The Coastal Depositional Systems along the Campania Continental Margin (Italy, Southern Tyrrhenian Sea) since the Late Pleistocene: New Information Gathered in the frame of the CARG Project

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Abstract

Extensive high-resolution mapping of the continental margin off the southern Campania region (eastern Tyrrhenian Sea) has revealed significant morphological and geological features which allowed us to outline the gradual modification of the of the coastal domains since the late Pleistocene. Swath bathymetry, acoustic images of the seafloor, seismic acquisition, core and bottom samples were used to implement a large database. Shore bodies ranging in age from pre- to post- last-glacial times have been identified in the uppermost 100 ms of the seismic stratigraphic record off the Sele and Bussento river mouths. The oldest bodies formed during the seaward retreat of the shoreline of the Late Pleistocene sea level drop. The peak of the retreat accounts for the growth of a shelf-margin, in the Salerno and Policastro Bays, and a mid-shelf, off Cilento, littoral body, at least 100 km long, during the last maximum lowstand phase. At that time, the River Sele flowed directly on the upper slope and formed a channelized drainage system, still preserved between a depth of 180 and 500 m, due to density flows that have transferred sediment from the coastal area directly into the Salerno Valley, an intraslope basin of the eastern Tyrrhenian margin. The postglacial sea level rise caused the fast drowning of the shelf and a partial preservation of the transgressive deposits. However a prograding wedge 1.5 km long and about 10 ms thick, which lies above the transgressive surface (90/60 m below the present day sea level), could represent a trace of the Younger Dryas climatic event. The rapid shore progradation during the $\sim$12 ky B.P. cold event testifies the sensitivity of the Sele coastal system even to minor climatic oscillations.

1 Introduction

The geological mapping Project of the Campania offshore (CARG project) allowed us to gather new geological (Chirp sonar Subbottom and Uniboom profiles, gravity cores and grabs) and morphological (Swath-bathymetric soundings and Sidescan Sonar images of seafloor) information, valuable to create maps of the seafloor at scales of 1:10000 and 1:25000, down to the 200 m isobath. The project was commissioned to the IAMC- CNR by the Regione

Campania (Settore Geotecnica, Geotermia e Difesa Suolo) about 8 years ago, to be realized according to the steering lines of the Italian Geological Survey, now ISPRA, Institute for Environmental Protection and Research. Mapping criteria focussed mainly on the physiographic features of the shelf/slope sector, the lithology and textures of sediment at the seafloor, the stratigraphic stacking pattern within the Late Quaternary depositional sequence (SDTQ). This project has been a valuable opportunity to investigate the morphology and stratigraphy and to map the southern Campania offshore thoroughly, implementing the high resolution geological and morphological data set of the CNR-IAMC. This report summarizes the main outcome of the surveys

2 Geological setting

The surveyed marine area is about 1500 km^2 and falls within four sheets of the National Geological Map of Italy (n. 486 Foce del Sele, n. 502 Agropoli, n. 519 Palinuro, n. 520 Sapri, Figure 1). It pertains to the Tyrrhenian side of the Southern Apennine range, which has been forming since the Late Pliocene- Early Pleistocene, along with the opening of the Marsili basin, within the Tyrrhenian Sea backarc basin (Marani et al., 2004). The Tyrrhenian border of the chain achieved most of its actual configuration by the Early Pleistocene, when SW-NE oriented alternating structural depressions and highs began to delineate. A set of low angled, south-east verging faults, and associated minor faults, led to the extensional deformation of the Meso-Cenozoic carbonate basement and the Miocene nappes and the formation of asymmetrical half-grabens [1, 11]. Throughout the Mid- and Late Pleistocene the extensional regime produced high-angle NW-SE oriented normal faults and trans-tensional faults that enhanced the vertical displacement of the margin of the chain with respect of the axial portion ([12] and references therein; [11]. A thick syntectonic Pleistocene sedimentary succession made of continental, volcanoclastic and marine deposits filled the structural depressions [3, 8]. The Piana del Sele- Golfo di Salerno half-graben, in particular, is a ENE-WSW oriented structural depression, which displays up to 2400 ms of post-orogenic sediment infill [3] and about 1000 m of Pleistocene sediment documented by offshore well stratigraphy. Seismic reflectors' geometries show evidence, locally, of transpressive deformation and tectonic inversion due to the effect of strike-slip faulting [22]. The deepest portion of the gulf, the Salerno Valley, sits at the foot of the Sorrento-Amalfi Peninsula and exceeds a depth of 1000 m to the south of Capri Island. The shelf areas of the Salerno Gulf contain the seaward front of the Sele, Tusciano, Picentino and Solofrone rivers' alluvial plains which prograded seaward by about 15 km starting from the MIS 5a and following the general retreat of the sea level during the Late Pleistocene [10, 21], (Figure 2). The offshore area included in the Agropoli and Palinuro sheets is the result of the Pleistocene evolution of the Cilento margin. The shallow position of the acoustic basement, and therefore the scarce accommodation space for sediment deposition [17], accounts for the formation of seaward prograding wedges, bounded by marine and subaerial erosive unconformities [25]. The basement consists of siliciclastic sequences pertaining to the internal "Liguride" and "Gruppo del Cilento" units and outcrops mainly along the Cilento

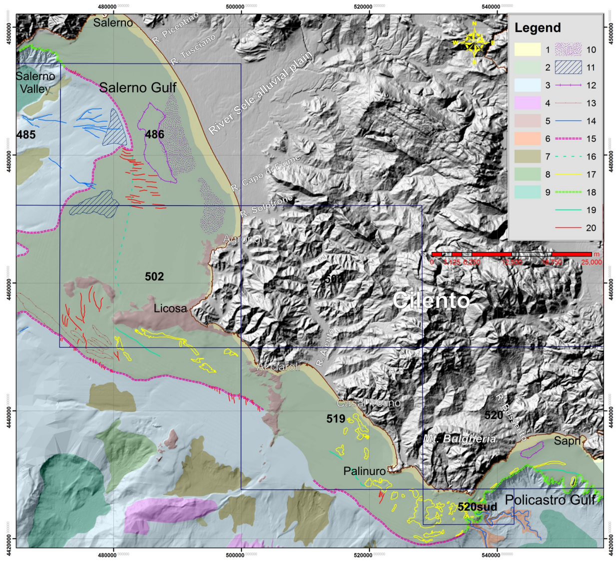

Figure 1: The continental margin off southern Campania region, between Salerno and Sapri, extensively surveyed by IAMC –CNR since the 2003, to accomplish the CARG project aims. Submarine topography is by swath bathymetry. 1) submerged beach; 2) continental shelf; 3) upper continental slope; 4) intraslope relief; 5) acoustic basement; 6) Infreschi fan system; 7) slope failure; 8) dismantling slope areas ; 9) intraslope basin; 10) gas charged sediment; 11) sediment waves field; 12) water escape features and plastic deformation of subbottom reflectors; 13) outer shelf marine erosional surface; 14) paleo-drainage system; 15) physiographic shelf margin; 16) buried lowstand deposits; 17) relic features; 18) withdrawing slope; 19) last glacial sea level terrace; 20) furrows.

coast [6, 7] and across the shelf [22]. The basement outcrops off Mt. Bulgheria coast (Palinuro and Sapri sheets) consist of carbonate rocks Upper Triassic to Lower Miocene in age, that on land are unconformably covered by Lower Miocene siliciclastic deposits (Caiazzo et al., 2006 and literature therein). This succession forms a N-verging fold thrust over the internal Liguride nappe [23], cut by a very complex pattern of faults. A major NE– SW trending fault borders Mt. Bulgheria towards the Gulf of Policastro graben, where the Meso-Cenozoic basement is lowered to about 3000 m below the sea level [5]. The shelf area (about 1200 km^2) between Salerno and Sapri underwent drowning, following the Holocene transgression [10, 9, 21, 20].

3 The shelf

The continental shelf widens roughly following the coastline, except off the Licosa and Palinuro promontories (Cilento coast), where it enlarges by more than 23 km seaward (Figure 1). Off the Sele and Bussento alluvial plains loose and smooth seabed

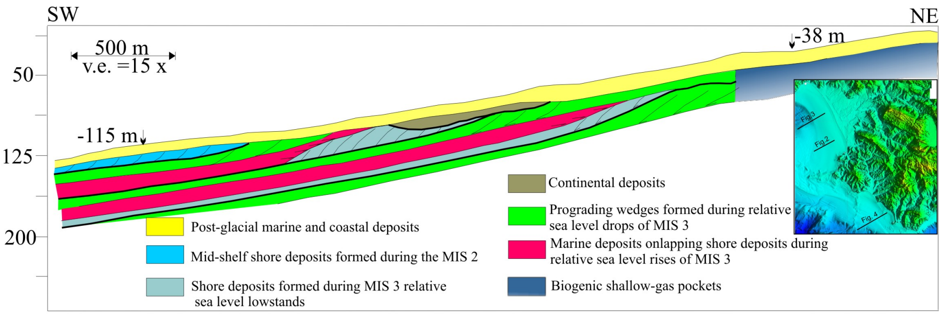

Figure 2: Schematic line drawing of Uniboom line off the River Sele, showing the regressive trend of shore deposits during Late Pleistocene sea level fall (modified after [10]).

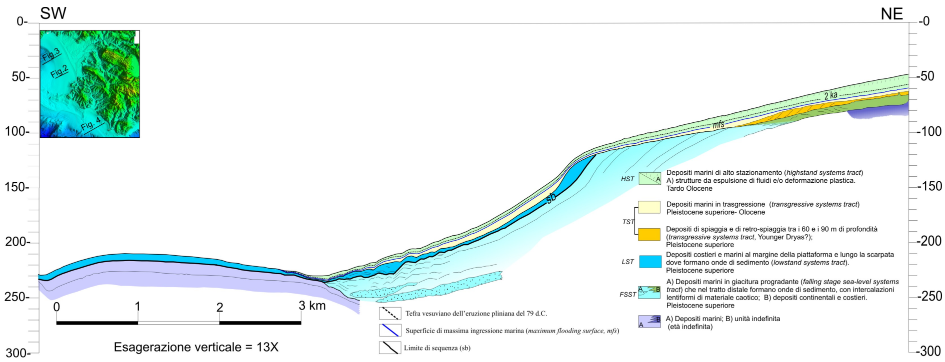

Figure 3: Subbottom chirp line across the Salerno Bay shelf and slope (from [21], modified).

prevails, whereas off the Cilento coast, the rocky substratum largely controls the morphological features and the seafloor lithology. Two rocky ridges crop out off Licosa Cape and Acciaroli, respectively E-W and N-S oriented (Figure 1). Several orders of terraces shape the seabed at various depth intervals: 160/140 m, 44/46 m, 18/24 m, 12/14 and 7/8 m [15, 2, 17]. The last three surfaces have been largely reported by scuba dive surveys and have been tentatively related to Tyrrhenian sea-level stages [2]. The shore belt is affected by both erosive and depositional processes, due to wave action and alongshore currents and is generally characterized by the occurrence of well sorted sand deposits. They extend down to a water depth of 10-12 m and include the outermost sand bars. Three different types of submerged beach can be distinguished along the Sele shore, based on the topographic profile: shoal bar, bar-trough (one or two) and mixed types with cells less than 100 m wide [13]. The Alento submerged shore develops in the form of a bar-trough system and the

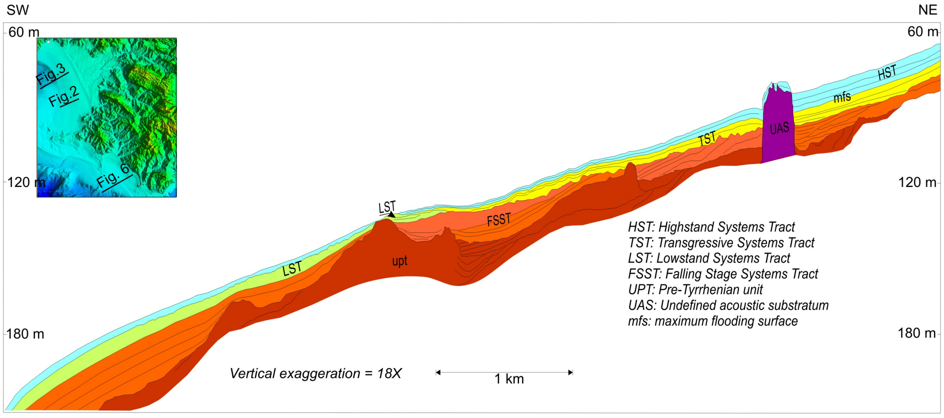

Figure 4: Subbottom chirp line across the Cilento shelf and slope.

Marina di Ascea shore in that of a shoal bar [14]. These features are controlled by the coastal morpho-dynamics and therefore may change rapidly. Sediment consists of coarse to medium, well sorted sand down to 3 m and, medium to fine, well-sorted fine sand down to10-12 m. The pelitic fraction is less than 20 Fine grained, poorly sorted deposits occur between the outer limit of the submerged shore and water depth of 40-50 m and form the inner shelf depositional system where sandy pelite lithofacies prevails. The pelite fraction increases beneath the *Cymodocea nodosa* meadows which trap the loose sediment at the seabed alternating with *Caulerpa racemosa*, recently introduced in the Tyrrhenian Sea [18].*Posidonia oceanica* meadows occur down to 25 m in sectors where terrigenous supply is scarce. The seismic acoustic profiles off the main river mouths show beneath the seabed a shallow unit with fluid escape and plastic deformation features (Figure 3). This unit is bounded at the base by a regular and conformable reflector lying halfway between the 79 A.D. Vesuvius tephra and the present-day seabed, between 40 and 70 m bsl (Figure 3). The unit, which lies seaward of shallow biogenic gas pockets can be associated to the estuarine depositional environment and might mark the boundary between the silty and the muddy prodelta system. The outer shelf environment ranges between 40-50 m bsl and the shelf break. Fine grained textures prevail, however a variable but valuable fraction of fine sand, mostly pumices, scoria and bioclasts, is common at the seabed where sediment waves and terraced areas occur (Figures 1 and 2). Conversely, in the same depth range off the Cilento Promontory authigenic bioclastic coarse sand and gravel lies eteropically to siliciclastic deposit. Shell fragments, bioclasts and rhodholits form the coarse fraction that largely tapers the rocky seabed and the terraced surfaces. The bioclastic and organogenic coarse sand and fine gravel (maerl facies) pertain to the "coastal detritus assemblage" Auct., and form decimetre thick patches at a water depth between 25 and 70 m; this lithofacies changes seaward into mud supported organogenic gravel and bioclastic sand typical of the "muddy coastal detrital assemblage" and may occur down to a depth of 90 m. Organogenic mounds, made of fouling organisms, encrust the travertine outcrops in the Salerno Bay and build up pinnacles on the rocky seabed off Acciaroli and Palinuro offshore. The outermost sector of the shelf, south of the River Sele to the Acciaroli Cape, corresponds to a morpho-structural high that lacks a modern terrigenous supply from the mainland. High resolution seismic sections show that the most shallow units pertain to the distal marine segment of the wedge which prograded seaward during the Late Pleistocene sea level fall and lowstand phases. They lie conformably on marine units possibly Middle Pleistocene in age (Figure 3). A set of furrows scratched into the seabed parallel to the isobaths could be due to present day seabed currents which border the shelf margin. Pleistocene relic morphologies outcrop at the seabed along the Cilento shelf (Figures 1 and 4) and consist of large irregular relieves in the first 80 m of depth or regular ridges sub-parallel to the isobaths and overlying the prograding reflectors of the outer shelf (Figure 1). Sediment texture consists of well sorted, coarse to medium sand and contains *Arctica islandica*shells and typical corals. These morphologies have been interpreted as relic ridges and bars formed during the maximum glacial lowstand [15, 25, 17]. The most evident morphological element of the Campania margin is the physiographic edge of the shelf, which occurs between 100 m and 230 m bsl; beyond it, lies the slope sector with a gradient of more than 1.5°. The varying extension, the different depth and gradient of the shelf could be accounted for by the stacking pattern of the systems tract pertaining to the Middle - Late Pleistocene depositional sequences, which allowed this sector of the Campania margin to expand. Indeed Sparker seismic profiles in the Cilento offshore show a deep stratigraphic unconformity below the Tyrrhenian marine unit, which develops down to a depth of 180 m and is largely affected by sub-vertical faulting [17], therefore possibly pertaining to the Middle Pleistocene lowstand phase.

4 The slope environment

Slope morphologies, with gradients of between 1.3° and 6° are quite uneven and include large erosive sectors shaped by slides or deeply engraved by gullies and canyon heads, alternating to slope relieves bordered by structural lineaments (Figure 1). Retreating slope sectors are evident off Salerno and Sapri towns, where erosive processes produced a dense net of downstream gullies with herringbone patterns and the shelf retreat (Figure 5). The slope sector which forms the southern boundary of the Salerno Valley is shaped by several slide headscarps, whose deposits reached great distances due to the high gradient of the slope. Off the Cilento coast, slide scars are confined to the upper slope and relative deposits accumulated into the elongated depocentres which are bounded seaward by slope relieves [24, 4]. Seaward of the 180 m isobath (where the HST wedge thins out) a paleo-channel system, possibly engraved by the outflows of the Sele, Solofrone/Capo di Fiume and Alento rivers, is still preserved. Indeed, during the lowstand stage of sea level these rivers flowed directly at the shelf edge forming small shelf-margin deltas and sediment underflows were transferred along the upper slope down to the Salerno Valley and Cilento offshore intraslope basin (Figures 1

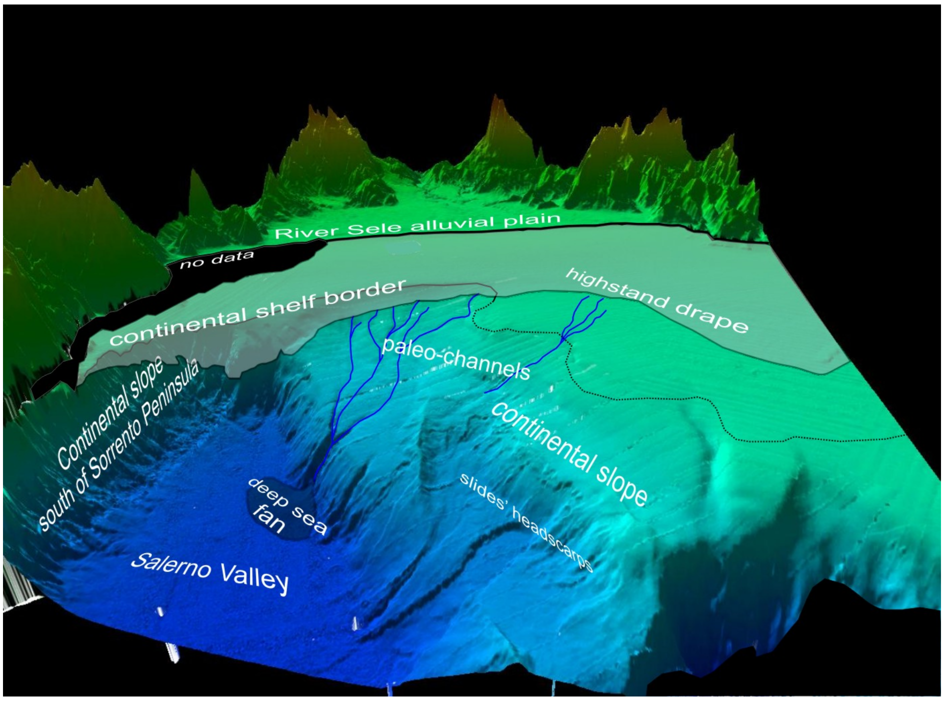

Figure 5: Relic channel system at the paleo-mouth of the Rivers Sele and Solofrone/Capo di Fiume, carved during the last lowstand phase of sea level.

and 5). A wavy unit developed at the bend of the upper slope in the Salerno Gulf (Figures 1 and 3). The geometries of the wavy reflectors and the location of the unit point to sediment drift structures and thus possibly to depositional processes related to bottom current dynamics [26]. It has been observed that the stratigraphic discontinuity within this unit may cause sediment failures along weak layers. A slope canyon-fan system with meandering thalwegs, levees, overflowing channels and fan lobes has been developing on the southern slope of Monte Bulgheria (Figure 1), possibly being fed by coastal sediment drift alongshore (Budillon et al., in press).

5 Depositional environments within the SDTQ

Several key elements for a sequence stratigraphic rendering were recognized and mapped within the SDTQ, from the coastline down to the water depth of 250 m, based on submarine morphology interpretation, sediment core stratigraphy, high resolution seismic records and bottom samples analysis. In particular, still-forming and completely-formed units were distinguished, according to analogous inland mapping criteria and steering lines of ISPRA. The first corresponds to the highstand systems tract (hst), which has been developing since 5-6 kyr BP, while the

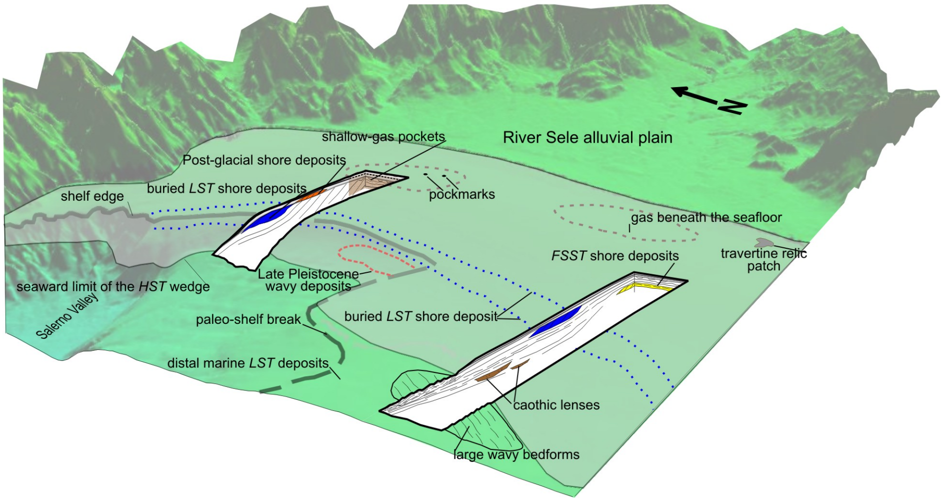

Figure 6: Schematic block diagram of the main stacking pattern and morphologies in the Salerno Bay (from Ispra, 2009, modified).

second represents the transgressive, lowstand and falling-stage systems tracts [19], stacked following the Late Pleistocene – Holocene sea level variations. Specifically, three still-forming depositional environments (beach, shelf and upper slope), two completely-formed depositional environments (relic shelf and relic slope) and one completely-formed unit, continental in origin, (a relic tabular plate of travertine, correlated with the inland outcrop of *Travertini di Paestum*) have been mapped. The most represented unit within the SDTQ is the highstand systems tract. It includes, landwards, the present day coastal system and consists typically of a tapering seaward wedge. The maximum thickness are shown on the inner shelf off the river mouths (Figure 4). In the Salerno Bay the HST depocentre is located off River Sele at a depth of 40 m, where it exceeds 10 m of depth and rapidly thins out seaward to less than 1 m of thickness about 20 km off the coast (Figure 6). It therefore goes beyond the shelfbreak in the northern sector, but it tapers in the southern part of the bay at about 160 m, on the relic outer shelf off Licosa Cape, due to the low sediment supply. Pre- and post-glacial shore units, featuring prograding geometries with offlap terminations, were identified off the Sele and Bussento river mouths. The oldest ones (Figure 2), lying below the maximum glacial unconformity, formed as a consequence of the seaward retreat of the shoreline during the last stages of the Late Pleistocene sea level drop and therefore show a regressive trend [10]. The regression of the shore system culminated, as largely reported at a global scale, during the 20-18 ky lowstand stage, which accounts for the prograding units commonly stacking at the shelf margin. Nevertheless the depositional terrace linked to the last glacial maximum is not always evident, since shore deposits relative to this phase are preserved in morphological steps (green dashed line, Figure 1), as already observed by Trincardi and Field [25]. Thus a mid-shelf prograding wedge marks the lowstand of the last glacial maximum off the Agropoli, Licosa and Acciaroli coasts. On the whole, relic deposits and coastal morphologies related to the last glacial maximum form a discontinuous belt, some time cropping out, some time draped by Holocene sediments, that can be followed for more than 100 km along the southern Campania margin (Figure 1). The post-glacial sea level rise resulted in a rapid drowning of the shelf, with a limited preservation of the transgressive units. Transgressive lithosomes are scarcely represented and rarely resolvable due to their thickness. However, a shore system, 1.5 km wide and 5-10 m thick (Figures 3 and 6), which lies above the transgressive surface, 90/60 m below the sea level, could be the remains of the Younger Dryas climatic event [16]. These bodies consist of a continuous set of prograding reflectors, with offlap and downlap lateral terminations, overlain by onlapping subhorizontal reflectors, topped in turn by the maximum flooding surface. Other lithosomes relative to the transgressive systems tract occur seaward to the shelf break and represent the healing phase of postglacial transgression [19]; besides they occur in morphological steps on the shelf between the transgressive and the ravinement surfaces, showing acoustic facies typical of transitional shore deposits.

6 Conclusions

The CARG Project allowed the acquisition of regularly spaced, high resolution data set valuable for geological, morphological and cartographic purposes. The large amount of data led to the redaction of four geological sheets in the Southern Campania marine area down to the upper slope environment, yet published (Ispra, 2009) or in press. In particular, within the Late Pleistocene Depositional Sequence, still-forming units and completely-formed units were distinguished. The first corresponds to the highstand wedge (hst), which has been developing since 5-6 kyr BP, while the second represents the transgressive, lowstand and falling-stage systems tracts, stacked following the Late Pleistocene – Holocene sea level variations. Pre- and post-glacial shore units, featuring prograding geometries with offlap terminations, were identified off the Sele and Bussento river mouths. The one lying above the transgressive surface, 90/60 m below the sea level, could be the effect of the Younger Dryas climatic event. A net of paleochannels along the upper slope indicate the position of Sele, Solofrone/Capo di Fiume and Alento river mouths during the glacial maximum retreat of the sea level and testify the density flows passage down to the intraslope basins (Figures 1 and 5). Nevertheless, although the main target has been achieved by mapping the seabed features, a large number of further scientific questions remain, to be addressed at a later date.

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