5. Subbottom Chirp profiles B50 and B50_1 located in the Agropoli offshore and corresponding geologic interpretation.

The B50 seismic profile is composed of two successive acquisitions (B50 and B50_1; Fig. 5), NNW-SSE trending and has been recorded at water depths ranging between 18.75 m (beginning acquisition) and 16.5 m (ending acquisition). The vertical penetration is of about 100 msec (about 62 m). The sea bottom is covered by grasses with marine Phanerogams, widely occurring in this bathymetric belt. A terrace rim

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has been recognized at the top of the acoustic basement at water depths of 17 m (Fig. 5). The seismo-stratigraphic units are herein described.

Unit 3: this unit is characterized by an acoustically-transparent seismic facies and by an irregular outer morphology. In particular, on the seismic line B50 it designs a palaeo-structural high (Fig. 5). The base of this unit cannot be recognized due to the occurrence of the sea bottom multiple (Fig. 5). The top of this unit is represented by an irregular unconformity (namely the C unconformity), which, landwards, onlaps on the S unit, corresponding with the acoustic basement (Fig. 5).

Unit 4: this unit forms the filling of wide palaeo-channels located at the top of the underlying seismic unit and is characterized by discontinuous and sub-parallel seismic reflectors. Its top is marked by an erosional unconformity (D unconformity).

Unit 5: it has been recognized only on the Chirp line B50_1 and is characterized by an acoustically-transparent seismic facies. Its top is characterized by a highly continuous seismic reflector (E unconformity). The outer geometry of the seismic unit suggests that it represents a wedge.

Unit 6: is characterized by parallel and continuous seismic reflectors. It crops out at the sea bottom, being the most recent seismic unit. Its base is represented by the D unconformity (seismic line B50) or alternatively, by the E unconformity (seismic line B50_1).

Sacoustic basement: is characterized by an acoustically-transparent seismic facies. It crops out at the sea bottom near shore (Fig. 5). The strong scattering of the seismic signal in correspondence to the top of the S unit has been observed. A terrace rim should be suggested at water depths of 17 m.

The seismic profile B51 (Fig. 5) is long 6.1 kilometers, NNE-SSW trending and has been recorded in water depths ranging between – 19.5 m (beginning of the acquisition) and – 12 m (end of the acquisition). The vertical penetration of the studied section is of about 100 msec (64.5 m). A terrace rim has been recognized at water depths of 18 m, genetically related with the terrace rim recognized at 17 m of water depth on the seismic profile B50 (Fig. 5). The following seismo-stratigraphic units have been recognized, separated by significant seismic reflectors corresponding with regional unconformities and/or paraconformities:

Unit 3: is characterized by an irregular outer morphology, delineating two palaeo-structural highs, bounded by three palaeo-channels, whose infill is represented by the seismic unit 4. The top of the seismic unit is represented by an irregular unconformity, having different depths, deeper in correspondence with the palaeo-channels and shallower in correspondence with the palaeo-structural highs. Its base cannot be identified due to the occurrence of the sea bottom multiple. Shallow gas widely affects this seismic unit, making the seismic facies locally acoustically-transparent.

Unit 4: is characterized by parallel and discontinuous seismic reflectors, representing the infill of wide palaeo-channels. Geometric configurations of bidirectional onlaps may be seen. The top of the seismic unit corresponds with the D regional unconformity.

Unit 6: is characterized by parallel and continuous seismic reflectors, having a wedge-shaped external geometry.

S acoustic basement: is distinguished from an acoustically-transparent seismic facies. A strong scattering of the acoustic signal has evidenced the occurrence of Posidonia grasses and locally, Posidonia mattes.

4. Discussion and conclusion

4.1 Ischia geological map

The geological evolution of the Ischia volcanic complex has been reconstructed based on recently acquired submarine seismic reflection data coupled with geological maps. The Ischia offshoreis characterized by alkali-potassic volcanic rocks(trachytes, latites and alkali-basalts) erupted from avolcanic complex whose activity lasted the last 55ky B.P. and realized during four main phases. Thefirst phase, older than 150 ky B.P. included the eruptionof pyroclastic products and interstratified lavaflows. The second phase (150-75 ky B.P.) controlledthe rising of

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lava domes along extensional faults controlledby a strong tectonic activity and the eruptionof pyroclastites. The third phase (55-20 ky B.P.) wasdominated by the eruption of the Epomeo Green Tuffs,covering the coastal relief of the island and filling theIschia graben. The fourth phase (10 ky B.P.-1302 A.D.)acted mainly in the Ischia graben, except that the Zarolava flow.

The main seismic sequences of the Ischiaoffshore have been reconstructed. Interpreted seismic sections crossing submarine slide deposits and submarinecanyon systems have been constructed based on seismicinterpretation to improve the understanding ofsubmarine features of the island offshore. The up-to-dated volcanologyand stratigraphy of the onshore sectors haveallowed to reconstructed a detailed geologic evolutionof Punta Imperatore, Capo Negro, Maronti, Barano,Punta San Pancrazio and Ischia bank sectors (Vezzoli,1988; Orsi et al., 2004; Brown et al., 2008; Aiello &Marsella, 2014) New insights on the detailed seismo-stratigraphic setting and the geological transects located at Succhivo, Punta dello Schiavo, Spiaggia degli Inglesi and Cava dell'Isola) have recently been suggested through the geological interpretation of seismic profiles (Aiello, 2018).

4.2 Agropoli geological map

4.2.2 Geological interpretation of the seismic units

Four seismo-stratigraphic units have been interpreted and correlated with Quaternary marine deposits which characterize the stratigraphic architecture of the continental shelf offshore the Cilento Promontory. The geological interpretation of these units is herein described. One of the most complete stratigraphic records of the Quaternary sequence and underlying acoustic basement, probably Upper Miocene in age, is offered from the seismic sections B50 and B50_1, crossing the inner Cilento continental shelf (Fig. 5).

A tentative interpretation of the seismic units is herein proposed based on the acoustic facies detected on seismic profiles. Unfortunately, no core data or well lithostratigraphic data are available in the area, in order to perform a quantitative interpretation in terms of lithology. Nonetheless this, marine geological maps have been constructed in the same area. The data available for geological mapping included sea bottom samples which have been used for the calibration of the Sidescan Sonar acoustic facies, representing the base for the marine geological maps. A sketch table has been constructed in order to show the seismic facies and the corresponding geologic interpretation studied in this paper.(Fig. 6).

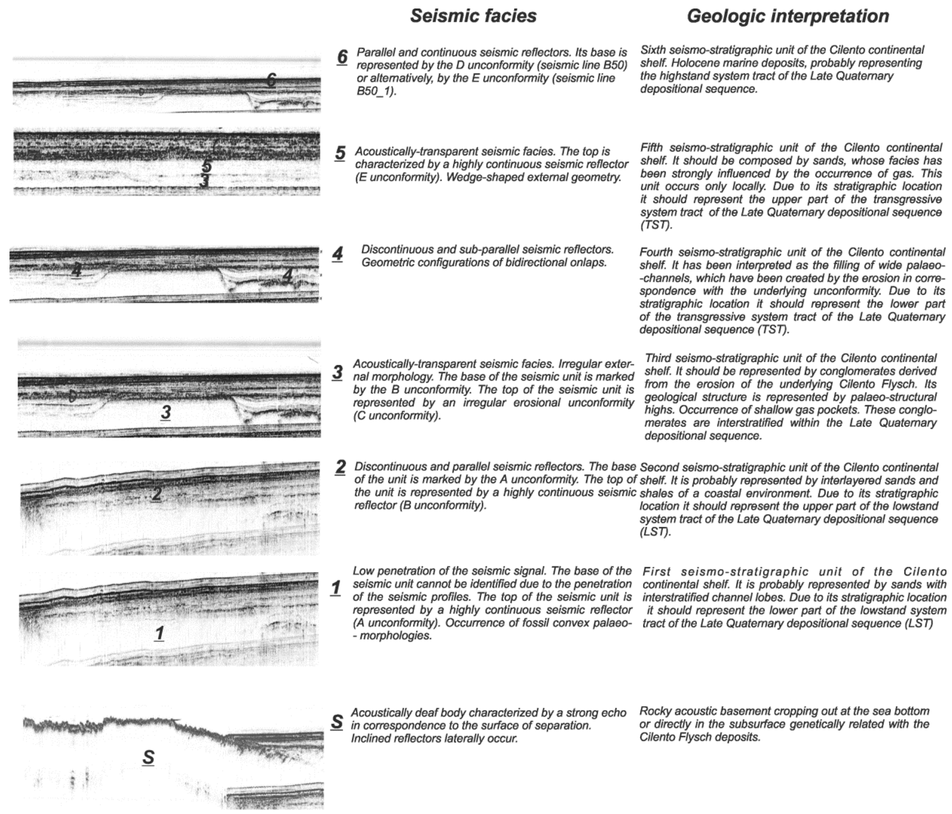

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Figure 6. Sketch table showing the seismic facies and the corresponding geologic interpretation in the Agropoli offshore (Southern Campania).

The unit 6 has been interpreted as the sixth seismo-stratigraphic unit of the Cilento continental shelf, represented by Holocene deposits, i.e. the highstand system tract (HST) of the Late Quaternary depositional sequence (Fig. 6).

The unit 5 has been interpreted as the fifth seismo-stratigraphic unit of the Cilento continental shelf, probably composed of sands, whose seismic facies has been strongly influenced by the occurrence of gas. A local occurrence of this seismic unit has been detected. Due to its stratigraphic location the unit should represent the upper part of the transgressive system tract (TST) of the Late Quaternary depositional sequence (Fig. 6).

The unit 4 has been interpreted as the filling of wide palaeo-channels occurring in correspondence with the underlying unconformity. Its stratigraphic location suggests that it represents the basal part of the transgressive system tract (TST) of the Late Quaternary depositional sequence (Fig. 6).

The unit 3 occurs as palaeo-structural highs, highly affected by shallow gas (Fig. 6). It represents the third seismo-stratigraphic unit of the Cilento continental shelf, probably represented by conglomerates derived from the erosion of the underlying Cilento Flysch (S unit).

The S acoustic basement is depicted from an acoustically deaf body, characterized by a strong echo in correspondence to the surface of separation (Fig. 6). Inclined reflectors laterally occur.

The acoustic basement underlying the Quaternary seismo-stratigraphic unit has been interpreted as genetically related with the Cilento Flysch. It widely crops out at the sea bottom and in the subbottom in areas surrounding the Cilento Promontory. The outcrops of the acoustic basement result wider than that ones previously mentioned in the Cilento area (Coppa et al., 1988; Ferraro et al., 1997).

Ethics Statement

I state that the ethics of this manuscript is correct.

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