

**BORNH****Bulletin of
Regional
Natural History****Formerly Bollettino della Società dei Naturalisti in Napoli****The relict deposits of the Cilento offshore (Southern Tyrrhenian Sea, Italy) based on seismo-stratigraphic data**Gemma Aiello¹, Mauro Caccavale¹DOI <https://doi.org/10.6093/2724-4393/12459>***Correspondence:**

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**Abstract**

Relict deposits (palimpsest and lowstand) deposits of the Cilento continental shelf were analyzed. Sub-bottom Chirp seismic sections were interpreted and calibrated with core data, previously known in literature. General seismo-stratigraphic framework has shown four main seismo-stratigraphic units, genetically related to the Cilento Group. The stratigraphic record of the palimpsest and lowstand deposits of the Cilento continental shelf is punctuated by significant stratigraphic surfaces, including the ravinement and the erosional surface of the acoustic basement, involved by wave-cut submarine terraces, carving the submerged portion of the Cilento Group. A seismo-stratigraphic unit with prograding clinoforms has been identified based on the seismo-stratigraphic interpretation and interpreted as genetically related to the MIS 4. These deposits are overlain by a seismo-stratigraphic unit, which is composed of coarse-grained organogenic sands, interpreted as relict sands, based on core calibration. The vertical stacking of these seismo-stratigraphic units forms sandy ridges (water depths of 130 m- 140 m), interpreted as submerged beach deposits, genetically related to the MIS 2 (Last Glacial Maximum; starting date 29 ky B.P.).

Keywords: relict deposits; seismo-stratigraphic units; Cilento offshore; Southern Tyrrhenian Sea, Italy.

Riassunto

In questo articolo vengono analizzati i depositi relitti (palinsesti e di stazionamento basso) della piattaforma continentale del Cilento. Le sezioni sismiche Sub-bottom Chirp sono state interpretate e calibrate con i dati di carotaggio, precedentemente noti in letteratura. L'assetto

stratigrafico generale della piattaforma continentale ha mostrato la presenza di quattro unità sismo-stratigrafiche, geneticamente collegate con il Flysch del Cilento. Il record stratigrafico dei depositi palinsesti e di *lowstand* della piattaforma continentale del Cilento è caratterizzato da superfici stratigrafiche significative, che includono la superficie di *ravinement* e la superficie erosiva del basamento acustico, incisa da terrazzi marini (*wave-cut*), che erodono la porzione sommersa del Gruppo del Cilento. Un'unità sismo-stratigrafica con clinoformi progradanti è stata identificata in base all'interpretazione sismo-stratigrafica ed interpretata come geneticamente collegata al MIS 4. Tali depositi sono ricoperti da un'unità sismo-stratigrafica, composta da sabbie organogene grossolane, interpretata come sabbie relitte in base alla calibrazione con i dati di carotaggio. L'arrangiamento verticale di tali unità sismo-stratigrafiche forma dorsali sabbiose a profondità comprese tra 130 e 140 m, interpretate come depositi di spiaggia sommersa, geneticamente collegati al MIS 2 (Last Glacial Maximum; 29 ky B.P.).

Parole chiave: depositi relitti; unità sismo-stratigrafiche; terrazzi deposizionali sommersi; offshore del Cilento; Tirreno meridionale; Italia.

Introduction

This paper aims at analyzing the relict deposits of the Cilento offshore (Campania continental margin, Southern Tyrrhenian Sea). It is based on the geological interpretation of seismo-stratigraphic data, consisting of Sub-bottom Chirp profiles, calibrated by the result of a published sediment core (Ferraro et al., 1997). In the Cilento offshore, two kinds of relict deposits have been identified based on a previous geological interpretation of Sub-bottom Chirp profiles: the palimpsest deposits and the lowstand deposits

(Aiello & Caccavale 2023). In this work, we complete the seismo-stratigraphic analysis of the relict deposits in the Cilento offshore (previously stated by Aiello & Caccavale 2023), interpreting further seismic sections to reconstruct the stratigraphic architecture of the Cilento offshore relict deposits.

Two types of sediments are present on continental shelves: sediments which are not in equilibrium with the present-day environmental conditions (relict sediments); and sediments which are in equilibrium with these conditions (Shepard, 1932; Emery, 1952; Curray, 1964; Emery, 1968; Belderson et al., 1971; Swift et al., 1971). The occurrence of coarse-grained sands, at a greater distance from the coast and at greater depths than fine-grained sands is an important evidence of the relict origin of sediments.

The concept of relict and palimpsest sediments has been deeply discussed by Swift et al. (1971). These authors have highlighted that the relict and the palimpsest sediments represent dynamic complexes in continuous modification, as a response to the actual depositional environment, and are controlled by the hydraulic regime. In this context, these deposits try to approach the equilibrium with the present-day environmental conditions. Using a stochastic process model for the simulations, several case histories in the continental margins of the world have been analyzed, including the high-energy, tide-dominated continental shelf deposits of the western Europe, undergoing an extensive reworking of the Pleistocene and Holocene transgressive deposits (Swift et al., 1971).

Orme (1982) discussed the concept of relict sediments in relationships to beaches and coastal geology. The present environment in which the relict sediments occur is not necessarily in equilibrium with the previous phases of sedimentation. It has been estimated that approximately 70% of the world's continental shelves are covered by sediment, which was deposited when the

shelves were largely exposed due to low sea levels associated with the glacial maxima of the Pleistocene. The sediments accumulated in several environments (subaerial, littoral, lacustrine, fluvial, lagoon, shallow marine, and periglacial) and subsequently became submerged by the post-glacial deposits.

The relict deposits can be composed of organogenic sands, often associated with siliciclastic deposits. This happens also in the case of the Cilento offshore, where organogenic sands have been detected based on seismo-stratigraphic data calibrated with core results (Aiello & Caccavale, 2023). These data can be interpreted according to the zonation of benthic assemblages in the Mediterranean Sea (Peres & Picard, 1964; Carannante et al., 1998). In the Mediterranean Sea, bioclastic deposits have been detected at water depths ranging between 40 m and 100 m ("Detritique Cotier" of Peres & Picard 1964; Carannante et al., 1988; Aiello, 2021). They derive from the reworking of benthic communities and consequent deposition both on mobile seabeds (biocoenosis of the "Detritique Cotier") and on hard seabeds (biocoenosis of the "Detritique du Large"). Because of the sea level rise, the deep seafloor was overlain by relict and drowned sediments, characterized by slow sedimentation and by the presence of glauconite ("Detritique du Large"; Carannante et al., 1988; Aiello 2021). Close to the study area, Aiello (2021) discussed the bioclastic deposits in the north-western sector of the Gulf of Naples, reporting rhodolith deposits occurring on the offshore of Ischia. Bioclastic deposits, consisting of coarse-grained volcanic sands with fragments of calcareous algae, medium-grained volcanic sands with fragments of echinoids and lamellibranch shells, and fine-grained sands with small bivalves, and gastropods, have been detected at several sectors of the Ischia Island. Abundant concretions of red algae also occur.

In this paper, further constraints on the

stratigraphic architecture of the relict deposits of the Cilento continental shelf based on Sub-bottom Chirp profiles are provided, giving an up-to-date stratigraphic framework, useful for next planning, monitoring and management of the coastal zones of this sector of the Eastern Tyrrhenian margin.

Geological setting

The Cilento offshore is a structural high, corresponding to the seaward's prolongation of the Licosa Cape structural high, bounded northwards and southwards by the Salerno Valley and the Policastro Gulf half-grabens. The Salerno Valley is a half-graben basin, controlled in the Early Pleistocene by the Capri-Sorrento Peninsula extensional master fault, bounding southwards the Sorrento Peninsula, and offsetting the Meso-Cenozoic carbonate sequences up to 1500 m (Aiello et al., 2009). The morpho-bathymetric setting of the study area is shown by the Digital Elevation Model (Fig. 1), which has been constructed merging the bathymetric data previously recorded by the CNR ISMAR of Naples, Italy, during several oceanographic cruises, starting from 1998 (D'Argenio et al., 2004).

The Cilento offshore structural high has been the subject of geological and seismo-stratigraphic studies, since the end of the 90s, when the interpretation of seismic profiles showed wide structural highs, characterized by an acoustically-transparent to chaotic acoustic facies (Trincardi & Zitellini, 1987; Aiello et al., 2011; Conti et al., 2017; Aiello et al., 2020; Dalla Valle et al., 2024; Aiello, 2024; Aiello & Caccavale, 2024). The stratigraphic architecture of the southern Campania continental margin is shown in Fig. 2 (Aiello et al., 2009). In particular, the geological interpretation of the seismic profile SAM4, from the Salerno offshore towards the structural high of the Cilento continental

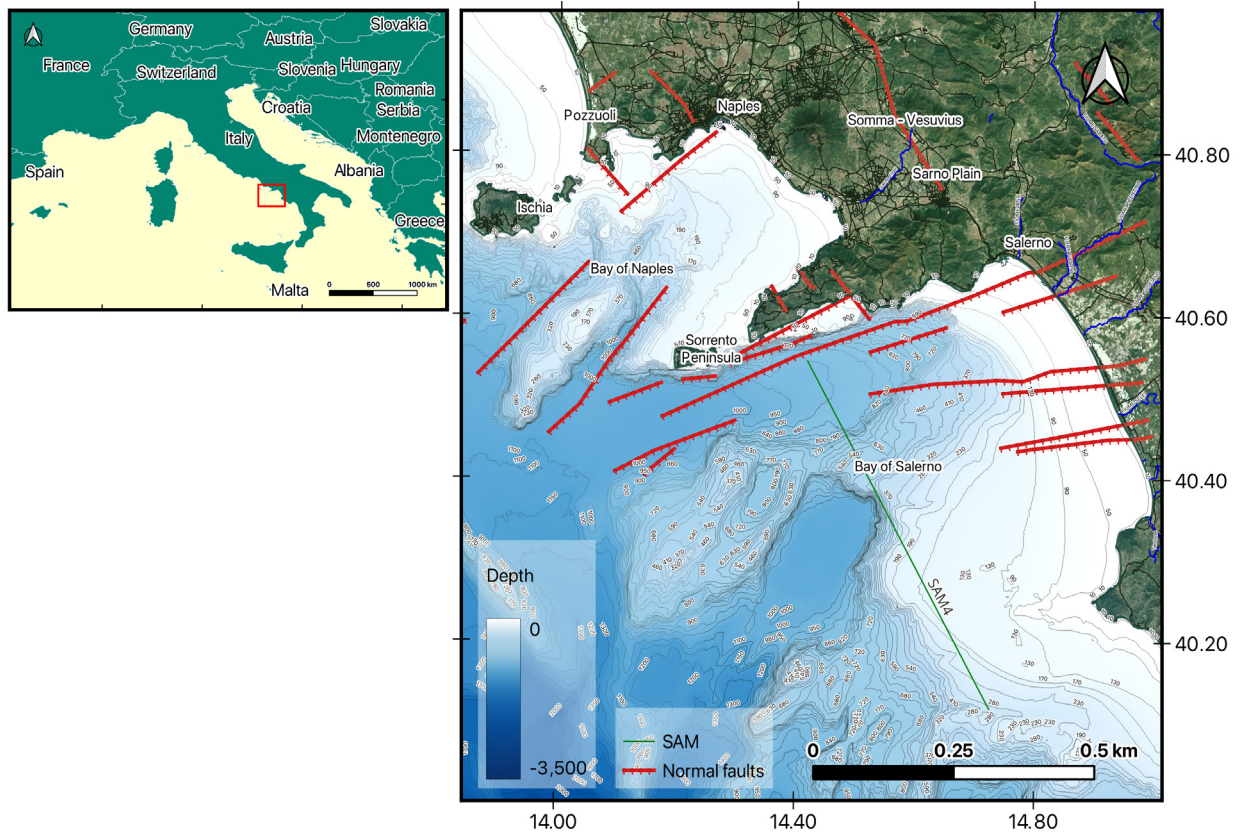


Figure 1: Digital Elevation Model of the Campania continental margin, including the Salerno-Cilento area. The location of the Naples and Salerno half-graben has been reported, coupled with the morpho-structural lineaments of the Campania continental margin. The source are the bathymetric data recorded by the CNR ISMAR of Naples, Italy, starting from the 1998 (D'Argenio et al., 2004).

shelf, shows the tectonic setting of the clastic multilayer, characterized by several normal faults. The seismo-stratigraphic units include Early Middle Pleistocene marine deposits (1 in Fig. 2), representing the bulk of the basin filling, and Late Pleistocene coastal and marine deposits (2 in Fig. 2). While the Early Middle Pleistocene seismo-stratigraphic unit is deformed by normal faults, the Late Pleistocene deposits are relatively undeformed and are characterized by progradational to parallel geometries in correspondence to the Cilento structural high and by parallel to subparallel geometries offshore of the Gulf of Salerno (Fig. 2). The acquisition of seismic profiles along the Tyrrhenian margin has confirmed this structural setting, highlighting how the Cilento structure is locally complicated by bending, reverse faults and basin inversion

(Aiello et al., 2011; Conti et al., 2017; Zitellini et al., 2020; Loreto et al., 2021).

In the emerged sector of the Cilento Promontory, the siliciclastic sequences ascribed to the Cilento Group crop out and have been involved in the deformation of the Apenninic chain (Vitale & Ciarcia, 2018; Fig. 2). These sequences represent the rocky acoustic basement of the Quaternary deposits of the continental shelf from the Licosa Cape to the Palinuro Cape (Fig. 2). Marine landscapes and habitats of the Cilento Geopark have been previously investigated (D'Angelo et al., 2020), as well as submerged marine terraces (Ferraro et al., 1997; Savini et al., 2021; Aiello & Caccavale, 2024). Anomalous morphologies, genetically related with rhodolith beds and of a probable biogenic origin, are still in course of investigation in

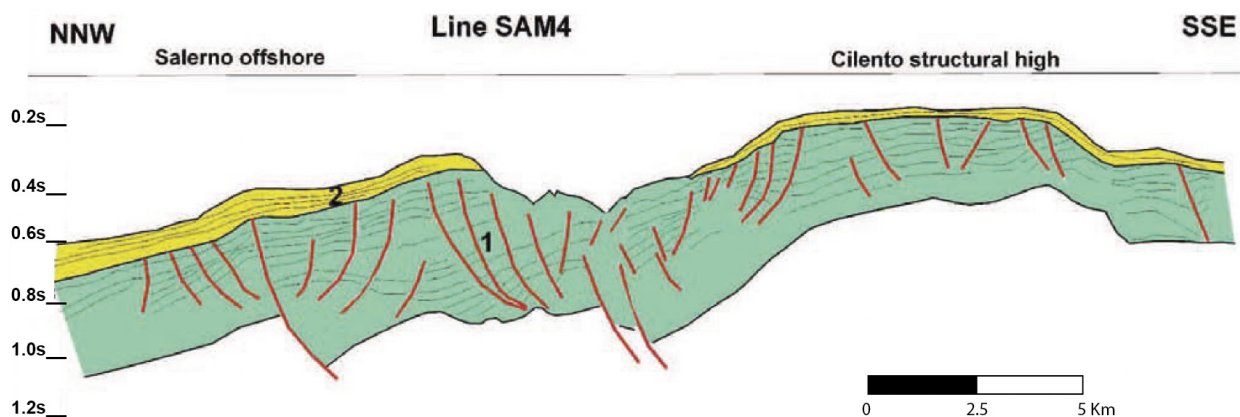


Figure 2: Line drawing of the multichannel profile SAM4, crossing the Salerno-Cilento area from the Salerno offshore towards the structural high of the Cilento continental shelf, already showing the stratigraphic architecture of the Campania continental margin (modified after Aiello et al., 2009). The location of the seismic profile is reported in Fig. 1. Vertical and horizontal scales have also been reported.

the frame of the CORSUB research project, funded by the Italian PRIN 2022 (Bazzicalupo et al., 2025). The morphological features have been divided into seven geoforms, including banks, ridges, fans, plains, ledges, terraces, boulder fields and boulder rocks, which, integrating information on the types of substrata and prevalent biota, have allowed for the identification of twelve landscape units in the 1:100.000 map (Martelli et al., 2016). These units have been grouped into 14 habitat units in the 1:30.000 habitat map (D'Angelo et al., 2020). The habitat map of the Licosa Cape area at the 1:30.000 scale has highlighted the occurrence of several submarine morphologies, including the spur of coralligenous bioconstruction, the wave-cut terraces with a mixed organogenic cover, the slopes with mixed organogenic sediments, the depositional terraces and the rocks. The habitat units genetically related to the coralligenous biota include the rocky banks, the banks with mixed organogenic sediments, the banks with a coarse-grained organogenic cover, the banks with a sandy organogenic cover, and the banks with a muddy cover. Subsequently, the wave-cut terraces offshore the Cilento Promontory

have been studied based on the geological interpretation of high-resolution seismic profiles (Aiello & Caccavale, 2024), showing the complex morpho-structural setting of this area and the probable relationships with the tectonic uplift phases involving the Southern Apennines and the eustatic sea-level falls during the Late Quaternary.

Materials and methods

The relict deposits of the Cilento offshore have been analyzed through the geological interpretation of seismo-stratigraphic data, consisting of Sub-bottom Chirp profiles acquired during the oceanographic cruise GMS03_01 (R/V Urania, National Research Council of Italy) during the scientific and technical activities for the realization of the geological sheet n. 502 "Agropoli" at the 1:50.000 scale of the Italian Geological Survey (Martelli et al., 2016; Fig. 3). In this paper, we have considered and interpreted five seismic profiles (B51, B52, B53, BL15, BL29_2), whose location is reported in Fig. 3. The seismic processing of the Sub-bottom Chirp profiles has been carried out with the software

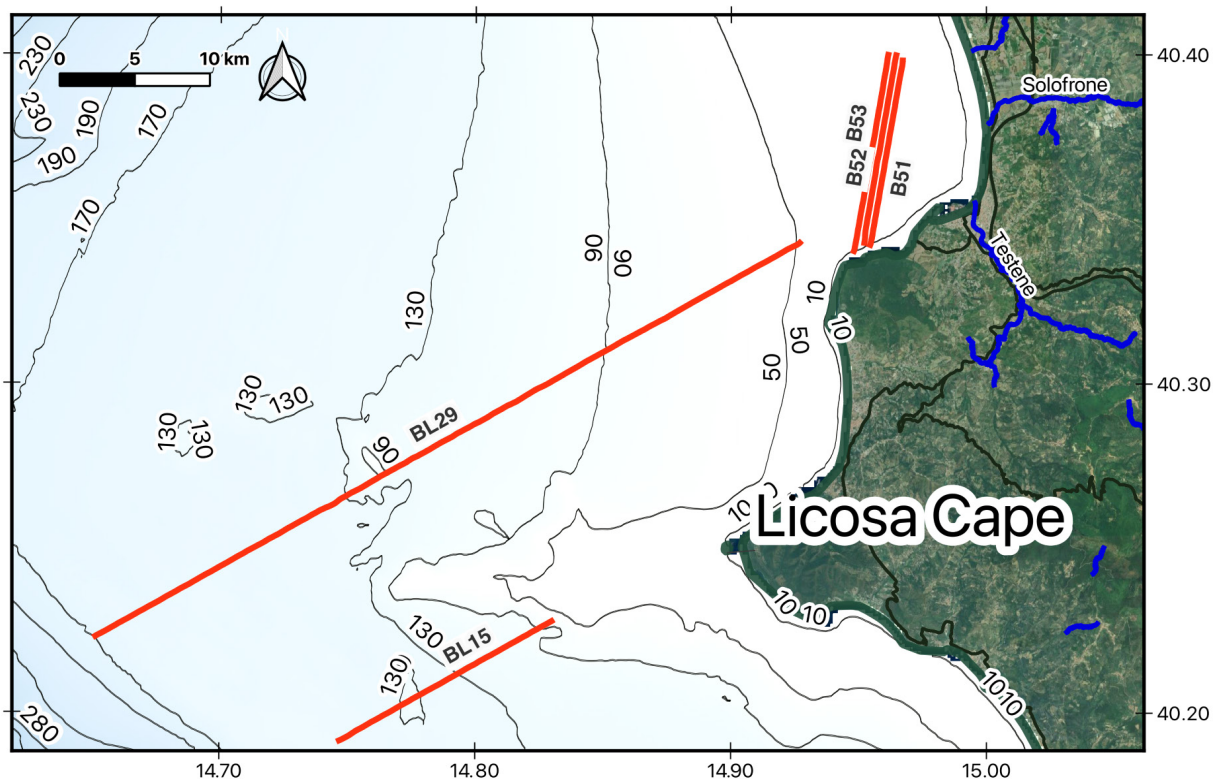


Figure 3: Location map of the seismic profiles analyzed in this paper (marked in bold red). The seismic profiles analyzed in this paper are respectively B51, B52, B53, BL 15, BL29.

Seismic Unix (SU), version SU44R28 (available online: <https://wiki.seismic-unix.org/start>), which has allowed a general improvement of the quality of the seismic sections and the production of the seismic sections as bitmap images. The main tasks in the processing of the seismic data were the exportation of the seismic traces from SEG Y to SU, the analysis of the frequency of the seismograms, and the use of FFT (Fast Fourier Transform) to visualize and analyze the frequencies of the seismic signal. Furthermore, the implementation of a high-pass filter with a low-cut frequency of 150 Hz has removed the seismic noise and the dark signal. A uniform gain was built up for each seismic trace, while a time-variant gain filter was set up to further enhance both the seismic signal and the deeper seismic horizons and the entire visualization of all the seismic lines. The outcome of the processing procedure was the visualization of seismic profiles with Seismic Unix employing a graphic

interface. In our interpretation, we refer to acoustic/seismic basement as a region of the subsurface showing a "strong" response to a seismic wave in the subsurface and represents the region beneath the deepest coherent or continuous seismic reflector or a stratified sedimentary succession.

The main lithological units in outcrop and the main landforms present offshore have been represented in the geological map (Fig. 4; Bonardi et al., 1988; Aiello et al., 2009; Vitale & Ciarcia, 2018; Guida & Valente, 2019; Aiello & Caccavale, 2021, 2022, 2023; Tursi et al., 2023). The source of the database used for preparation of the geological map is specified (Bonardi et al., 1988; Vitale & Ciarcia, 2018). We suggest which lithological units of the Cilento promontory could form the basis of the profiles in order to highlight a certain correlation between what has emerged and what is submerged, referring to the San Mauro and Pollica Formations (Fig. 4). These

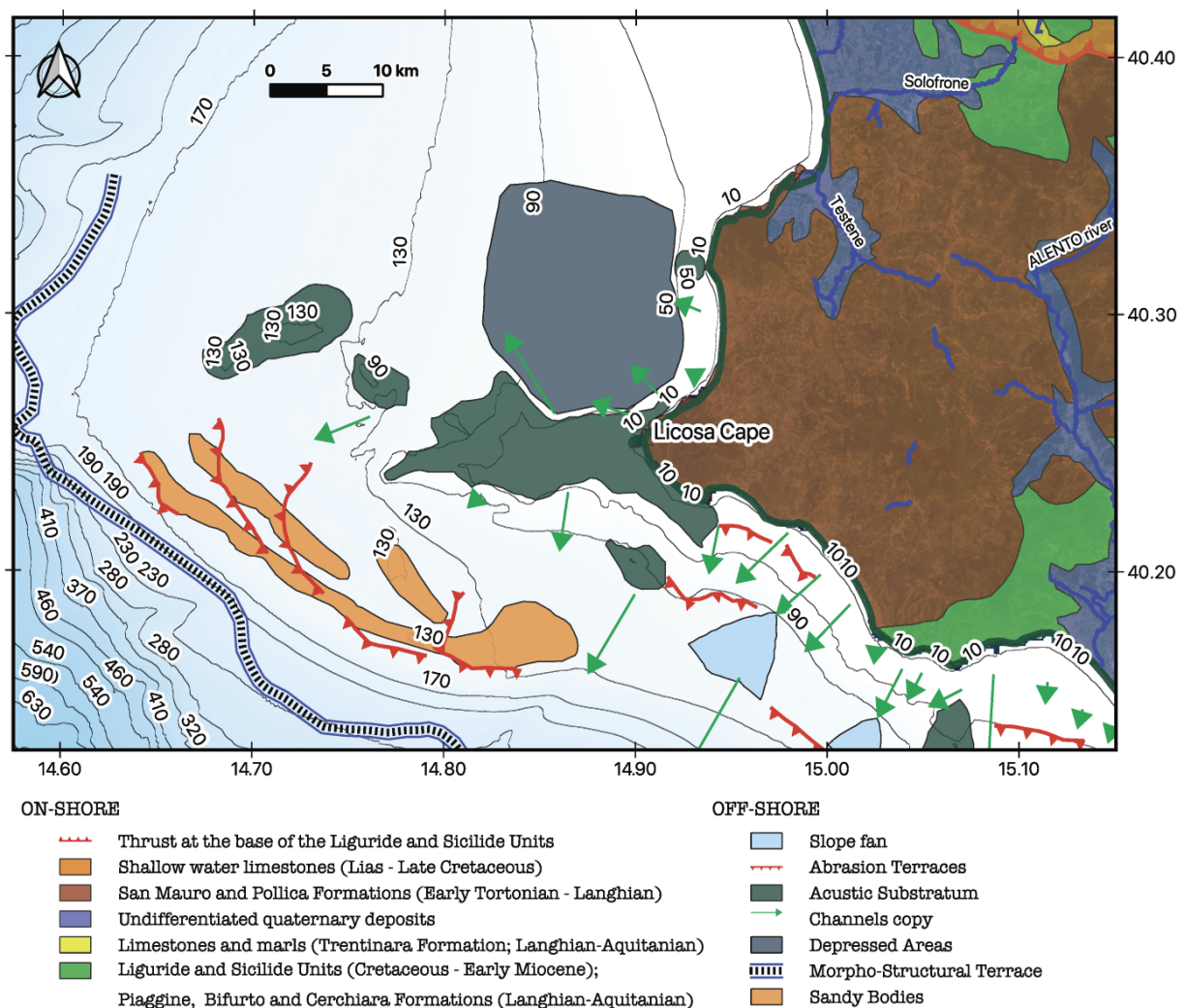


Figure 4: Geological map of the Cilento Promontory and geomorphologic map of the Cilento offshore (modified after Bonardi et al., 1988; Vitale and Ciarcia, 2018). Key. Onshore: Thrust at the base of the Liguride and Sicilide Units; Shallow water limestones (Lias-Late Cretaceous); San Mauro and Pollica Formations (Early Tortonian-Langhian); Undifferentiated quaternary deposits; Limestones and marls (Trentinara Formation; Langhian-Aquitania); Liguride and Sicilide Units (Cretaceous-Early Miocene); Piaggine, Bifurto and Cerchiara Formations (Langhian-Aquitania). Offshore: Slope fan; abrasion terraces; acoustic substratum; channels; depressed areas; morpho-structural terrace; sandy bodies.

lithological units could form the acoustic basement in the seismic profiles.

The geomorphological map of the Cilento offshore shows a wide continental shelf up to 250 meters deep (Fig. 4). While the continental shelf north of the Licosa Cape is flat, the marine area around the Licosa Cape is a E-W trending structural high, made up of remnants of terraced surfaces on rocky terrain (Aiello & Caccavale, 2024). They are especially prevalent in the bathymetric zone spanning 10 to 20 meters, though the rocky acoustic

basement can reach 60 meters. A sudden break in slope from 60 to 80 m corresponds with the passage from the structural height of the Licosa Cape to the outer shelf. The mapped landforms include the outcrops of the acoustic substratum, the relict sandy bodies, the slope fans, the abrasion terraces, the morpho-structural terraces, the depressed areas, coincident with the depocenters, and the erosional channels, coupled with the rims of a wide submerged terrace (Fig. 4).

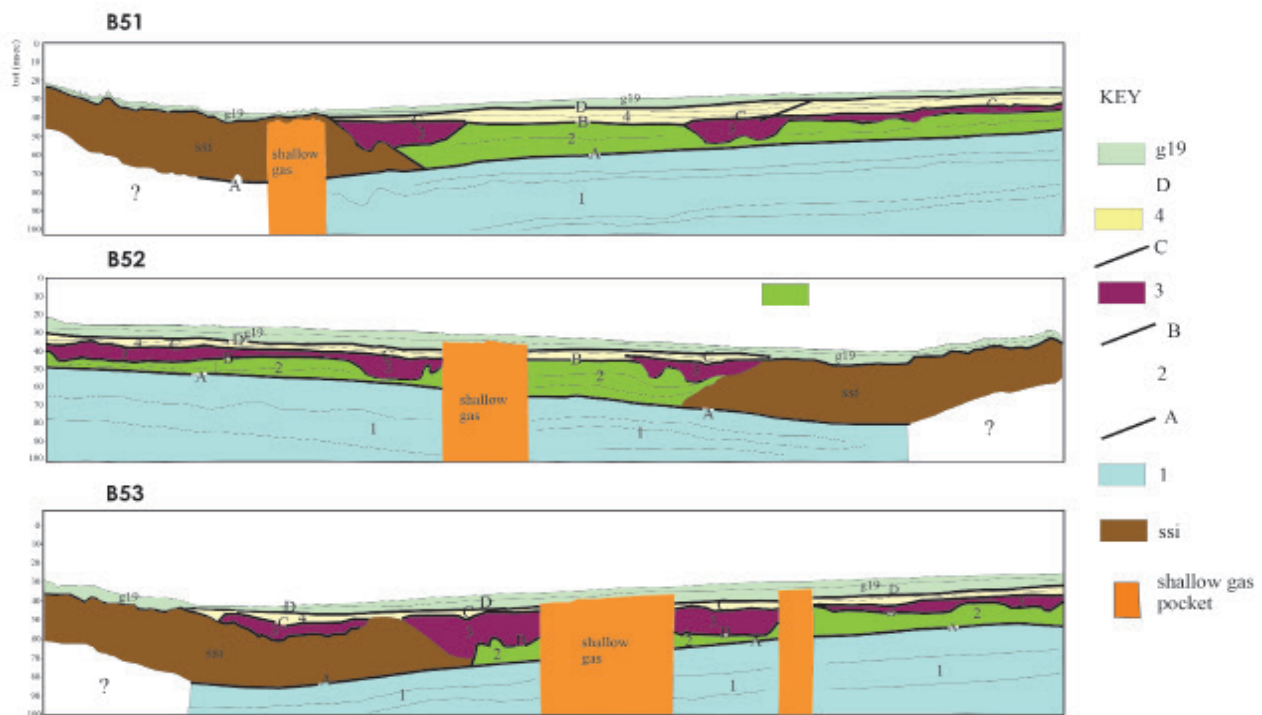


Figure 5: Seismic profiles B51, B52, and B53 and corresponding geological interpretation. Key: g19: Inner shelf deposits (Holocene); D: Regional unconformity located at the top of the seismo-stratigraphic unit 4; 4: seismo-stratigraphic unit 4; C: regional unconformity located at the top of the seismo-stratigraphic unit 3; 3: seismo-stratigraphic unit 3; B: regional unconformity located at the top of the seismo-stratigraphic unit 2; 2: seismo-stratigraphic unit 2; A: regional unconformity located at the top of the first seismo-stratigraphic unit; 1: seismo-stratigraphic unit 1; ssi: acoustic basement, genetically related to the Cilento Group; shallow gas pockets, suggested by wide acoustic anomalies in the seismic sections. The location of the seismic profiles is reported in Fig. 3.

Results

The general seismo-stratigraphic framework is outlined based on the geological interpretation of seismic profiles B51, B52 and B53, whose location is represented in Fig. 1. Six main seismo-stratigraphic units have been distinguished, separated by four regional or local unconformities (Fig. 5). The Cenozoic substratum (ssi), is composed of siliciclastic rocks, Cenozoic in age, genetically related to the Cilento Group and herein interpreted as the S. Mauro and Pollica Formations (Fig. 4); it corresponds to the acoustic basement of the sedimentary units. The first seismo-stratigraphic unit (seismo-stratigraphic unit 1) is characterized by an acoustically transparent seismic facies and a wedge-shaped external geometry, onlapping the Cenozoic substratum

(ssi), Late Pleistocene in age. It is bounded by the reflector A, interpreted as a paraconformity or stratigraphic continuity. The second seismo-stratigraphic unit (seismo-stratigraphic unit 2) is characterized by an acoustically transparent seismic facies, and by a wedge-shaped external geometry, and rests in onlap the Cenozoic substratum (ssi). The reflector B represents a local unconformity, recognized at the top of the seismo-stratigraphic unit 2. The third seismo-stratigraphic unit (seismo-stratigraphic unit 3) is characterized by an acoustically transparent to chaotic seismic facies, and by a few discontinuous reflectors, representing the filling of intra-platform depressions and characterized by bidirectional onlaps on the underlying unconformity, probably Late Pleistocene in age. The reflector C represents a local unconformity, recognized at the top of pockets of coarse-grained residual materials,

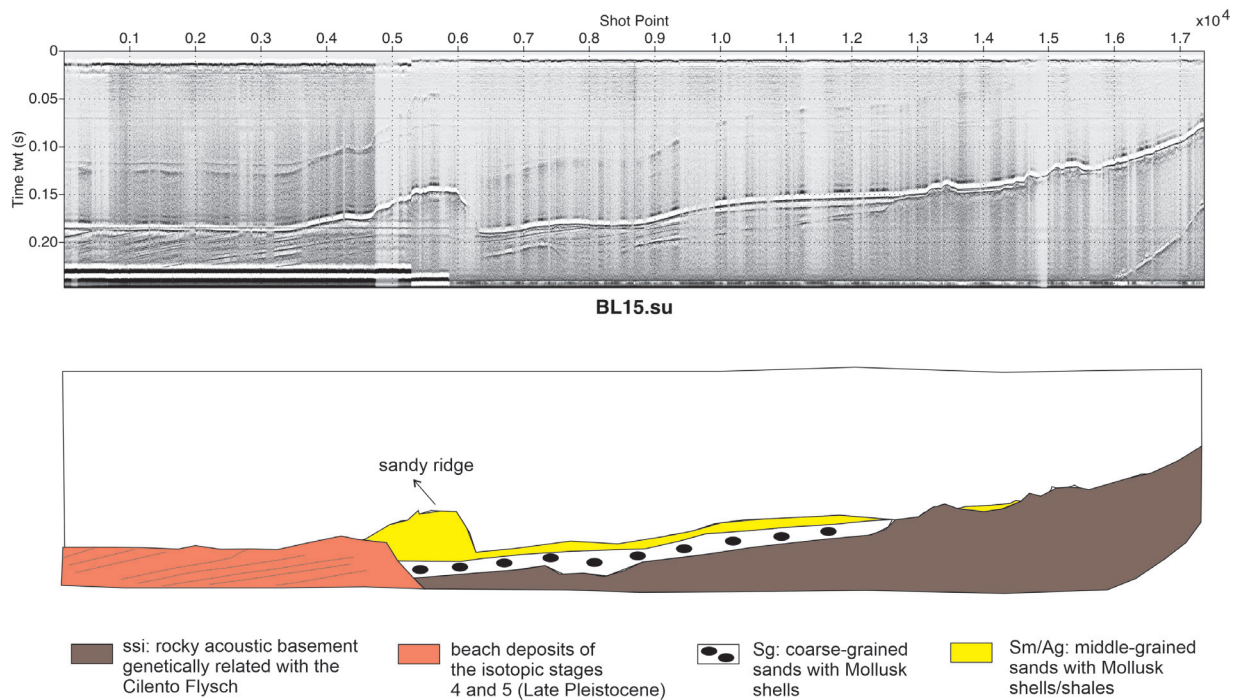


Figure 6: Seismic profile BL15 and corresponding geologic interpretation. The location of the seismic profile is reported in Fig. 3. Key: ssi: rocky acoustic basement genetically related with the Cilento Flysch; beach deposits of the isotopic stages 4 and 5 (Late Pleistocene); Sg: coarse-grained sands with Mollusk shells; Sm/Ag: middle-grained sands with Mollusk shells/shales.

deposited in depressions or channels involving the seismo-stratigraphic unit 3. The fourth seismo-stratigraphic unit (seismo-stratigraphic unit 4) is characterized by parallel to sub-parallel reflectors, from continuous to discontinuous, of high amplitude, probably composed of alternating sands and shales, probably Holocene in age. The reflector D represents a regional unconformity, genetically related to the Wurmian erosional surface. The uppermost seismo-stratigraphic unit is represented by the inner shelf deposits (g_{19}). According to the keys of the geological sheet n. 502 "Agropoli" (Martelli et al., 2016), they are represented by coarse-grained litho-bioclastic sands, with a scarce matrix, interlayered with middle-to-fine-grained litho-bioclastic sands. Seismic profile BL15 has shown the ssi seismo-stratigraphic unit, overlain in onlap by the Sg unit, correlated with coarse-grained sands with Mollusk shells (Fig. 6). There is a main facies change, since the Sg seismo-stratigraphic unit changes into the progradational unit, which

is involved by an erosional truncation at the sea bottom. The Sm/Ag seismo-stratigraphic unit composes a sandy ridge outcropping at the sea bottom. Its thickness is very reduced proceeding landwards. The ridge appears to be formed by basement rocks draped by the Sm/Ag seismo-stratigraphic unit.

Seismic profile BL29 (Fig. 7) displays the Pleistocene relict marine units (PLS). The corresponding seismo-stratigraphic unit is characterized by an acoustically transparent seismic facies and composes a morphological high at the shot point 0.3 (Fig. 7). The PLS unit is overlain by the progradational unit. Westwards of the morphological height, the progradational unit clearly shows prograding clinoforms, while to the east parallel reflectors appear, probably cut perpendicular to the direction of progradation (Fig. 7). A small palaeo-valley, filled by the Highstand System Tract deposits, has also been recognized (Fig. 7).

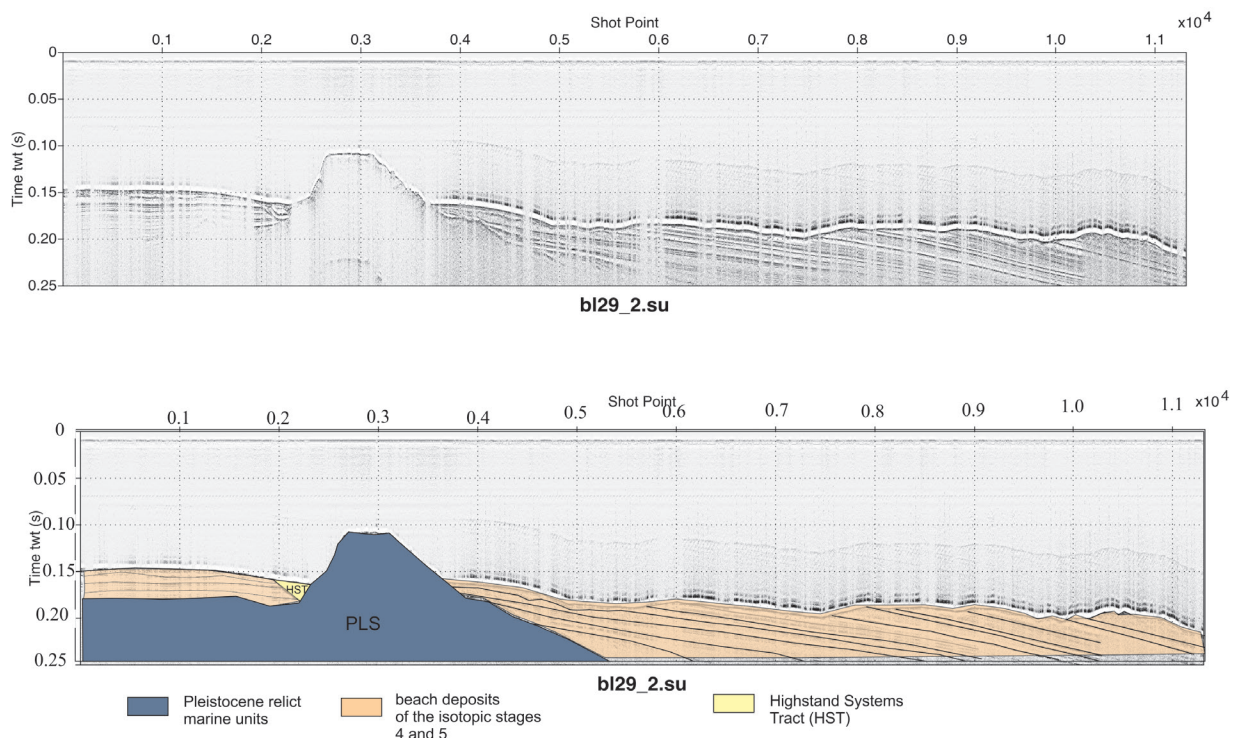


Figure 7: Seismic profile BL29_2 and corresponding geologic interpretation. The location of the seismic profile is reported in Fig. 3. Key. PLS: Pleistocene relict marine units; beach deposits of the isotopic stages 4 and 5; HST: Highstand Systems Tract.

Discussion and conclusions

The geological interpretation of the seismo-stratigraphic units, previously described, is herein provided. The ssi unit represents the rocky acoustic substratum and is genetically related with the Cilento Flysch Formation, widely outcropping in the surrounding coastal belt of the Cilento Promontory. The progradational seismic unit, overlying the ssi unit, is interpreted as the beach deposits of the isotopic stages 4 and 5 (Shackleton et al., 2003; Lisiecki & Raymo, 2005; Rohling et al., 2008; Railsback et al., 2015; Hearty & Tormey, 2017; Shackleton et al., 2021; Thompson & Creveling, 2021; Malmierca-Vallet & Sime, 2023). The Sg unit, overlying the progradational seismic unit has been interpreted as the submerged beach deposits, deposited during the last lowstand phase of the isotopic stage 2. The Sg unit has been calibrated by the core data, previously

published (Ferraro et al., 1997), as composed of coarse-grained organogenic sands, rich in Mollusk shells (*Arctica islandica*, cold host of the Pleistocene). The high-water depths where this unit is located (130-140 m), together with its composition, let us suppose that it represents relict sands. The Sm/Ag unit has been calibrated by core data, previously published (Ferraro et al., 1997), suggesting that the Sm unit is composed of medium-grained sands, with Mollusk shells, while the Ag unit consists of shales. With the aim of discussing the MIS data, it is useful showing the correlation of submerged depositional terraces with Marine Isotope Stages based on the data of Savini et al. (2021; Fig. 8). Based on Savini et al. (2021), the submerged depositional terraces occurring in our studied areas are genetically related to the Marine Isotope Stage 4, but for sure affected also by the sea-level fluctuations of Marine Isotope Stage 2 (Fig. 8). Unfortunately, at the moment absolute datings (radiocarbon, OSL) are not

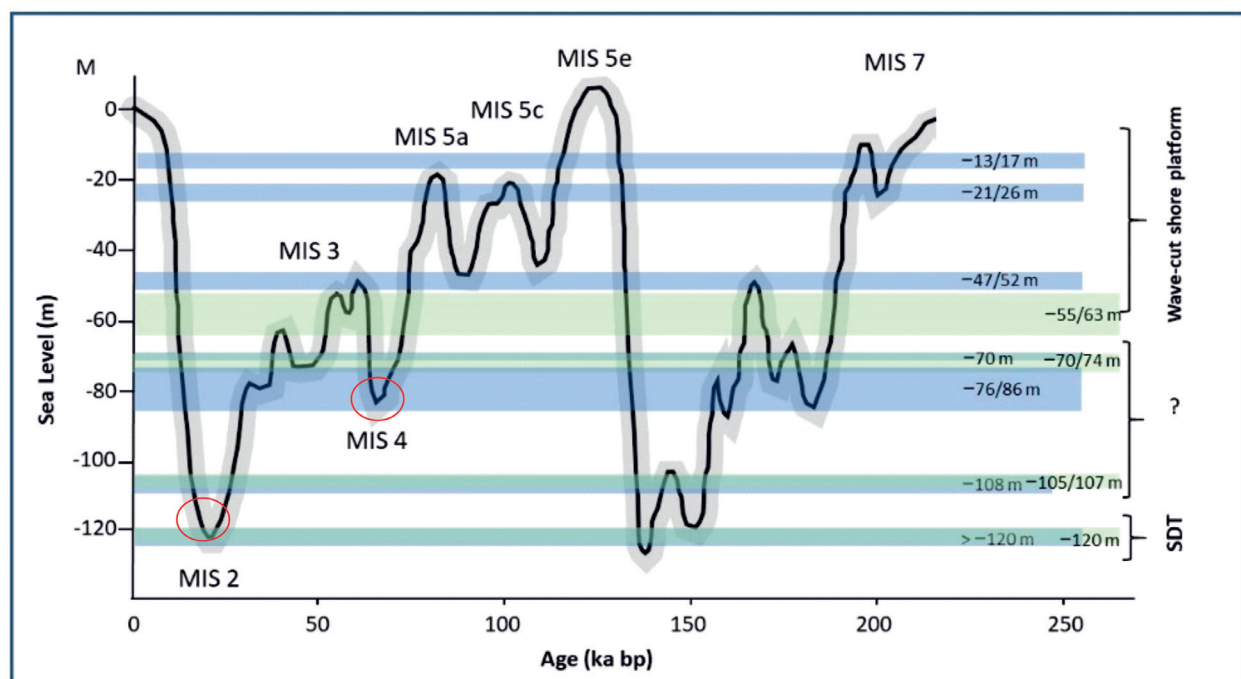


Figure 8: Marine Isotopic Stages (MIS) in the Cilento offshore (modified after Savini et al., 2021). This figure reports a graph of the eustatic sea level fluctuations (expressed in meters) referred to the last 200 ky (calibrated age). Major depth intervals where Submarine Depositional Terraces (SDT) are located have also been reported.

still available to strengthen this interpretation, but these data will be probably acquired in the future in the frame of the CORSUB project (Bazzicalupo et al., 2025).

The sedimentary distribution model (Peres & Picard 1964) has described the biocenosis of the "Détritique Cotier" and the biocenosis of the "Détritique du Large". Between the biocenosis of the mobile sea-bottoms, the most important one is the "Détritique Cotier", which is the most suitable in the study area. The nature of the "Détritique Cotier" is highly variable and depends on the nature of the substratum and of the surrounding circalittoral formations. It consists both of gravels and sands derived from the dominant rocks, and of bioclastic debris mainly composed of Mollusk shells, Bryozoans and calcareous algae. These organisms and the corresponding facies and biocenosis are compatible with the circalittoral zone, extending from the lower limit of the infralittoral down to the maximum depth where multicellular photosynthetic forms can exist; in practice this is about 200 m

and light intensity, at such depths, is very low. Having discussed the characteristics of the Détritique Cotier based on literature data (Peres & Picard 1964), due to its sedimentological composition and bathymetric location, the Sg unit can be correlated with the "Détritique Cotier" and interpreted as relict sands. As previously stated, the relict sands are sedimentary deposits along the continental shelf that are out of equilibrium with the actual sedimentary dynamics. These deposits represent paleo-beaches, whose formation occurred at low sea-level conditions during the last glacial period or during the subsequent rising phase that characterized Holocene.

Some 22 thousand years ago, during the last glacial period, the sea was at about 120 m below the present-day sea level. The resulting global warming induced glacial melting (Ruddiman & McIntyre, 1981; Duplessy et al., 1981; Bard et al., 1987; Ruddiman, 2006), causing a rapid sea-level rise, up to a level comparable to the present-day one,

which was achieved 6 thousand years ago (Chappell & Shackleton, 1986; Fairbanks, 1989; Lambeck & Nakada, 1992; Rohling et al., 1998; Lambeck et al., 2002; Siddall et al., 2003; Blanchon et al., 2009). This led to the establishment of different littoral environments along the continental shelf. Relict sandy deposits along the continental shelf may be buried by pelitic sediments of recent deposition or, alternatively, they crop out at the sea bottom. Even though relict sandy deposits are present on the continental shelf at depths ranging between 30 m and 130 m, the optimal exploitation zone for nourishment purposes is currently restricted between 50 m and 100 m of water depth (Beachmed, 2003). In the Cilento offshore the relict deposits have been identified based on the geological interpretation of Sub-bottom Chirp profiles (Figs. 5-7). The obtained results have been integrated into the geological data, previously obtained by marine geological mapping (Martelli et al., 2016; Aiello & Caccavale, 2021), highlighting the occurrence of the Lowstand System Tract and of the Pleistocene relict marine units. The Lowstand System Tract is composed of coarse-grained organogenic sands, including abundant shell fragments, particularly of Mollusks (*Arctica islandica*), Echinids and Bryozoans.

The coarse-grained organogenic sands grade upwards into medium-grained sands and pelitic covers, having a variable thickness. They form coastal wedges overlying the shelf margin progradations and represent portions of submerged beaches, genetically related to the last sea-level lowstand (Antonioli, 2012; Maselli et al., 2014; Deiana et al., 2021; Mattei et al., 2022; Giaccio et al., 2024).

The Pleistocene marine units, relict or palimpsest, are made up of coarse-grained to fine-grained marine deposits, of well-sorted sands and gravels with bioclastic fragments and of medium-to-fine-grained sands with a pelitic coverage, having a variable thickness, but less than 2 m. They are in the north-western and south-western sectors of the

study area and represent relicts or palimpsests of beach and continental shelf environments. Being located below the beach deposits of the isotopic stages 4 and 5, they stand for the remnants of older beach systems.

The geological evolution of the Cilento continental shelf can be outlined. In the context of a pervasive climatic warming phenomenon, occurring during the Late Pleistocene-Holocene, there was a pronounced elevation of sea levels on a global scale (Vellinga & Leatherman, 1989; Willis et al., 2010; Cazenave & Cozannet, 2014).

The sedimentary processes that controlled the deposition and consequent preservation of these relict deposits, especially concerning sea-level dynamics have been analyzed. Transgressive and highstand deposits have been identified on the continental shelves of all the world (Trincardi & Field, 1992; Cattaneo, Steel, 2003; Bozzano et al., 2006; Martorelli et al., 2010; Ridente, 2018). During this transgressive phase, the accelerated rate of sea level rise, coupled with the gentle gradient of the Cilento continental shelf, resulted in the nearly synchronous flooding of wide areas of continental shelf, as well as in a significant landward shifting of the coastal and marine facies. Consequently, the geological interpretation derived from the Sub-bottom Chirp profiles did not allow the identification of retrogradational seismo-stratigraphic units, which have constructed beach systems that were deposited during the transgressive period. Conversely, highstand and lowstand deposits have been thoroughly documented based on seismo-stratigraphic analyses.

Despite the cyclical oscillations, the sea continues to descend from the end of isotopic stage 5a (Oppo et al., 2001; Railsback et al., 2015; Fig. 8) until it reached isotopic stage 2, where it was situated in the Mediterranean Sea at a depth of roughly 120 meters. This situation stands for a forced regression.

The progradational wedges of the Cilento offshore were deposited during this forced regression, enabling a platform widening of

several kilometers. The coastline's seaward migration in response to the relative drop in sea-level controls the forced regression. This type of regression happens when the sea level drops because the coastline must regress because of the base level dropping, without accounting for the sediment supply (Hunt and Tucker, 1992; Posamentier et al., 1992; Posamentier and Morris, 2000; Trincardi and Correggiari, 2000; Ridente and Trincardi, 2005). In a shoreface setting, progradational deposits are deposited alongside the fluvial incision during the forced regression.

It can be concluded that the sea level dynamics was an important factor in controlling the deposition and the preservation of the relict deposits of the Cilento continental shelf. Sand prospecting in microtidal beaches focuses on relict deposits generated on the shelf when sea levels were lower than they are now. During the last post-glacial sea-level rise the coastal and marine facies underwent a landwards shifting. As the sea bottoms continued to deepen, they leave behind a variety of sedimentary deposits. The deposited materials display substantial lithologic, geometric and sedimentological differences, highlighting the complex relationships between erosional and depositional transgressive processes on the continental shelf that have been controlled by both tectonic uplift and sea level fluctuations. (Swift et al., 1971; Hunt & Tucker, 1992; Posamentier et al., 1992; Posamentier & Morris, 2000; Trincardi & Correggiari, 2000; Cattaneo & Steel, 2003; Ridente & Trincardi, 2005). The paleo-morphology of the continental shelf and the presence of morphological stages at its surface may be connected to the frequent preservation of shelf downlapping deposits (Trincardi and Field, 1991; Cattaneo & Steel, 2003). This preservation of marine deposits has been found also in the study area.

The limitations found based on the techniques and methodological approach used in this research mainly consist in the lacking of a systematic grid of cores in the Cilento

offshore. In fact, we can only refer to the cores available in literature (Ferraro et al., 1997), but a few shallow cores have been recently collected during the TREMOR oceanographic cruise for the realization of the PRIN 2022 CORSUB project (Bazzicalupo et al., 2025). In the framework of the PRIN 2022 CORSUB, it is possible that absolute dates (radiocarbon, ^{14}C of shell fragments and rhodoliths) of the available samples will be realized, so integrating the geological analysis of the relict deposits of the Cilento continental shelf. Future perspectives for advancing knowledge of the relict deposits of the offshore Cilento coast will include the realization of a denser grid of high-resolution Sub-bottom profiles and detailed bathymetric maps using the R/V Gaia Blu of the National Research Council of Italy, equipped with three Multibeam systems (MBES), allowing for a detailed recognition of the morpho-structures genetically related to the relict deposits.

Author contributions

Conceptualization: G.A., M.C.

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