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Chapter

THE STRATIGRAPHIC SETTING OF CONTINENTAL SHELVES OF SOUTHERN ITALY INVESTIGATED THROUGH SEISMIC STRATIGRAPHY: TECHNIQUES, METHODOLOGIES AND CASE STUDIES FROM CAMPANIA AND BASILICATA OFFSHORE (SOUTHERN TYRRHENIAN SEA)

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ABSTRACT

The stratigraphic setting of continental shelves of Southern Italy is here studied and discussed through seismo-stratigraphic techniques and methodologies, focussing on case histories located in Campania and Basilicata offshore (Southern Tyrrhenian sea, Italy). Seismo-stratigraphic techniques and methodologies are examined, referring, in particular, to the Naples, Agropoli and Maratea areas (Campania and Basilicata regions).

In the Campania offshore the stratigraphic architecture of the volcaniclastic basins of the Volturno Basin, Ischia offshore and Naples Bay is shown in detail and interpreted through the concepts of seismic stratigraphy. Regional geological concepts have also been utilized for a better land-sea interpretation of the seismic units filling the observed sedimentary basins.

A correlation with land geology of Southern Apennines has been attempted to obtain a better geological comprehension of the interpreted structures.

In the Volturno Basin (northern Campania) the trending of the seismic units is controlled by the Massico structural high, bounding the basin towards the north-west and controlling depositional geometries typical of a NE-SW striking fan complex. Deep litho-stratigraphic well data tied to the seismic lines have highlighted the pyroclastic layers and

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the conglomeratic strata of the lagoon and delta environments, evolving upwards towards marine sediments. Complex strata patterns have been revealed by seismic data in the Quaternary basin filling, overlying the Meso-Cenozoic carbonatic basement and the related flysch deposits.

Seismo-stratigraphic evidence on buried volcanic structures and overlying Quaternary marine deposits are here presented to reconstruct the stratigraphic setting of the south-eastern continental shelf of the Ischia island (Naples Bay) and to draw attention to new implications on the marine geophysics and volcanology of the volcanic complex. In the eastern Ischia offshore relic volcanic edifices, representing the remnants of hydromagmatic volcanic vents, mostly formed by hialoclastites and indicating an emplacement in a subaqueous environment have been investigated through high resolution seismics.

The stratigraphic architecture of the Capri Basin and the Salerno Valley, tectonically-controlled and located southwards of the Capri-Sorrento master fault, strongly down throwing the Meso-Cenozoic carbonates cropping out in the Sorrento Peninsula has been studied in detail. The Capri Basin is a deep basin located southwards of the Naples Bay, filled by Pleistocenic-Holocenic sediments overlying Meso-Cenozoic carbonates. The Salerno Valley is a half-graben filled by three seismic units corresponding to Quaternary marine deposits, overlying Miocene siliciclastic chaotic sequences.

The stratigraphic setting of the Quaternary marine successions of the Agropoli continental shelf, located offshore the Punta Licosa morpho-structural high, characterized by wide outcrops of rocky acoustic substratum and resulting from the seaward prolongation of the structural-stratigraphic units cropping out onshore in the adjacent emerged sector of the Cilento Promontory has been studied.

In conclusion, the example of the continental shelf and slope off the Maratea Valley has been investigated. The relationships between the geological and structural settings on land and the seismic stratigraphy in the surrounding offshore have been examined. The geological framework of the Maratea Valley is connected with the late Pleistocene and Holocene geologic evolution on the shelf and slope, mainly in terms of late Quaternary sea level glacio-eustatic fluctuations.

1. INTRODUCTION

Seismic stratigraphy of selected sedimentary basins located offshore the continental shelf of Southern Italy in the Campania and Basilicata regions (Volturno Basin, south-eastern Ischia island, Naples Bay, Capri Basin, Salerno Valley, Agropoli shelf and Maratea Valley) is here discussed. Detailed and up-to-date geological setting of these areas is presented to give a better geological framework of the presented data in the regional setting of the Eastern Tyrrhenian margin.

Seismo-stratigraphic techniques and methodologies are discussed, focussing, in particular, on some volcanic areas, i.e. the Volturno Basin [Aiello et al. 2011a], the Ischia island [Aiello et al. 2011b] and the Naples Bay [D’Argenio et al. 2004; Aiello et al. 2004b; 2005; 2011c; 2011d], where the Quaternary volcanic activity prevented the application of classical stratigraphic concepts, due to the occurrence of sedimentary sequences and interlayered volcanic bodies (volcanites and volcaniclastites).

On the other side, some pure sedimentary areas, i.e. the Capri Basin [Aiello et al. 2011b], the Salerno Valley [Aiello et al. 2009a], the Agropoli continental shelf and the Maratea Valley [Aiello et al. 2010a] will be discussed.

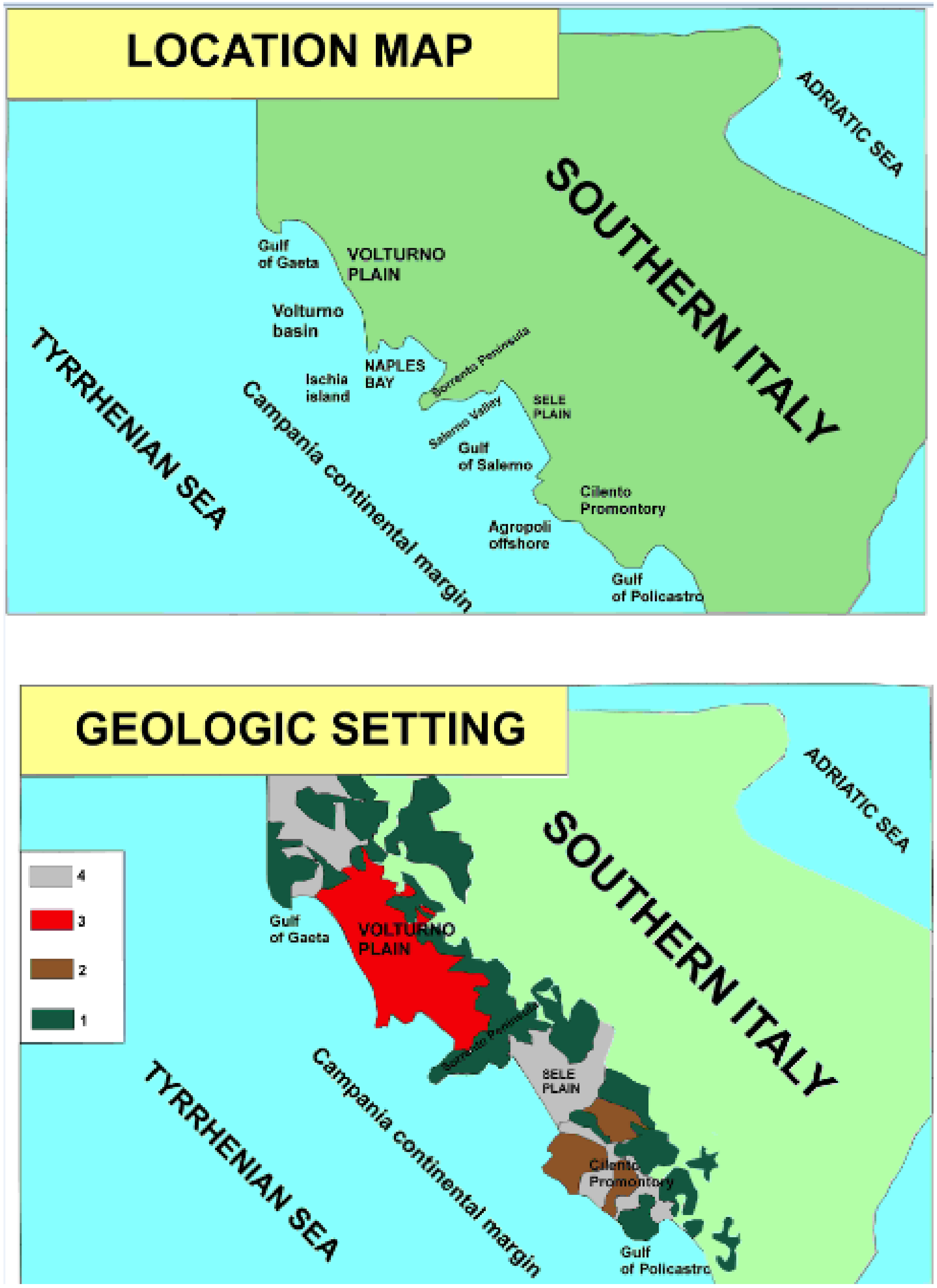


Figure 1. Sketch map showing the location of the study sedimentary basins and the geological setting (in the lower part of the figure) of the Campania Region (Southern Italy). 1: Meso-Cenozoic carbonates. 2: Siliciclastic flysch deposits. 3: Quaternary volcanic deposits. 4: Quaternary alluvial, coastal and marine deposits.

In these sedimentary basins a strong interaction between sedimentation and tectonics controlled high sedimentary rates and the deposition of thick seismic sequences, well detectable through high resolution seismic datasets utilized in the geological interpretation. Regional geological concepts will also been used for a better land-sea geological interpretation of the seismic units filling the sedimentary basins in the study areas. A correlation with onshore geology of Southern Apennines [D'Argenio et al. 1973; Bigi et al. 1992] will be carried out in order to obtain a better geological understanding of the interpreted structures.

A sketch map reporting the location of the study area has been constructed (Figure 1). On this map the main sedimentary basins study in this chapter have been reported for a better comprehension of their localization.

2. SEISMO-STRATIGRAPHIC TECHNIQUES AND METODOLOGIES

The methodologies and criteria followed in the geological and geophysical data interpretation derive from the type of data utilized in marine geology (reflection seismics) and by the methods of seismic interpretation (high resolution sequence stratigraphy). In particular, this chapter includes different types of geophysical datasets, highly varying both in resolution and in penetration. In the case histories of Volturno basin, Capri basin and Salerno Valley, deep multichannel seismic lines have been interpreted, where the stratigraphic relationships between the deep seismic units of the acoustic basement and the Quaternary seismic sequences filling the sedimentary basins are observed (Volturno basin, Capri basin, Salerno Valley). In the case histories of the Ischia island and of the Maratea Valley single-channel Sparker seismic lines and multichannel Watergun seismic profiles have been respectively analyzed, allowing for a detailed investigation of the Quaternary seismic stratigraphy at an intermediate scale. Finally, in the case history of the Agropoli offshore, high resolution Subbottom Chirp profiles have been interpreted in detail, allowing for a detailed geological reconstruction of subsurface stratigraphy of the first ten of meters under the sea bottom.

The geological structures of the subsurface and the related sedimentary seismic sequences, in lateral contact with wide outcrops of rocky acoustic basement at the sea bottom have been interpreted in detail. This has allowed to analyze the stratigraphic architecture of the Quaternary marine deposits, which are particularly well developed in the depocentral areas included between the Solofrone river mouth and the Agropoli town (Figure 1), while are practically lacking or scarcely developed in correspondence to the Punta Licosa structural high. Particular attention has been paid to the study of the stratigraphic relationships between the Quaternary marine deposits and the rocky acoustic basement, resulting from the seaward prolongation of the structural-stratigraphic units cropping out onshore in the northern Cilento Promontory ("Flysch del Cilento" *Auct.*) [Ciampo et al. 1984] [Bonardi et al. 1988].

The rapid evolution of the research in the field of the Earth Sciences and the importance played by the geological mapping in the management of the territory and of corresponding coastal areas have underlined the necessity of a new geological survey of Southern Italy for the realization of an up-to-date geological cartography, having a high information content, particularly referring to the marine areas (CARG Project); [Catalano et al. 1996]; [Fabbri et al. 2002]. Apart from to define the dynamics of the recent and actual sedimentation, the knowledge acquired with the CARG research project represents an instrument of management and planning of the territory. It is a valid support for a sustainable use and the protection of the coastal zone and continental shelf.

In this framework, the Institute of Marine and Coastal Environmental Area (IAMC) of Naples, National Research Council of Italy (CNR) has carried out many oceanographic cruises, which have contributed to the geological survey of a high number of geophysical data and sea bottom samples.

The techniques and criteria for the realization of marine geological maps get inspiration from some general principles including a homogeneous approach between different areas to obtain comparable cartographic products, synthetic and sketch representations also in areas where the internal geometry or the areal trending of mapped targets appear complex in detail and to put enough emphasis on the stratigraphic relationships which characterize depositional bodies having a different age.

The methodological criteria based on which the geological maps are constructed derive from an integration of the sequence stratigraphy interpretation of very high resolution seismics (VHRS); the facies analysis on core data related to the first meters of sediments; the biostratigraphic and geochemical analysis and the absolute dating of marker levels and stratigraphic units included between them; the detailed reconstruction of the bathymetry and morphology of the sea bottom, with particular attention to the areas characterized by a strong erosional-depositional dynamics, as the sea bottoms characterized by large-scale sea bottom morphologies on the continental shelf (active, palinsest or relic) or on the slope and basin, by mass transport deposits having a wide extension, mainly in prodelta and slope zones and by canyons or other minor erosional structures on the continental slope [Fabbri et al. 2002].

The seismo-stratigraphic analysis has allowed to distinguish the main seismic units, separated by regional unconformities, tectonically and/or eustatically controlled. The geologic interpretation of the seismic sections has been carried out based on both geomorphologic and seismo-stratigraphic criteria. In the Punta Licosa offshore the acoustic basement is characterized by outcrops having a wide extension and corresponds with the Cenozoic substratum, genetically related to the “Flysch del Cilento” *Auct.* [Bonardi et al. 1988]; [Bigi et al. 1992]. The top of the acoustic basement often corresponds to a polycyclic erosional surface, terraced at different water depths under the sea bottom. This evidences that the area has been involved by strong vertical movements during the Pleistocene. These movements have been controlled by the interaction between the glacio-eustatic fluctuations of the sea level and the tectonic uplift involving the study area [Cinque et al. 1994]; [Brancaccio et al. 1995].

The seismic units recognized at sea have been interpreted in terms of depositional sequences; the unconformities have been then interpreted in terms of Type 1 or Type 2 sequence boundaries, or classified in terms of local unconformities, mainly at the top of sacks filled by coarse-grained materials, deposited in the incisions, which characterize the top of the acoustic substratum. These units belong to the Late Quaternary Depositional Sequence; in this sequence the space and time evolution and the lateral and vertical migration of the coastal marine, continental shelf and slope depositional environments during the Late Pleistocene-Holocene glacio-eustatic cycle have been recorded. The study stratigraphic succession records the variations of the accommodation space of the Late Quaternary deposits during the last 4th order glacio-eustatic cycle, ranging between 128 ky B.P. (Tyrrhenian stage) and the isotopic stage 5e [Catalano et al. 1996].

This approach allowed to obtain information comparable among all the margins of the Italian Peninsula, without that this information is too much influenced by local or particular aspects [Aiello and Budillon 2004]. The last Late Quaternary sea level rise, having an excursion of about 120 m and a maximum rate in the order of 10 m/1 ky has left a mark on the morphologic and stratigraphic setting of all the Italian continental margins. The deposits related to this process are strongly different from area to area as a function of different sedimentary supply, morphological framework and oceanographic regimes; among this approach the facies, internal geometries and thickness of Quaternary deposits, recording the process of sea level rise in a differential way on various continental margins, may be studied.

The main survey method utilized in the field of marine geology for cartographic aims is the reflection seismics. It is limited by two main factors: the vertical resolution obtained with the seismic profiles, defining the minimum thickness below which it is not possible to recognize a deposit and the spatial resolution, which is a function of the distance separating close seismic profiles and which determines the minimum extension below which a deposit is not correlatable. The type of seismic source and the acquisition system (vertical resolution) and the line spacing must be choose based on the minimum dimensions of the geological bodies which have to be mapped.

2.1. Stratigraphic Units in Geological Mapping

The continental margins in the Mediterranean have been the subject of several marine geological studies during the last 30 years. They are heterogeneous surveys, which have produced large database, but heterogeneous and difficult to use. During this period geological and geophysical data, with different aims and mainly conventional methods (middle resolution seismics and single channel analogic recording and samples among piston coring limited to the first 4 or 5 meters of the subbottom) have been acquired. In most cases the results of this phase of study have been presented in a descriptive way and with a scarce attention to the nature of the sedimentary processes and their power of preservation in the geological record. For this reason, the comparison among different zones may be facilitated by a multidisciplinary approach based on the use of sequence stratigraphy. Another problem includes the representation of the geological bodies cropping out in areas where the Late Quaternary depositional sequence doesn’t occur. This happens in areas involved by erosional processes and starved during the Late Quaternary or on continental margins involved by a strong volcanic activity. In these cases, three types of deposits should be distinguished and mapped:

- sedimentary deposits oldest than the Late Quaternary depositional sequence, subdivided based on lithostratigraphic and chronostratigraphic criteria with definition of large-scale stratigraphic units;
- volcanic and volcaniclastic deposits (subdivided for age and composition);
- crystalline rocks (subdivided for age and composition).

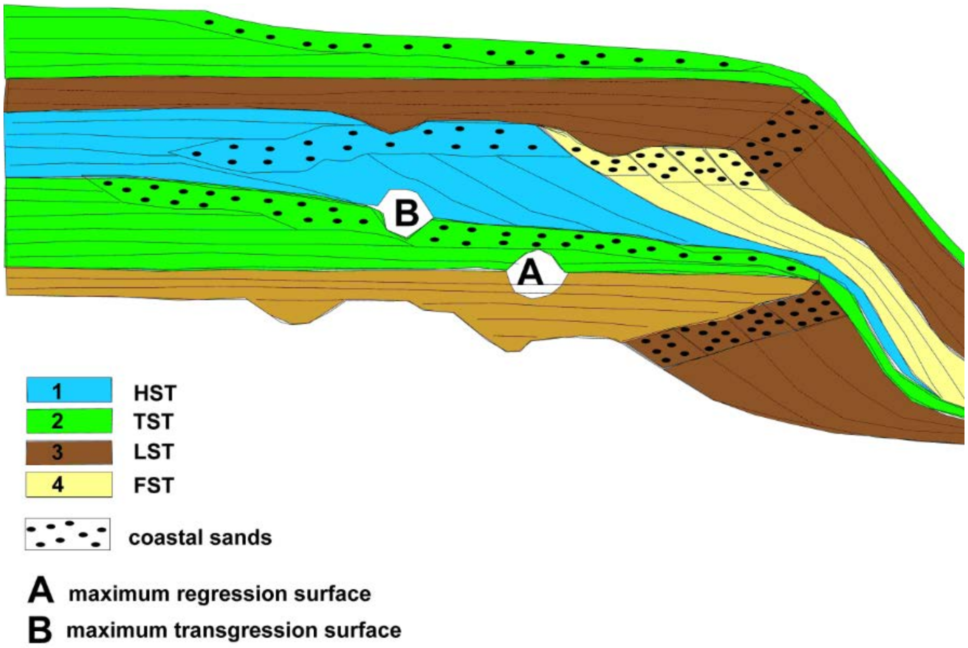
2.1.1. Stratigraphic Units and Sequence Stratigraphy

To the aim of subdividing and mapping the sedimentary deposits on the Italian continental margins we should choice an approach similar to that one adopted by the terrestrial cartography, based on the recognition of lithostratigraphic units into a chronostratigraphic framework (Formations or other units having an upper or lower hierarchical order).

The definition of lithostratigraphic unit is based on the differences among lithologic and facies characters with respect to other units on which it is put in lateral or vertical contact. As it has been individuated, each unit is then put in the geological time through the reference to geochronologic and chronostratigraphic units. This has been obtained through methodologies having a variable nature (biostratigraphic, magnetostratigraphic, geochemical, radiometric) on samples collected into each chronostratigraphic unit without a particular attention to the nature and the chronostratigraphic meaning of its physical boundaries. A precise time interval should be registered by one or more units having a variable thickness and areal extension.

A further step should be that to recognize unconformity surfaces at a regional scale bounding complex rock bodies composed by one or more lithostratigraphic units; the units defined based on unconformable limits are defined as Unconformity Bounded Stratigraphic Units (UBSU) [Chang, 1975];[Sloss, 1988]; [Galloway, 1989]; [Goldhammer et al., 1990]; [Miall, 1990]; [Mitchum and Van Wagoner, 1991]; [Christie-Blick, 1991]; [Sacchi et al., 1999]. These units have a genetic meaning linked to the nature of the bounding surfaces; in this sense, they conceptually include a wide range of stratigraphic units; between them there are the cyclostratigraphic units, differentiated based on the type of cyclicity which characterizes them (eustatic, climatic, tectonic).

The cartographic use of cyclostratigraphic units, in particular of the depositional sequences, is at the moment still difficult in the field of the surface geology, due mainly to the lacking of certain time references.



(modified after Vail et al., 1977; Christie-Blick, 1991; Helland-Hansen and Gjelberg, 1994).

Figure 2. Sketch stratigraphic section in relation to the depth A and the time B, showing the geometric relationships between system tracts and the distribution of siliciclastic facies in the depositional sequences bounded by unconformities. System tracts: HST: highstand system tract; TST: transgressive system tract; LST: lowstand system tract; FST: falling sea level system tract.

The adoption of guide concepts of sequence stratigraphy during cartographic surveys has been strongly recommended by the CNR Commission for the Geological and Geomorphological Cartography through the recognition of their potentiality for a better comprehension of the space and time relationships between geological bodies [Catalano et al., 1996]; [Fabbri et al., 2002]. The main unit on which the sequence stratigraphy is based is the depositional sequence, defined as the whole of the sedimentary deposits formed during a complete cycle of relative sea level variation. Its boundaries are constituted of surfaces of discontinuity and correlative surfaces of continuity, formed during the phases of relative sea level fall (Figure 2). [Mitchum et al. 1977] [Vail et al. 1977]; [Van Wagoner et al., 1988]; [Posamentier and Vail, 1988]; [Wright and Marriott 1993]; [Carter, 1998]; [Amorosi et al. 1999]; [Ardevol et al. 2000]; [Miall and Miall, 2002].

In a depositional sequence several phases of the cycle are defined by the response of the depositional systems or by the tracts of contemporaneous depositional systems (systems tracts). They represent stratigraphic units of minor hierarchy and precise genetic and temporal connotation; these sequence stratigraphic units constitute the sedimentary bodies more useful and significant for the cartographic representation. Moreover, they represent units which can be strongly framed from a temporal point of view and in which several depositional systems may be defined; these latter ones correspond to lithostratigraphic units (Formations), which may be defined and mapped, realizing a conceptual and practical link with the terrestrial cartographic approach [Fabbri et al., 2002].

2.1.2. Seismic Resolution and Sedimentological Expression of the Guide Surfaces

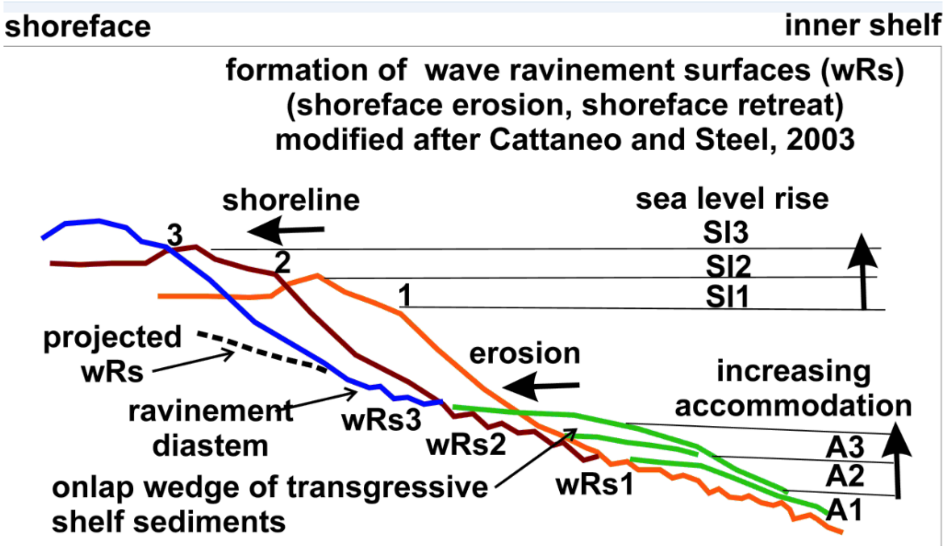
Three guide surfaces represent the physical boundaries allowing to define and subdivide a depositional cycle: the transgressive surface, marking the beginning of the relative sea level rise on a continental margin [Schlager 2005]; [Hongfu and Jinnan, 2010], the maximum flooding surface, which records the maximum landwards shifting of the shoreline [Haq et al., 1987]; [Van Wagoner et al., 1988] [Galloway, 1989]; and the surface of subaerial exposure, formed under conditions of sea level fall [Van Wagoner et al., 1988]; [Saller et al., 1999]; [Fitzsimmons and Johnson, 2000].

Other significant surfaces are the ravinement surface [Swift, 1975]; [Demarest and Kraft, 1987]; [Nummendal and Swift, 1987] [Miall 1997]; [Cattaneo and Steel, 2003]; [Aiello and Budillon, 2004], [Nordfjord et al., 2009] [Peters et al., 2009] and the regressive surface of submarine erosion [Plint, 1988]. [Wescott et al., 1999] [Catuneanu et al., 2009] [Helland Hansen and Hampson, 2009].

Both the surfaces have been formed by the erosion of the shoreface, in conditions respectively transgressive and regressive; these surfaces, often more easily identifiable with respect to the others, may occur in the systems tracts, but they haven’t a chronostratigraphic meaning, because they are diachronous (Figure 3).

Other surfaces may form due to the submarine erosion operated by bottom currents; these surfaces, also if having a wide regional extent, do not find no location in any stratigraphic sketch diagram developed starting from the seismic stratigraphy [Christie-Blick, 1991].

The regional correlation of the physical surfaces of stratigraphic discontinuity at the base and in the inner part of the Late Quaternary Depositional Sequence represent the starting point for the individuation of the geological bodies to be mapped and for planning a strategy of sampling of the marine subbottom aimed to solve stratigraphic problems and to characterize the depositional environments.



(modified after Cattaneo and Steel, 2003).

Figure 3. Sketch inner-shelf to shoreface stratigraphic section showing the formation of multiple ravinement surfaces (wRs1, wRs2, wRs3 in the figure) in transgressive deposits during a continuous transgression. During the transgression across a high-gradient topography, the landward movement of the shoreline is relatively slow and the process of ravinement (erosion by wave action) at the shoreface has more time to rework and redeposit sediment. This results in shoreface retreat, formation of a ravinement surface and thick transgressive deposits above the ravinement surface.

2.2. The Late Quaternary Depositional Sequence

A depositional sequence is represented by a relatively conformable succession of genetically related strata, bounded by subaerial unconformities or their correlative conformities [Mitchum et al. 1977]; [Vail et al., 1977]; [Bally et al., 1987]. A subaerial unconformity is defined as a surface formed through subaerial exposure and erosion and includes features formed by downcutting rivers, soil processes and karst processes. Every depositional sequence is the stratigraphic record of one relative sea level cycle; consequently, the depositional sequences have a predictable internal structure of surfaces and system tracts, i.e. associations of coeval depositional systems, such as the coastal plains, the continental shelves and the submarine fans.

In the most accepted model of depositional sequence (four system tract model) all the depositional sequences include the lowstand systems tract (LST), the transgressive system tract (TST), the highstand system tract (HST) and the falling-stage system tract (FST). As a general rule, a depositional sequence begins with the slow rise following a sea level fall and continues through the next fall of the sea level. These systems tracts are bounded by important guide surfaces; the lowstand and trasgressive system tracts are separated by the trasgressive surface; the trasgressive and highstand systems tracts are separated by the maximum flooding surface. The highstand and falling-stage systems tracts are separated by the basal surface of forced regression.

In particular, in the Late Quaternary Depositional Sequence (SDTQ) the seismo-stratigraphic analysis has highlighted depositional systems respectively referred to the sea level fall (FST); [Helland-Hansen and Gjelberg, 1994]; to the sea level lowstand (LST) and related internal subdivisions [Posamentier et al., 1991], to the transgressive phase (TST) [Posamentier and Allen, 1993]; [Trincardi et al., 1994] and to the highstand phase of sea level (HST); [Posamentier and Vail, 1988]. A sketch stratigraphic section of the Late Quaternary Depositional Sequence and corresponding systems tracts has been already shown in Figure 2.

The widespread volcanic activity, which controlled the stratigraphic architecture of the Volturno basin and of the Ischia island (among the selected case histories shown in this chapter) has prevented the application of a classical stratigraphic approach, due to the occurrence of interlayered sedimentary sequences and intervening volcanic bodies (volcanites and volcaniclastites) [Aiello et al., 2011a]; [Aiello et al., 2012b]. To this aim, the regional example of the Ischia island is meaningful and needs to be further explained to clarify this concept.

The Ischia island represents an alkali-trachytic volcanic complex, whose eruptive activity lasted from the Late Pleistocene up to historical times [Vezzoli 1988]. The oldest rocks date back to about 150 ky and crop out in several sectors of the coastal belt of the island, with particular abundance in correspondence to the “Scarrupata di Barano”, a steep slope located south-eastwards of the island. This evidence concurs to suggest the occurrence of a resurgent caldera, about 10 km wide, where the eruptive activity and tectonics gave rise to the uplift along faults of the Mount Epomeo block [Orsi et al. 1991]; [Acocella et al. 2004]; The main eruptive events of the Ischia-Procida-Phlegrean system suggest at least five eruptive cycles, ranging in age from 135 ky B.P. to prehistorical and historical times [Civetta et al., 1991].

The Ischia island and its submerged sectors show a wide spectrum of hints concerning the relative sea level oscillations, resulting from the interactions between the sea level eustatic oscillations and the volcano-tectonic ground movements during the Late Pleistocene, in particular before and after the eruption of the Epomeo Green Tuffs (55 ky B.P.) [Vezzoli 1988]. They include geomorphological hints (uplifted marine terraces, steep incisions, beach fossil deposits), biostratigraphic and paleontologic hints (i.e. fossil remnants of malacofaunas or of benthic organisms uplifted at different elevations, rhizomes of *Posidonia oceanica* embedded in beach deposits), radiometric hints (i.e. fragments of the hermatipic coral *Cladocora coespitosa*), archeological and historical hints (submerged walls) [Buchner 1986], more than geophysical ones (geodetical measurements with GPS) [Del Gaudio et al. 2011].

In the case history of the Ischia island, the occurrence of isolated volcanic bodies as intrusions, domes, volcanic necks and tabular, acoustically-transparent seismic units allowed particularly complex the sequence stratigraphic approach in the geological interpretation of seismic profiles. While the volcanic or sub-volcanic bodies (i.e. lava flows, domes, intrusions) cannot be penetrated through the reflection seismics because they are acoustically-transparent, the pyroclastic edifices and/or the buried pyroclastic deposits may be well detected, due to their internal stratification. As a consequence, the seismic stratigraphy offshore the Phlegrean Fields and the Ischia and Procida island volcanic complexes is more complex and difficult to interpret with respect to that one of the eastern sector of the Naples Bay, where sedimentary seismic units overcome, eastwards of the Dohrn canyon morpho-structural lineament [Aiello et al., 2001]; [Aiello et al., 2005]; [Aiello et al., 2011b]; [D’Argenio et al. 2004]; [Di Fiore et al. 2011].

On the other side, the shelf areas of the Salerno Gulf contain the seaward front of alluvial plains of the Sele, Tusciano, Picentino and Solofrone rivers, prograding seawards by about 15 km starting from the isotopic stage 5a and following the general retreat of the sea level during the Late Pleistocene [Budillon et al., 1994]; [ISPRA, 2009]; [Budillon et al., 2011]. The offshore area included off Agropoli and Palinuro is the result of the Pleistocene evolution of the Cilento margin. The shallow location of the acoustic basement and the scarce accommodation space for sediment deposition have allowed for the formation of seaward prograding wedges, bounded by marine and subaerial erosional unconformities [Ferraro et al. 1997];[Trincardi and Field, 1991] [Aiello et al. 2010b].

The continental shelf between the Palinuro Cape and the Scalea Cape, including the main physiographic units of the Policastro Gulf and the Maratea Valley [Aiello et al., 2010a] shows very reduced sedimentary deposits and is crossed by the heads of several channels, triggering wide erosional processes. Its extension is variable, with maximum values reaching 7.5 kilometres off the Sapri town and minimum values of less than one kilometer between the Sapri town and the Bussento river mouth. The shelf is characterized by a maximum extension in correspondence to the Policastro Gulf, where it reaches a width of about 7 kilometres. Like the Salerno basin, the Policastro basin also proves a thickness of sediments of less than one thousand meters, with a subsidence velocity estimated in the order of 0.2-0.6 m/ky [Bartole, 1983]; [Bartole et alii, 1984]; [Sacchi et al., 1994]. Offlap sedimentary successions occur in the study area, determining a seaward progradation of more than 10 kilometres. The prograding sedimentary wedges, deposited during the lowstand phases of the sea level of the Middle-Late Pleistocene were eroded during the phases of subaerial exposure of the continental shelf and the successive episodes of eustatic sea level rise [Ferraro et alii, 1997]. This has determined the formation of wide erosional surfaces at several stratigraphic highs, truncating the prograding units.

The area is characterized by the occurrence of a wide erosional surface, extending from the sea bottom up to –160 m of water depth; this suggests that this surface correlates with the last glacial episode (18 ky B.P.), i.e.the wurmian regression. Bioclastic sands, characterized by prograding reflectors, occur along two belts localized between 120 m and 160 m of water depth and parallel to the Tyrrhenian shoreline. These deposits are interpreted as parts of submerged beaches related to the isotopic stage 2, based on the identification of the *Arctica islandica*, cold host of the Pleistocene, actually extinct in the Mediterranean [Trincardi and Field, 1991]; [Ferraro et alii, 1997].

2.2.1. Main Components of the Late Quaternary Depositional Sequence

The main characteristics of the system tracts related to main phases of the last sea level glacio-eustatic cycle are here discussed, focussing, in particular, on Naples and Salerno Bays. The stratigraphic meaning and the representation on geological maps of each system tract are herein resumed.

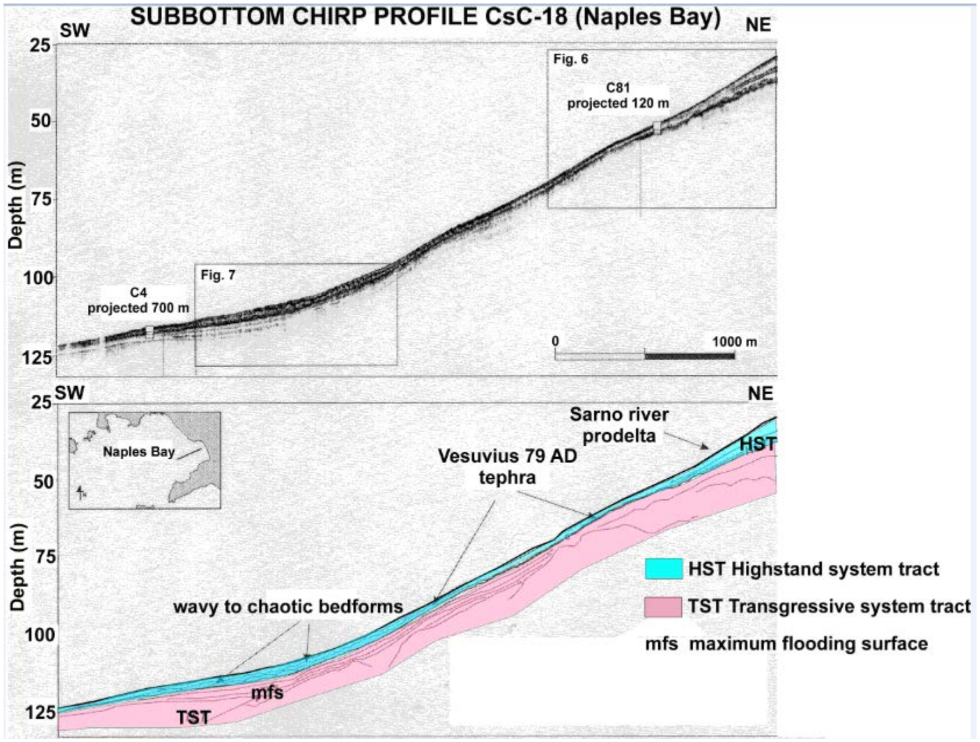
2.2.1.1. Highstand Deposits (HST)

The highstand deposits are younger than the phase of maximum marine ingression happened at the end of the sea-level rise (about 4-5 ky B.P.) and show their maximum thickness in the inner shelf, next to the main deltas (i.e. Po, Tiber, Arno, etc.) along the Italian coast, while reduce to a few meters on the outer shelf [Fabbri et al., 2002]. Some exceptions to this trending are found in some sectors of the Adriatic, Ionian and Tyrrhenian margin, where the fluvial supply under conditions of sea level highstands are such to allow the deposition of a distal muddy drape on the outer shelf and slope. Regional examples are located on the continental shelf off the Tremiti islands [Correggiari et al., 1992], off the Sele river [Trincardi and Field, 1991; [Budillon et al., 1994]; [Budillon et al., 2011], off the Tiber river [Trincardi and Normark, 1988]; [Bellotti et al., 1994]. In presence of exceptionally high siliciclastic supply we observe turbidite deposition and construction of channel-levee complexes on the slope and in the basin (i.e. the Crati submarine fan) [Ricci Lucchi et al.., 1984]; [Critelli and Le Pera, 1984]; [Colella and Di Geronimo, 1987].

The map representation of HST deposits is usually redacted through isochronopach maps, reporting the thickness of the deposits in milliseconds. The curve corresponding to the thickness of 2 meters of the HST deposits (about 2.5 msec) represents the practical boundary of resolution of the adopted seismic instrument.

In the case history of the Adriatic basin, the thickness distribution of the highstand deposits is influenced by the supply (Po and minor rivers) and by the geostrophic circulation, which re-distributes the sediments parallel to the Italian shoreline, from NW to SE, preventing their dispersion towards the center of the basin. An interaction among the distribution of the fluvial supply and the oceanographic regime has been observed also on other continental margins of the Italian peninsula, as in the Tiber delta [Belluomini et al., 1986]; [Trincardi and Normark, 1988]; [Bellotti et al., 1994]; [Bellotti et al., 1995]; [Rendell et al., 2007] and in the Sele delta [Trincardi and Field, 1991]; [Budillon et al., 1994]; [Barra et al., 1998]; [Barra et al., 1999] [D’Acunzi et al., 2008]; [Budillon et al., 2011]; [D’Argenio et al., 2011]; [Alberico et al., 2012]. Highstand deposits of the Naples Bay have been intensively studied in the frame of research projects of marine geological mapping of the Campania Region (Aiello et al., 2001; 2012a]; [D’Argenio et al., 2004]; [Sacchi et al., 2005]; [Insinga et al., 2008]; [Molisso et al., 2010]. They have been widely documented in the Sarno prodelta system, where their age, constrained through piston cores seems to be Upper Holocenic. Seismic interpretation has revealed that the Upper Holocene highstand sequence off the Sarno prodelta system is affected by an extensive creeping involving the post-79 AD succession [Sacchi et al., 2005]. The deformation due to the creeping is documented by the slumping of semi-consolidated strata over a basal surface represented by lithologic discontinuity between the base of the 79 AD tephra deposits and the underlying hemipelagite. Seismic data also suggest that gravitational instability of this area has been induced, or enhanced by significant volcano-tectonic deformation and local uplift of the seafloor, pre-dating the eruptive event [Sacchi et al., 2005]. The seismic signature of the HST deposits off the Sarno prodelta, as well as off the northern Salerno Bay, is characterized by a thick reflector, developing in the upper part of this stratigraphic unit. It can be correlated with the volcaniclastic layer deposited offshore during the 79 AD plinian eruption of the Vesuvius [Conforti 2003]; [Insinga 2003]; [Sacchi et al. 2005]. The thickness of the 79 AD pyroclastic deposits ranger from a maximum of about 200 cm in the shoreface-foreshore area off the Sarno river mouth, to some 10 cm at the shelf edge. Offshore the Sarno river mouth the post AD79 succession (Figure 4) is characterized by a low angle sigmoidal pattern of reflectors and displays a thickness between 7 m at the shelf edge and 1 m towards the bottomset [Figure 4; Sacchi et al., 2005]. The post AD79 sequence is characterized by wavy bedforms, associated with internal wave-like to chaotic structure, previously interpreted as sediment failure due to creep [Aiello et al., 2001].

The stratigraphy of gravity cores has shown that the HST (Holocene) deposits recovered off the Sarno river mouth consists mostly of bioturbated prodelta mud (sandy silt) punctuated by tephra deposits at various stratigraphic levels [Conforti 2003]; [Insinga 2003]; [Sacchi et al. 2005].



(modified after Sacchi et al., 2005).

Figure 4. Subbottom Chirp profile CSC-18 offshore the Sarno river mouth (Naples Bay) and corresponding geological interpretation. Note that the 79 AD tephra, calibrated through gravity cores collected in the Naples Bay (Sacchi et al., 2005) separates the transgressive system tract deposits (TST in the seismic section) from the highstand system tract deposits (HST in the seismic section).

Different tephra deposits may significantly vary in terms of thickness and average grain size. The most prominent one is represented by the tephra deposited by the Vesuvius during the plinian eruption of 79 AD.

All the stratigraphic successions recovered from the Naples Bay show that the 79 AD tephra overlies an erosional surface of older strata, consisting of biorturbated sandy silts. In particular, the 79 AD tephra is characterized by graded coarse to medium sands and/or gravels in proximal areas and by sandy silt with fine-grained lithics and bioclasts in more distal areas [Sacchi et al., 2005].

Highstand deposits in the Salerno Gulf have been recently investigated in the frame of the CARG research project [Budillon et al., 2011]. The seismic acoustic profiles offshore the Sele and Alento river mouths have shown, beneath the seabed, a shallow unit with fluid escape and plastic deformation features.

This unit is bounded at the base by a regular and conformable reflector lying halfway between the 79 AD Vesuvius tephra and the present day seabed, at water depths ranging between 40 and 70 m. The unit, which lies seaward of shallow biogenic sand pockets can be related to estuarine depositional environments and might mark the boundary between the silty and the muddy prodelta system [Budillon et al., 2011].

The highstand system tract, developed since 5-6 kyr B.P. includes, proceeding landwards, the present day coastal system and typically consists of a tapering seaward wedge. In the

Salerno Bay the HST depocentre is located off the river Sele at a depth of 40 m, where it exceeds 10 m of depth and rapidly thins out seaward to less than one meter of thickness. Pre- and post-glacial shore units, featuring prograding geometries with offlap terminations, were identified off the Sele and Bussento river mouths. The oldest ones, lying below the maximum glacial unconformity, formed as a consequence of the seaward retreatment of the shoreline during the last stages of the Late Pleistocene sea level fall and has been interpreted as the effect of the Younger Dryas climatic event [Budillon et al., 2011]. These bodies consist of a continuous set of prograding reflectors, with offlap and downlap lateral terminations, overlain by onlapping sub-horizontal reflectors, topped in turn by the maximum flooding surface. Other lithosomes relative to the transgressive system tract occur seaward to the shelf break and represent the healing phase of the postglacial transgression [Hunt and Tucker, 1992]; [Budillon et al., 2011]; however, they occur in morphological steps on the shelf between the transgressive and the ravinement surfaces, showing acoustic facies typical of transitional shore deposits.

2.2.1.2. Transgressive deposits (TST)

The transgressive deposits, originated in continental, coastal paralic or marine environment during the phases successive to the Late Quaternary sea level rise generally appear reduced in thickness and studied with very high resolution seismic profiles and piston cores. In continental shelf areas characterized by low gradients, i.e. the Adriatic basin [Fabbri et al., 2002], the landward shifting of the depositional systems related to the coastal and paralic environment is maximum proceeding with the onset of the sea level rise. The Italian continental margins document the variability of facies, internal geometry, sedimentologic expression and marker horizons [Trincardi et al., 1994]. The most significant one is the ravinement surface; in the TST it separates underlying paralic deposits from overlying marine deposits [Catuneanu 2002].

The ravinement surface is a scour cut by waves in the upper shoreface during the shoreline transgression [Bruun 1962]; [Swift et al. 1972]; [Dominguez and Wanless 1991]. This erosion may remove as much as 10-20 m of substrate [Demarest and Kraft, 1987], as a function of the wind regime and related wave energy in each particular region. The ravinement surface is onlapped during the retrogradational shift of facies by transgressive shoreface deposits (coastal onlap). In a vertical profile that preserves the entire succession of facies, the ravinement surface separates coastal strata below (beach sands in an open shoreline setting, or estuarine facies in a river mouth setting) from shoreface and shelf deposits above. Where the transgressive coastal deposits are not preserved, the ravinement surface may rework the underlying regressive strata and the subaerial unconformity [Embry, 1995]. In the latter case, the ravinement surface becomes part of a sequence boundary.

In the Naples Bay the TST deposits were deposited during the rising of sea level (18-6 ky B.P.). It was documented by several authors [Milia and Torrente, 2000]; [Milia and Torrente, 2003] and consists of three minor stratigraphic units.

The second of them corresponds to a thick progradational unit overlying the Neapolitain Yellow Tuff (18 ky B.P.), the Penta Palummo Bank and the Miseno Bank. This minor stratigraphic unit, lying at depths of 70-80 m, is bounded on top by a marine flooding surface and at the base by a downlap to concordance surface. The unit has been interpreted as having been deposited during the sea level rise between 12 and 9 ky B.P.

In the Gulf of Pozzuoli this progradational unit exhibits a lateral transition into a unit showing horizontal bedding. A series of volcanic edifices, two of them are the tuff cones of Nisida Bank and Nisida Island [Sacchi et al., 2009]; [Aiello et al., 2012b] overlie the TST deposits in the eastern sector of the Pozzuoli Gulf. This volcanic unit includes mounds that are either internally stratified or chaotic. In the Bay of Naples volcanic units that are younger than 5 ky B.P. are mainly made up of small volcanic mounds, magmatic intrusions, lava extrusions and associated to debris pyroclastic flows. Volcanic mounds occur offshore Capo Miseno [Milia and Torrente, 2000], whereas magmatic intrusions are present in the Pozzuoli Bay [Milia and Torrente, 2000; Aiello et al., 2012]. On the other side, recent debris flows were detected offshore Vesuvius, offshore Agnano, offshore Averno and Monte Nuovo [Milia and Giordano, 2002].

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, which lies above the transgressive surface, 90/60 m below the sea level, could be the remains of the Younger Dryas climatic event [Fairbanks 1989]. These bodies consist of a continuous set of prograding reflectors, with offlap and downlap lateral terminations, overlain by onlapping sub-horizontal reflectors, topped in turn by the maximum flooding surface [Budillon et al., 2011].

2.2.1.3. Lowstand System Tract Deposits (LST)

The deposits originated in sea level lowstand during the last Quaternary glacial episode (isotopic stage 2) [Martinson et al., 1987] may be distinguished in mass transport deposits, base of slope turbiditic systems and shelf margin progradational wedges. Each sector of continental margin does not include all the three types of deposits, but only one or two. The development of each of the three types of lowstand deposits is a function of the morphological setting and regime of clastic supply. The mass transport deposits usually have a great lateral extension and are characterized by chaotic reflections or acoustic transparence, erosional base and thickness from several meters [Marani et al., 1986]; [Mongardi et al., 1995]; [Trincardi and Normark, 1988]; [Trincardi et al., 1994].

Typical examples of these deposits come from the deepest area of the Meso-Adriatic Depression [Trincardi et al., 1994] or from some peri-tyrrhenian basins [Trincardi and Normark, 1988]; [Mongardi et al., 1995]. Turbiditic base of slope systems are characterized by depositional relief having a limited area extension and channellised in the proximal area; levees composed mainly of muddy sediments may be related to channels more stable during geological time or characterized by a major supply of fine-grained sediments. Examples of these kind of lowstand deposits come mainly from physiographic immature margins in areas characterized by strong sedimentary supply during the Quaternary (for instance the Paola Basin, in the Eastern Tyrrhenian margin); [Argnani and Trincardi, 1990].

Progradational wedges having a variable geometry characterize wide sectors of continental shelf margin; these kinds of progradational wedges may include also the first phases of sea level rise, in areas subject to great clastic supply. In this case, it will be evident a component of vertical aggradation in the topset areas and a tendency to the progressive landward shifting of the coastal onlap.

In the Naples Bay wide relic prograding wedges have been identified through seismic stratigraphy, constituting the bulk of the stratigraphic architecture of the continental shelf

[Aiello et al., 2001]; [D'Argenio et al., 2004]; [Ruggieri et al., 2007]; [Aiello et al., 2011b]. Seismic interpretation of multichannel profiles already showed the stratigraphic architecture of seismic units and related unconformities [Aiello et al., 2001]; [D'Argenio et al., 2004]. Several seismic sequences separated by unconformities have been distinguished by the interpretation of seismic profile NAM3 (Figure 5). The acoustic basement is represented by Meso-Cenozoic platform carbonates, cropping out onshore in the Sorrento Peninsula and in the Capri island and organized as a monoclinalic structure dipping north-westward. The basin filling consists mainly of two prograding wedges, each one characterized by distintive acoustic patterns and seismic facies. The oldest one (unit 2) is interpreted as a wide relic prograding wedge, north-westwards dipping, formed by siliciclastic deposits, probably Pleistocene in age and occurring offshore the Sorrento Peninsula and the Capri island.

On the continental shelf the seismic reflectors are truncated by a main subaerial unconformity, indicating a main relative sea level fall and a strong basinwards shifting of coastal and marine facies, accompanied by sedimentary bypass and strong erosion on shelf and slope. Above the unconformity B the clinoforms of unit 3 progressively onlap the slope and basin areas up to the continental shelf. Unit 3 represents a wedge-shaped, transgressive unit developed in slope and basin settings and composed of siliciclastic deposits. A wide prograding wedge, showing well-preserved offlap breaks and thickening from the shelf towards the slope overlies this unit. The unit gives rise to relic morphological highs and was probably supplied by the mouth of the river Sarno during the Middle-Late Pleistocene (Figure 5). Lowstand deposits have been however recognized on the margins of the Phlegrean banks (Miseno, Nisida and Pentapalummo). Thick regressive prograding deposits have been recognized based on seismic interpretation on the south-eastern flank of the Pentapalummo Bank [Aiello et al. 2012b]. Here oblique progradational patterns seem to prevail.

In the Salerno Gulf shore bodies, constituting the LST deposits, formed during the seaward retreatment of the shoreline of the Late Pleistocene sea level drop [Budillon et al., 2011].

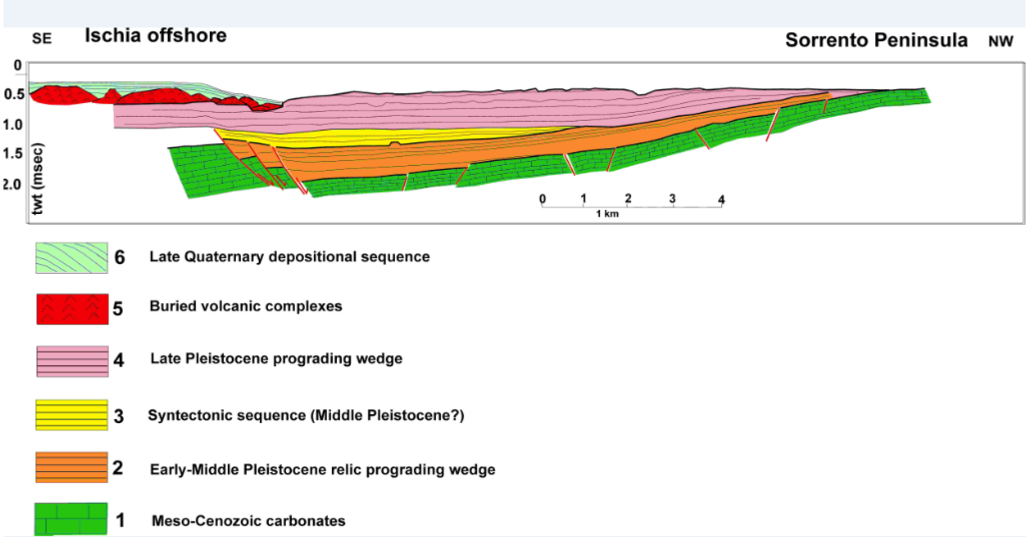


Figure 5. Line drawing of the multichannel seismic profile NAM3.

The peak of the retreat accounts for the growth of a shelf margin, in the Salerno and Policastro bays, and a mid-shelf littoral body offshore the Cilento Promontory, long at least 100 km, during the last maximum lowstand phase. During these geological times the Sele river flowed directly on the upper slope and formed a channellized drainage system, still preserved between water depths of 180 and 500 m, due to density flows that have transferred sediments from the coastal area directly into the Salerno Valley, an intraslope basin of the Eastern Tyrrhenian margin [Aiello et al., 2009a]; [Budillon et al., 2011].

2.2.1.4. Falling Sea Level System Tract Deposits (FST)

It is well known that the eustatic sea level cycles during the Quaternary are characterized by sea level falls relatively slow and discontinuous and by faster sea level rises. About the 90% of the geological time, during these kinds of eustatic cycles, is absorbed by falling sea level and lowstand phases. The Mediterranean continental margins show many examples of falling sea level deposits having different geometries, area extension and lithologies [Tesson et al., 1990]; [Trincardi and Field, 1991; [Hernandez-Molina et al., 1994]; [Hunt and Gawthorpe, 2000]; [Posamentier and Morris, 2000]; [Aiello and Budillon, 2004]; [Nichols, 2009]; [Desjardins et al., 2012].

Diagnostic criteria for the recognition of forced regressive deposits include the occurrence of a significant zone of separation between successive shoreface deposits, the presence of sharp based shoreface delta front deposits, the occurrence of shallower clinoforms from proximal to distal environments and the absence of fluvial and/or coastal plain/delta plain capping the proximal portion of regressive deposits [Posamentier and Morris, 2000].

The FST deposits consist of progradational wedges emplaced through a mechanism of erosional or forced regression [Curray, 1964]; [Posamentier et al., 1992] recognized through the progressive seaward and downward shifting of the coastal onlap. These deposits may be adjacent between them or separated by a zone of non-deposition and transport, more or less extended. In the first case the deposits of forced regression are continuous and start with the highstand progradation and terminate with the lowstand phase.

In the Naples Bay FST and LST deposits are composed of progradational units, the tops of which are located at depths ranging from – 130 m and – 150 m, occurring at the seaward termination of the wide subaerial erosional surface affecting the volcanic banks of the Phlegrean area [Milia and Torrente, 2000]; [Milia and Torrente, 2003]; [Aiello et al., 2005].

2.2.1.5. Sequence Boundaries (SB)

Sequence boundaries are unconformities updip and a correlative conformities downdip. They are usually related to subaerial exposure and erosion and marked by abrupt basinwards shift of sedimentary facies [Mitchum et al., 1977]; [Vail et al., 1977]; [Van Wagoner et al., 1988]; [Catuneanu, 2006]; [Catuneanu et al., 2010]; [Miall, 2012]. This abrupt shift of sedimentary facies is called a forced regression, in order to distinguish it from a normal regression, in which a shoreline moves seawards due to the sedimentation [Posamentier et al., 1992; Hunt and Gawthorpe, 2000]. Sequence boundaries are generated by a relative fall in sea level, produced by changes in the rate of tectonic subsidence or by changes in the rate of eustatic rise.

Two sequence boundaries have been defined as a function of the ratio between the rate of sea level fall and the rate of subsidence at the shelf margin [Vail et al., 1984]; [Posamentier and Allen, 1993]. Type 1 sequence boundaries form when the rate of eustatic sea level fall exceeds the rate of subsidence; as a consequence, the subaerial exposure of the whole continental shelf occurs. The type 2 sequence boundaries are typical of the continental margins in which the rate of subsidence of the outer shelf is higher than the rate of sea level fall; more or less extended parts of the continental shelf rest submerged or subject to deposition. Type 1 sequence boundaries are characterized by more extended phenomena of fluvial incision [Vail et al., 1977]; [Christie-Blick, 1991]; [Helland Hansen and Gjelberg, 1994].

2.3. Facies Analysis and Schematic Representation of Depositional Environments

The system tracts pertaining to the Late Quaternary depositional sequence include deposits characterized by facies related to continental, paralic coastal, shelf and deep sea depositional environments. The marker horizons constituting the base and the top of the system tracts may be represented by variable sedimentological expressions due to the differences between the facies and the occurrence and entity of related erosional phenomena.

One main aim of facies analysis is to study the characteristics of sediments in relationship to the processes which have controlled their transport and emplacement [Hallam, 1987]; [Bosellini and Ricci Lucchi, 1994]. The facies analysis allows for the reconstruction of the palaeo-environments and of their distribution in space and time through the analysis of the depositional processes and of their relationships with the geometries of the sedimentary bodies.

The basic concept for the environmental reconstruction is the facies, indicating a group of strata, which differs with respect to the other strata of the same succession. The facies analysis is a technique using several research sectors in the geological field, integrating them in order to interpret the ancient environments. The facies of a rocky body is defined based on the physical attributes, as the lithological type (composition, grain-size and texture), the shape and the thickness of the strata, the sedimentary structures and the fossils. This term underlines the lithological aspects of the sedimentary deposits pertaining to different depositional environments, but in the same time interval. Sedimentary facies and depositional environments are used to reconstruct the old history of the Earth.

The sedimentology is concerned with the identification of depositional processes and the recognition of ancient depositional environments in the stratigraphic rock record. The identification of various sedimentation processes from their deposits, or sedimentary facies, is crucial to the recognition and palaeogeographic reconstruction of ancient sedimentary environments. Sedimentary facies are visually distinguishable descriptive varieties of sedimentary deposits, with different facies indicating different modes of sediment deposition. For this purpose, sedimentology combines knowledge derived from studies of modern environments and laboratory experiments and uses this knowledge to understand the origin of sedimentary rocks (ancient deposits). The stratigraphic analysis of facies successions gives insight into the depositional processes, palaeoenvironmental conditions and development history of sedimentary basins and allows for the prediction of the geometry, lateral extent and spatial distribution of sedimentary rock bodies, including hydrocarbon and water reservoirs.

2.3.1. Continental Deposits

The continental deposits may occur at the sea bottom or in the first subbottom mainly in shallow marine areas controlled by subaerial exposure during Quaternary glacial periods. They consist mainly of alluvial plain deposits in which extended fluvial systems have been recognized, characterized by channel deposits with incised thalwegs and levees. The inter-channel zones are characterized by soil formation. The filling of the fluvial incisions may be characterized by sediment highly varying in grain-size and by filling geometries related to meanders or braided streams. These geometries may often be recognized on high resolution seismic profiles. The continental deposits recognized in the Late Quaternary Depositional Sequence at sea mainly belong to lowstand and transgressive system tracts.

2.3.2. Paralic and Coastal Deposits

The coastal and paralic depositional systems greatly vary both in morphology and depositional style. This variability reflects different budgets between the available sediments (type and quantity) and the oceanographic regime (wave-dominated, tide-dominated or mixed). As a general rule, the Mediterranean is characterized by a microtidal regime; the most of the coastal systems on the Italian margins is dominated by the waves. Coastal and paralic deposits may theoretically form in each phase of a relative sea level fluctuation cycle, but are characterized by different facies; regressive systems form in condition of sea level fall (forced regressions) [Posamentier et al., 1992] or when the siliciclastic supply counter-balances the relative sea level rate.

Transgressive systems deposited in areas previously of alluvial plain which are progressively drowned, are starved and characterized by the occurrence of more or less wide intertidal and subtidal environments in the beach zone. These systems often occur in the TST deposits. During this phase the fluvial thalwegs incised by the rivers during the previous subaerial exposure on the shelf are drowned and give rise to estuarine depositional systems. In many cases a relevant component of the filling of estuaries and lagoons comes from the sea and is operated by alongshore currents, tides and storms.

2.3.3. Continental Shelf Deposits

The sediments of the actual continental shelves may be summarized into three main types [Fabbri et al., 2002]: sediments deposited in a phase during which the shoreline was seaward advanced with respect to the present-day location and successively drowned (relic sediments); sediments deposited in a phase during which the shoreline was seaward advanced with respect to the present-day location and successively drowned, but then reworked due to currents, storm waves or tides (palinsest sediments); sediments related to the Late Quaternary highstand in equilibrium with the present-day depositional processes.

The continental shelf of the Naples Bay has a variable width, ranging between 2,5 km (offshore the western sector of Capri island) and 10-15 km (offshore the Sorrento coast). Such a submarine topography is controlled by the interactions between subaerial and submarine volcanism, strongly involving the Gulf during the Late Pleistocene and the linear erosion and sediment drainage along main axis of Dohrn and Magnaghi canyons [Aiello et al., 2005]; [Di Fiore et al., 2011].

The eruption centres occurring on the islands of Procida, Vivara and Ischia range in age between 150 kyr and historical times [Rosi and Sbrana, 1987]; [Vezzoli, 1988].

2.3.4. Deep Sea Deposits

Slopes, basins and submarine highs are less influenced by the sea level fluctuations during the Late Quaternary. Based on the piston core data acquired during the last 30 ky in all the Mediterranean sea it is clear that the last sea level rise and the successive sea level highstand are represented by drapes of clayey sediments (Holocene drapes). Under the Holocene drapes four main types of deposits occur [Fabbri et al., 2002]: turbidite deposits having a variable nature and referred to specific depositional elements as channel-levee systems, lobes and distal, not channellised deposits; mass gravity transport deposits; deposits originated by bottom currents and related erosional or condensed surfaces; pelagic drapes. Different types of turbiditic deposits, mass gravity transport deposits and pelagic drapes have been widely recognized on the sea bottom of the Naples Bay, in the frame of research programmes of submarine geological mapping [Aiello et al., 2001]; [Aiello et al., 2008]; [Aiello et al., 2009b]; [Aiello et al., 2009c].

2.3.5. Mass Gravity Transport Deposits

Mass gravity transport deposits, varying in nature, internal organization and areal extension have been recognized in the Late Quaternary successions of the Italian peninsula. Their emplacement may happen under conditions of lowstand, relative sea level rise and highstand of the sea level [Galloway et al., 1991]; [Correggiari et al., 1992]; [Trincardi and Field, 1991]; [Trincardi et al., 2003]; [Aiello et al., 2009c]; [Di Fiore et al., 2011].

Main slide scars in the Dohrn and Magnaghi canyons have been indicated based on the interpretation of Multibeam bathymetry [Di Fiore et al., 2011]. The gravity instability map of the Naples bay canyons has already shown that chief submarine instability areas are respectively located [Di Fiore et al., 2011]: at the head of the Dohrn western branch, showing a double retrogressive head, controlled by extensive submarine erosion; on the western slope of the Dohrn western branch, at its boundary with the eastern flank of the Banco di Fuori morpho-structural high, where a set of coalescent, large slide scars, not related to the canyon’s thalweg, may be observed; on the continental slope, north of the Capri structural high, where large scars are suggested by the trending of the isobaths next to the Dohrn canyon thalweg.

The geomorphological interpretation suggest that the submarine instabilities are located: around the Dohrn western branch, from the canyon’s head to the middle of the branch, north of the Banco di Fuori morphostructural high; on the continental slope southwards of the Magnaghi canyon, where two large areas of instability, not connected with the canyon’s thalweg, may be observed; on the north-western slope of the Banco di Fuori morpho-structural high, where the concave trending of the isobaths suggests the occurrence of an incipient and/or fossil slide scar.

3. GEOLOGICAL SETTING

3.1. Volturno Basin

The Campania and Latium Tyrrhenian margin includes tectonic domains that can be recognized along the central-southern Tyrrhenian offshore between the Ostia-Anzio coast

(Latium; FIGURA 2 da Aiello et al., 2011) and the Policastro Gulf (Campania). On the Campania and Latium margins, Quaternary basin fillings overlie submerged “internal” (western) tectonic structures of the Apennine chain, resulting from the seaward extension of the tectonic units cropping out in the coastal belt of the central and southern Apennines [D’Argenio et al., 1973]; [Parotto and Praturlon, 1975]; [Bigi et al., 1992]. These units usually form the acoustic basement of the coastal basins and they are composed either of terrigenous-shaly basinal sequences (“Units Sicilidi”, “Unità Liguridi”, “Flysch di Frosinone”, “Flysch del Cilento”); [D’Argenio et al., 1973]; [Parotto and Praturlon, 1975]; or of thick platform and basinal carbonates. Both such sequences are widely exposed on the adjacent mainland [Bartole et al., 1983]; [Bartole 1984]. The tectonic extension that accompanied the uplift of the southern Apennines that began in the Early Pliocene and continued to the Early-Middle Pleistocene had a major role in the present-day physiography of the Campania and Latium Tyrrhenian margin. Quaternary marine and continental sediments of the Campania coastal plains reach a thickness of up to 3000 m in the Volturno Plain [Ortolani and Torre, 1981].

The stratigraphy of the subsurface of the Volturno Plain is well known because the area has been intensively explored by oil companies (AGIP and ENEL, Italy). The borehole data reveal a Plio-Quaternary sedimentary succession that is composed of alluvial deposits (sands and conglomerates) and by marine and transitional sediments, with the insertion of lava and pyroclastic deposits [Ortolani and Aprile, 1978]; [Mariani and Prato, 1988]; [Brancaccio et al., 1991]. The depocenter of the Neogene succession has been observed in correspondence with the mouth of the Volturno river, where a sedimentary thickness exceeding 2500 msec is reached (corresponding to 3500 m to 4000 m deep). On the other hand, the Mesozoic carbonatic basement was down thrown by synsedimentary listric faults, which gave rise to wedging geometries during the Pleistocene [Mariani and Prato, 1988].

The Volturno Plain and its adjacent offshore can be distinguished into two sectors with different geological and geophysical characteristics: north and south of the 41st parallel; and in correspondence with the mouth of the Volturno river. These differences regard mainly the seismic stratigraphy of the sedimentary units and the occurrence, southward of this boundary, of a well-developed magnetic anomaly field, with a complex trending [Fedi and Rapolla, 1987].

The pre-Miocene basement coincides with the acoustic basement seen with the seismic reflection profiles. This acoustic basement is frequently composed of Mesozoic carbonates that correlate with the “Abruzzi and Latium carbonate platform” tectono-stratigraphic units [D’Argenio et al., 1973], which widely crop out in the Aurunci and Massico mountains. As observed in other sectors, the acoustic basement coincides with the top of buried volcanic edifices, both onshore and offshore [Zitellini et al., 1984]; [Mariani and Prato, 1988]; [de Alteriis et al., 2006]. The geomorphological evolution of the Volturno plain between Middle Pleistocene and Holocene times was reconstructed based on outcrop data and boreholes [Romano et al., 1994]. The age model relies on [^{230Th}]/[^{234U}] dating of fossiliferous layers in the cores. The stratigraphic succession is made up of six stratigraphic units. The lowermost is represented by marine sediments, the top of which date from 126 ky B.P. to 42 ky B.P. and correlates with two pumice outcrops on the eastern edge of the Volturno plain. The second unit is constituted of pyroclastic and lavic deposits, which correlate with two pumice outcrops on the eastern edge of the Volturno plain.

The third unit is composed of transitional and marine deposits that are related to isotopic substage 3.3 and date to 55 ky B.P. to 50 ky B.P. The fourth unit is the Campanian Ignimbrite *Auct.* and dates to 42 ky B.P. to 27 ky B.P. [Scandone et al., 1991]. The fifth unit is represented by locally reworked pyroclastic deposits of the fourth phlegrean period [Di Girolamo et al., 1984]. Finally, the sixth unit is composed of clays, silt and peat layers of lagoonal environments that are Holocene in age (10 ky B.P. onwards).

In order to reconstruct the Holocene evolution of the Volturno river coastal plain, a geomorphological survey was carried out and three boreholes were drilled in the southern plain [Barra et al., 1996]. New stratigraphic data were available from pre-existing boreholes from scattered locations on the plain.

For samples obtained from boreholes A, B, C, ostracod analysis, lithostratigraphic observations and AMS ^{14}C dating were carried out. The Holocene deposits outcrop along the coastal beach ridges of the strand plain and in the flat back-barrier depression, the northern area of which is partially occupied by the composite and raised meander belt of the Volturno river. These deposits lie on the subaerial erosional landscape carved in the Campanian Ignimbrite formation (the latter being 42 to 27 ka BP in age) during the last glacioeustatic lowstand.

The wedge-shaped sedimentary body (up to 30 m thick) is composed of sands and silts near the coast (penetrated by core A) and of clays, peats and silts (cores B and C) in the inner part of the plain. Both the sedimentary reconstructions carried out on the well logs and the three-dimensional arrangement of the Holocene sedimentary units allowed for both the reconstruction of the sediment geometry and the assessment of the major palaeo-environmental changes occurred in the area as a result of relative sea level changes. The lower part of the Holocene succession is represented by a trasgressive barrier-lagoon system, the onset of which is marked by beach sands. The inferred age of this marine layer is about 10 ky B.P. Due to the persistence of the sea level rise, the barrier complex shifted inland, up to a maximum distance of 1.5 km from the modern position, and the lagoon depression also migrated inland. The subsequent late Holocene environmental history was characterized by a regression phase dominated by deposition, which resulted in the progradation of the palaeo-shoreline to its modern position.

This progradation is identified by up to 10 m of Holocene deposits composed of dune sands, passing downwards to shoreface and transitional sands. Although no precise chronological constraints are available for the ^{14}C dates obtained from peaty layers, it seems that the change from a transgressive to a regressive trend of the coastline occurred when the phase of the sea level rise ended and gave way to minor fluctuations around its present position.

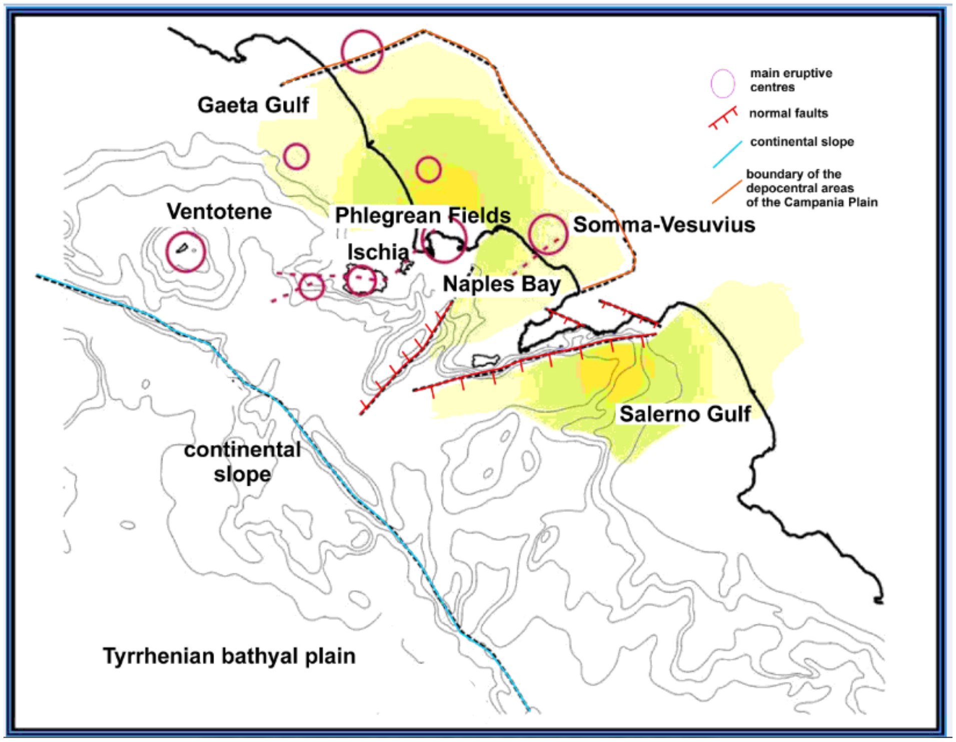
The structural features related to the 41st parallel fault zone, including the Ortona-Roccamonfina fault line have been recently studied by [Bruno et al., 2000], who revealed ESE-WNW to E-W and NE-SW striking faults. The activity of these faults developed during Pliocene-Early Plestocene times and is consistent with strike-slip movements. The faults are responsible for the SSE translation of the seaward prolongation of the Mount Massico horst. The 41st parallel fault system represents a deep-seated transfer fault system, formed as a response to different rates of the Tyrrhenian sea opening. The strike-slip and the normal movements along the 41st parallel fault and the Ortona-Roccamonfina faults are consistent with a NW-SE (Apenninic) extension.

3.2. Naples Bay and Ischia island

3.2.1. Regional Geologic Setting

From a geological point of view it is possible to put into an unique context the areas of the Phlegrean Fields and of the Ischia, Procida and Vivara islands, since they share the same tectonic setting and a common origin of magmas. They are alkali-potassic magmas which characterize all the Campania volcanoes and are, in turn, subdivided into an ultra-potassic series (leucitites and leucites-phonolites, i.e. the Vesuvius volcanic complex) and a potassic series (trachybasalts, latites-trachytes and phonolites, i.e. Ischia-Procida, Phlegrean Fields). This subdivision was already recognized in the Roccamonfina stratovolcano [Appleton, 1972], localized in the Campania Plain, to the north of the 41st parallel lineament (Figure 6) [De Alteriis and Toscano 2003].

The whole Ischia region pertains to the Eastern Tyrrhenian margin, located on a thinned continental lithosphere, transitional towards the more properly oceanic area, occurring in the Tyrrhenian bathyal plain [Sartori 2003]. The lithospheric extension, which accompanied the opening of the Tyrrhenian basin from the Pliocene to today has produced in the upper crust a strong vertical and horizontal tectonics. Along the structural lineaments, mainly Apenninic (NW-SE) and counter-Apenninic (NE-SW) the uprising of highly differentiated magmas gave rise during the last two million of years, as testified by the drilling of andesitic rocks in the subsurface to the north of the Phlegrean Fields [Ortolani and Aprile 1978].



(modified after De Alteriis and Toscano 2003).

Figure 6. Sketch map showing the main active or recent main tectonic lineaments of the Neapolitain-Phlegrean offshore. Arrows indicate gravitational instabilities (debris avalanches and debris flows).

Starting from the Late Pliocene and up to the Early Pleistocene (1.8 My B.P.), tectonically-controlled sedimentary basins, having a rectangular shape, striking parallel to the Tyrrhenian shoreline, have individuated [Cinque et al. 1997]; [Mariani and Prato 1988]; [Brancaccio et al. 1995]. The Campania Plain may be considered as resulting from the down throwing of the Meso-Cenozoic carbonatic-terrigenous basement, representing the bulk of the Apenninic chain.

This basement crops out in the Sorrento Peninsula as a NW dipping monoclinalic structure, having an average inclination of 8°-10° and crops out at the Massico Mount (to the north of the Volturno river). The sedimentary filling of the Campania Plain is represented by alluvial and deltaic deposits, interlayered with pyroclastites and lavas, Early Pleistocene in age. Based on the interpretation of multichannel profiles recorded in the Naples Bay [D’Argenio et al. 2004], the thickness of the Pleistocene sedimentary wedge has been evaluated in the order of 1.5 sec (twt), corresponding to 2 kilometers [Aiello et al. 1997a]; [Aiello et al. 1997b]; [Marsella et al. 2002].

Northwards of the Naples Bay the thickness of the Quaternary sediments is maximum in correspondence to the Volturno river mouth, where a main depocentral area occurs. The alluvial plain of the Volturno river joins seawards into the continental shelf, with the fluvial thalwegs and the related actual and fossil deltaic systems of the Sarno-Sebeto rivers in the Naples Bay and of the Volturno river in the Gaeta Gulf. Northwards of Naples the continental shelf appears well developed and wide about 15 kilometers in the Gaeta Gulf and is interrupted by polygenic volcanic complexes as the Phlegrean Fields or by strato-volcanoes as the Somma-Vesuvius.

3.2.2. Volcanology

The volcanism of the Phlegrean and Vesuvian areas is originated by the uprising of magmas having a potassic affinity, characteristic of all the Latium-Campania region, known in literature as the “Roman comagmatic province” [Peccerillo and Manetti, 1985]. The occurrence of rich in potassium magmas, often including the leucite as the main mineral, is a characteristic of many Neogene-Quaternary magmatic provinces of the Mediterranean area, including the Latium-Campania region, the Aeolian Arc, the Hellenic Arc and some examples of Anatolia and Iran [Keller, 1983]. All these magmas are not directly related to active subduction magmas, but their origin is strongly linked to old slabs of oceanic or continental lithosphere, subducted during the Europa-Africa convergence.

Several petrographic suites have been distinguished in the Roman comagmatic region [Peccerillo and Manetti, 1985], including rocks from trachybasalts to trachytes, a highly potassic suite from leuco-tephrites to leuco-phonolites and ultrapotassic series. These magmas are particularly enriched in incompatible elements and are characterized by high values of the isotopic ratio $^{87}Sr/^{86}Sr$, indicating a strong crustal contamination.

In the local frame of the Phlegrean-Ischian magmatism, the degree of differentiation may be more or less elevated, depending on the parking time in magmatic tanks, on their depth and on the entry of fluids. This explains the high heterogeneity of the petrographic types cropping out in the Ischia island, coming from the alkaline basalts to the latites and the hyper-alkaline trachytes.

The high content in potassium and the consequent abundance of syneruptive minerals has allowed for the Phlegrean-Ischian rocks a wide application of techniques of absolute dating, such as the K-Ar and more recently, the Ar-Ar. To these ones, the use of the ^{14}C method for the paleosols and the fossil organic remnants, found as carbonized woods in subaerial pyroclastic deposits.

These two main techniques applied during the last 30 years with an increasing precision due to the improvement of the analytic techniques, have furnished a notable amount of datations, which have allowed for a systematic control of the relative stratigraphy.

A sketch synthesis of the eruptive chronology related to Ischia, Procida and Phlegrean Fields has been reported in the following table (Table 1). [De Alteriis and Toscano, 2003].

It is worth noting that the subdivision in eruptive cycles at the Ischia island is mainly based on geochemical parameters, in particular the abundance of trace elements [Poli et al., 1987], more than on the volcanology. At the same time, both in the Procida island and in the Phlegrean Fields volcanic complex, the subdivision in activity phases is suggested mainly by the stratigraphy, more than by the magmatic differentiation.

Table 1. Chronology of the main eruptive events in the Ischia-Procida-Phlegrean Fields system (modified after de Alteriis and Toscano, 2003), compiled based on the syntheses of Vezzoli (1988) and Rosi and Sbrana (1987)

Ischia island	Procida island	Phlegrean Fields volcanic complex
1st cycle, older than the eruption of the Green Tuffs of the Epomeo Mt. (135-100 ky B.P.)	Volcanoes or eruptive centres of Vivara, Fiumicello, Pozzo Vecchio, Terra Murata, all older than the stratigraphic marker of the Epomeo Green Tuffs (55 ky B.P.)	
2nd cycle, Green Tuffs of Epomeo-Citara	“Breccia Museo” (Punta della Lingua) (40-28 ky B.P.)	
3st cycle (33-28 ky B.P.)		“Campanian Ignimbrite” (35-30 ky B.P.) or alternatively, cycle of the Campanian Ignimbrites
4th cycle, prehistorical (18-10 ky B.P.)	Solchiaro volcano (18 ky B.P.)	Cycle (mainly subaqueous) of the Yellow Tuffs (35-10.5 ky B.P.), including the Neapolitan Yellow Tuff
5th cycle, prehistorical-actual (10-0 ky B.P.)		Cycle (mainly subaerial) (10.5-8 ky B.P.) (Agnano1, Minopoli, Baia and Fondi di Baia)
		Recent cycle (mainly subaerial) (Cigliano 2, Agnano2, Senga, Astroni, Solfatara, M.te Nuovo) (4.5 ky B.P. – 1538 A.D.)

3.3. Agropoli Offshore

The geology of the Agropoli offshore is strongly conditioned by the geology of the adjacent Cilento Promontory, particularly in the Punta Licosa structural high [Bigi et al., 1992]; [Ferraro et al., 1997]; [Bonardi et al., 1988]; [Ciarcia et al., 2011]. Quaternary marine successions are well developed in the depocentral areas located between the mouth of the Solofrone river and the town of Agropoli. In the Punta Licosa morpho-structural high, whose offshore sector constitutes a marine ridge elongated in the Agropoli offshore, the rocky outcrops result from the seaward prolongation of the stratigraphic-structural units, widely cropping out onshore in the adjacent emerged sector of the Cilento Promontory ("Flysch del Cilento" *Auct.*) [Ciampo et al., 1984]; [Bonardi et al., 1988].

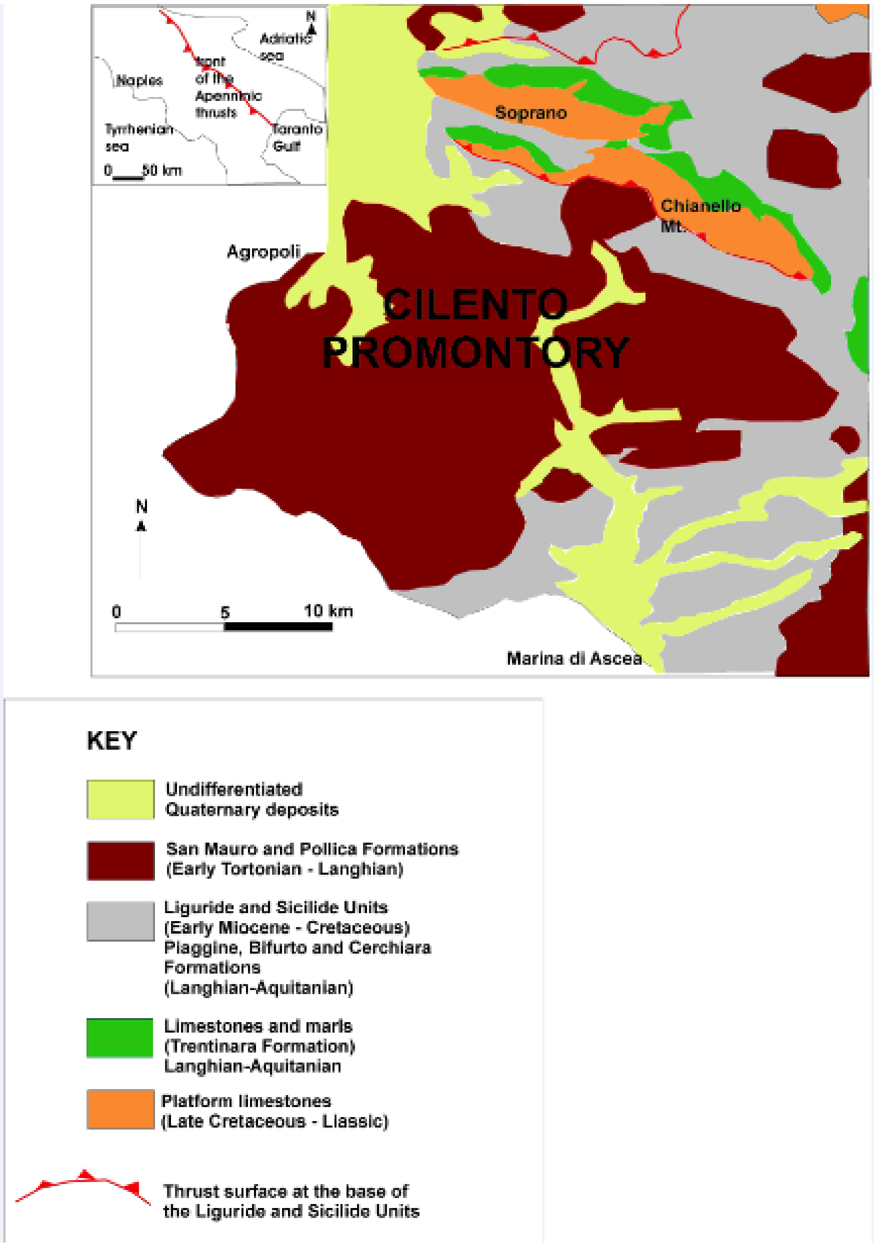
The Cilento Promontory represents a morpho-structural high, interposed between the coastal depressions of the Sele Plain – Salerno Gulf and of the Policastro Gulf. Its reliefs are composed of thick successions of turbidite siliciclastic and carbonatic sequences, dipping landwards into the main carbonatic reliefs of the Southern Apennines ("Alburno-Cervati Unit" *Auct.*). The terrains cropping out in the Cilento Promontory are composed of siliciclastic rocks, accumulated into deep basins are formed by siliciclastic rocks, accumulated into deep basins during a time interval ranging from the Late Mesozoic and the Late Miocene. The oldest one of these formations is the North Calabrian Unit, the highest stratigraphic-structural unit in this sector of the Southern Apenninic chain.

In the Cilento area it is represented by a formation ranging in age from the Malm to the Oligocene, composed of dark clays, marls and marly limestones, reaching a thickness of 1300 meters. The North Calabria unit is overlain by Early Miocene synorogenic units, showing a degree of deformation minor with respect to the overlying tectonic units.

The Cilento Flysch includes the Formations of Pollica, S. Mauro and Monte Sacro, showing an overall thickness of about 1500 meters [Bonardi et al., 1988]; [Zuppetta and Mazzoli 1995]; [Figure 7].

In the western sector of the Cilento Promontory several morphological depressions filled by alluvial deposits, whose origin has to be attributed to NNE-SSW (Alento Plain) and NW-SE (S. Maria di Castellabate and S. Marco Plains) trending structural elements, occur. The formation of these depressions happened during the Late-Middle Pleistocene [Brancaccio et al., 1995]; they include transgressive-regressive cycles referred to the glacio-eustatic oscillations of the isotopic stages 9, 7 and 5 [Shackleton and Opdyke, 1973], down thrown of several tens of meters with respect to their original altitude, between the end of the Middle Pleistocene and the beginning of the Late Pleistocene.

The Cilento Promontory has been involved by a vertical uplift of more than 400 m during the Early Pleistocene and the Middle Pleistocene. Absolute estimates of the entity of the Pleistocene uplift which involved the Cilento Promontory have been obtained through the vertical distribution of the Pleistocene marine terraces along the Cilento coasts. In the Northern Cilento the oldest marine terraces (Middle Pleistocene) are located at a maximum altitude of 350 m s.l.m. [Cinque et al., 1994]. At the Bulgheria Mt. (southern Cilento) the marine terraces of the Late Pliocene-Early Pleistocene are lifted at altitudes of 450 m above sea level; on the other side, the terraces of the Emilian are lifted at heights of 350 m above sea level [Baggioni et al., 1981]; [Lippmann-Provansal, 1987]; [Borrelli et al., 1988].



(modified after Zuppetta and Mazzoli, 1995).

Figure 7. Geological sketch map of the Cilento Promontory. These authors have carried out a structural analysis of the Cilento Unit, including turbiditic and siliciclastic terranes (Pollica and San Mauro Formations), Langhian-Tortonian in age. These terranes underwent both pre-tectonic and tectonic deformational events. The first ones have originated synsedimentary structures of a slumping type and syndiagenetic structures, including sedimentary dykes. The earliest tectonic events have originated minor reverse faults, conjugate with respect to the stratification, while the main ones have produced a regional folded structure, southwestwards verging. The latest tectonic events have produced a slight folding with domes and basins. The shear surface at the top of the Cilento unit has been interpreted as a backthrusting of the carbonatic terranes of the Alburno-Cervati unit. Based on this palaeotectonic reconstruction the Cilento Flysch represents the deformed filling of a Middle Miocene foredeep basin.

Morphological elements of the coastal areas relative to palaeo-stands of the sea level during the Late Pleistocene (isotopic stages 5e and 5c) evidence an overall tectonic stability of this tract of the shore from the Tyrrhenian stage to present-day [Romano, 1992]. The lack of relevant vertical movements during the last thousand of years is evidenced by the altimetric position of the Versilian beach deposits; these deposits have been observed in the fluvial coastal depressions, incised during the previous glacial regression, for more than 2 kilometers in the inner of the shoreline [Cinque et al., 1994].

The present-day coastal cliffs of the Cilento are incised in the arenaceous-silty successions of the "Pollica Formation" [Bonardi et al., 1988]. The geological survey of the Quaternary deposits between the towns of Agropoli and Ogliastro Marina has evidenced the occurrence of five sea level palaeo-stands at altitudes ranging between 25 m and 1.5 m above sea level. The oldest levels, the Comenale Complex and the S.Antonio-S. Marco sandstones Complex have been tentatively ascribed to the stages 9 and 7 of the isotopic stratigraphy [Martinson et al., 1987]. The successive paleo-stands (+ 8, + 10, + 4 m above sea level) are represented by abrasion terraces and notches, ascribed to the stages 5e and 5c of the isotopic stratigraphy.

3.4. Maratea Offshore

The Maratea Valley (Basilicata, Southern Italy) and the surrounding offshore is characterized by deep gravitational movements, involving the calcareous-dolomitic formations (tectonic units "Alburno-Cervati" and "Bulgheria-Verbicaro"), interpreted as sackung-type phenomena. The complex morpho-structural setting of the study area has been influenced by Pleistocene extensional tectonics, probably still active. The tectonic dislocations, characterized by a strike-slip component on a regional scale [Schiattarella 1998] have controlled the tectonic superimposition of the Bulgheria-Verbicaro Unit on the Crete Nere Formation. This formation outcrops in tectonic contact with the Alburno-Cervati unit ("Campania-Lucania carbonate platform" *Auct.*); [D'Argenio et al., 1973]; [Ippolito et al., 1975], cropping out on the right side of the valley.

The Alburno-Cervati unit is mainly composed of calcilutites and calcarenites, Cretaceous in age, and of grey calcilutites and calcarenites with *Alveolinae* and *Spirolinae*, with intercalations of green and red marls of the Trentinara Formation [Selli, 1962]. The succession passes upwards to Miocene flysch deposits [Selli, 1962], constituted of glauconitic calcarenites, marls and sandstones (pre-orogenic flysch), by polychrome calcirudites (Piaggine breccias) and sandstones in strata and banks, marls and silty marls (sinorogenic flysch) [Sgrosso, 1981].

Normal faulting, block rotations and structural widening of the valley are produced as an effect of differential velocity during strike-slip tectonics. The "Crete Nere" flysch ("Liguride Units") takes on a plastic behaviour due to high water contents. It is affected by a flow-type, relatively deep process (30-50 m) within the valley and near the sea. It constitutes a lubricant base for detrital covers and carbonatic units outcropping along its left flank and nearest reliefs, where deep gravitational movements develop.

The geological sketch map of the study area [Aiello et al., 2010a] has shown the main stratigraphic-structural and morphological lineaments of the study area, related to the activity of palaeo-landslides and recent landslides. In particular, the outcrop of the carbonate rocks in the Maratea Valley is localized on the southern rim of the valley. In the Monte Crivo area both fossil and recent scarps occur; moreover, reactivation processes due to deep gravitational processes are documented. Large slabs of breccias and limestones related to the slide bodies occur in the central part and along the south-western and south-eastern flanks of the valley, surrounded by breccias and detritus, Holocene in age. A main direction of the slide movements towards the Tyrrhenian coastline has been surveyed [Rizzo, 1997].

The Tyrrhenian continental margin between the Salerno Gulf and the Calabria region (Southern Italy) is characterized by several physiographic units [Coppa et al., 1988]; [Ferraro et al., 1997].

Proceeding from north towards south, the continental shelf of the Salerno Gulf is situated in correspondence of a peri-tyrrhenian basin (Sele Basin) and is characterized by a slope of 0.3°-0.8° and by a gradual shelf break, located at a depth varying between – 120 m and – 210 m. The Salerno continental shelf presents a thick Holocene sedimentation; at the base of this sedimentation, the wurmian erosional truncation occurs, cutting older deposits, frequently characterized by Pleistocene prograding wedges.

The Cilento continental shelf, located in correspondence to the structural high of the Cilento Promontory, shows a slope varying between 0.3° and 0.8°; its shelf break, located at – 220 m of depth, is abrupt. This continental shelf is characterized by a scarce or absent Holocene sedimentation and by the wide diffusion of relic deposits and morphologies; it reaches its maximum widening in correspondence of the Acciaroli town.

The continental shelf between the Palinuro Cape and the Scalea Cape (including the main physiographic unit of the Policastro Gulf) shows very reduced sedimentary deposits and is crossed by the heads of several channels, triggering extended erosional processes. Its extension is variable, with maximum values reaching 7.5 kilometres at Punta degli Iscoletti and off Sapri and minimum values of less than one kilometer between Punta degli Iscoletti and the Bussento river mouth. The continental shelf shows its maximum extension in correspondence to the Policastro Gulf, where it reaches a width of about 7 kilometres.

Like the Salerno Basin, the Policastro basin also shows a thickness of sediments of less than one thousand meters, with a subsidence velocity estimated in the order of 0.2-0.6 m/1ky [Bartole, 1983]; [Bartole et al., 1984]. Offlap sedimentary successions occur in the study area, determining a seaward progradation of more than 10 kilometers. The prograding sedimentary wedges, deposited during the lowstand phases of the sea level of the Middle-Late Pleistocene were eroded during the phases of subaerial exposure of the continental shelf and the successive episodes of eustatic sea level rise [Ferraro et al., 1997]. This has determined the formation of wide erosional surfaces at several stratigraphic highs, truncating the prograding units.

The area is characterized by the occurrence of a wide erosional surface, extending from the sea bottom up to – 160 m of water depth; this suggests that this surface correlates with the last glacial episode (18 ky B.P.), i.e. the wurmian regression. Bioclastic sands, characterized by prograding reflectors, occur along two belts localized between – 120 m and – 160 m of water depth and parallel to the Tyrrhenian shoreline; these deposits are interpreted as parts of submerged beachs related to the isotopic stage 2, based on the identification of *Arctica islandica*, cold host of the Pleistocene, actually extinct in the Mediterranean [Trincardi and Field, 1991]; [Ferraro et al., 1997].

Vertical normal faults involve the sectors of the outer shelf and upper slope, propagating in some cases up to the present-day sea bottom; this suggests a recent tectonic activity, often triggering instability processes along the slope.

The trending of the continental shelf between Palinuro Cape and Scalea Cape and of related isobaths follows the physiography of the present-day coastline. The shelf break is abrupt and reaches water depths inferior to – 95 m in correspondence to the narrowest sectors of the shelf, while in the more extended sectors it reaches – 150 m of water depth. In proximity of the shelf break a morpho-structural terrace occurs with a slope of about 10 meters and a step of about 100 meters [Pennetta, 1996a; 1996b]. The main source of sediments of the inner shelf is represented by the Bussento river and its tributaries, draining a wide hydrographic basin located between Torre Orsaia and Casaletto Spartano; they are responsible for the formation of a mouth coastal system having low sandy coasts from Torre Orsaia to Villammare. Under the wurmian erosional surface, seaward prograding deposits occur. They are silty-sandy and relic, genetically related to lowstand phases of sea level. Above this unconformity, coastal and marine depositional systems have been recognized and seem to be linked to the progressive retreating of the coastline induced by the eustatic rise successive to the glaciation, determining a vertical aggradation of the continental shelf of about 10-15 m. The continental shelf is reached by several channel heads, dissecting the slope and inducing the generalized recession of the platform break; this evolves into an abrupt slope; over the shelf break, mass gravity movements, as slumpings, originate.

The shelf/slope system, occurring in this sector of the eastern Tyrrhenian margin, is quite immature from a morphological point of view, as shown by the occurrence of thin sedimentary deposits. Large volumes of sediments occur in the Sapri basin; the sediment collecting role played by this basin is facilitated by the effect of barrier operated by the submarine highs bounding the basin itself [Fabbri et al., 1981]. The Sapri Basin is bounded to the north and to the west by the abrupt and incised continental slope surrounding, and to the south, by the narrow continental shelf, with high gradients located between Punta degli Iscoletti and Capo Scalea while to the west it is bounded by some morpho-structural highs (slope ridges) with a N-S direction, that are subparallel to the coastline and act as a threshold for sediment dispersal.

4. DATA ACQUISITION AND PROCESSING

4.1. Volturno and Capri Basins

A high resolution shallow marine seismic survey (Sister – Seismic Investigations in South Tyrrhenian Extensional Regions) has been carried out in the 1999 aimed at collecting regional deep seismic sections on the Southern Tyrrhenian continental margins and in the Tyrrhenian bathyal plain [Bertotti et al. 1999]; [Korevaar et al. 2000]; [Pepe et al. 2010]; [Aiello et al. 2008]; [Aiello et al. 2011a]; [Aiello et al., 2011b]; [Aiello et al., 2011d].

Removal/reducing coherent noise such as multiples has allowed for an accurate velocity analysis and to the application of the predictive deconvolution. This technique concurred to obtain high-quality seismic data, also in areas where the occurrence of pyroclastic levels and volcanic bodies produce a high scattering of the acoustic energy.

Table 2. Acquisition parameters of the seismic survey Sister

Type of seismic source	N.2 Airguns, G/I gun SI/Sodera
Record length	5 sec (two-way travel times)
Shot interval	25 m
Hydrophones interval	12.5 m

The seismic data have been recorded digitally, using airguns, a 48 channel seismic streamer and a system of seismic acquisition and processing. The acquisition parameters are represented in the Table 2.

The seismic processing has been carried out through the software “ProMax2D” (Landmark Ltd.) and the “Seismic Unix” (Colorado School of Mines) [Aiello et al. 2011b]. The applied flux of elaboration consisted of pre-processing, processing and of post-stack processing.

The pre-processing included the trace editing geometry; the processing included the trace muting (top), the bandpass filtering, the automatic gain control, the predictive/spiking deconvolution, the velocity analysis, the Normal Move-Out (NMO) Correction and the Common Depth Point (CDP) Ensemble/Stack. Finally, the post-stack processing included the Heigen vector filtering. The seismic data have been promoted to produce stacked sections, ready to be interpreted.

The technique of multiple attenuation was made up of both stacking and predictive deconvolution. The move-out between the primary reflections and the multiple ones was discriminated through the stacking defining a correct velocity function of the primary reflections and relieving the mistaken coherent noise [Yilmaz 1988]. The efficiency of stacking improves with the increase of both coverage and maximum offset, increasing the trace numbers to be added to the CMP-gathers.

The predictive deconvolution has been carried out in order to eliminate or reduce the multiple signals which characterize the seismic sections, allowing to get back the high frequencies and to reconstruct the waveform. On the other side, the deconvolution consisted of the convolution of the seismogram with a reverse filter (filter of Wiener), improving the temporal resolution of the datum. After the deconvolution, the seismic data will appear more compressed and, therefore it will be simpler to identify the seismic reflectors during the geological interpretation.

4.2. South-Eastern Ischia Offshore

A densely-spaced grid of single-channel seismic profiles has been recently acquired and interpreted in the frame of research programmes of marine regional cartography (CARG Project) financed by the Region Campania, Sector of Soil Defence, Geothermics and Geotechnics during the realization of the geological sheet n. 464 “Isola d’Ischia” at the scale 1:25.000 [Aiello et al., 2012; in press]. Some of the collected seismo-stratigraphic data are here interpreted and discussed to highlight new implications on the structural and stratigraphic setting of the Ischia volcanic complex, focussing, in particular, on the south-eastern offshore of the island [Aiello et al. 2012; in press].

The seismic grid analyzed in this paper has been recorded through a Sparker Multitip seismic source in the frame of the CARG research program, financed by the National Geological Survey of Italy coupled to the Regione Campania during the activities of acquisition and mapping of sea bottoms of the Ischia island up to the – 200 m isobath (Geological Map n. 464 "Isola d'Ischia"; scale 1:25.000; 2010; in press) [Aiello et al. 2009b].

The seismic lines have been plotted on the marine DEM of the Ischia island, allowing for a detailed geological interpretation of main morpho-structures occurring at the sea bottom. The seismic grid consists of 13 dip seismic lines in the southern Ischia offshore, perpendicular to the shoreline and 2 tie lines parallel to the shoreline [Aiello et al. 2012; in press].

The seismic acquisition has been carried out by using a multielectrode sparker system (SAM96 model). The advantages of the Multitip Sparker include shorter pulse lengths for an equivalent energy discharge, as well as an increase in peak pressure, i.e. the amplitude of the outgoing acoustic wave. The sparker source used in this survey generated 200 J in the 200-2,000 frequency range. The ship positioning was determined using a GPS system with a position accuracy of 1 m. All the seismic sections were recorded graphically on continuous paper sheets with a vertical recording scale of 0.25 s. The best vertical resolution was approximately 1 m for sparker data. The seismic grid covering south-eastern Ischia island facilitated stratigraphic correlations between seismic sections and revealed structural and stratigraphic variations along the seismic lines. On the other side, Multibeam bathymetric data have been collected by using the Reson Seabat 8111 Multibeam Sonar system, which properly works in the 50-600 m depth range. The Multibeam system, interfaced with a Differential Global Positioning System (DGPS), was mounted on keel of ship and composed of a ping source of 100 kHz, 150° degree for the whole opening of the transmitted pulse and a 101 beams-receiver, with a beam opening of 1.5°. Sound velocity profiles (CTD) were regularly recorded and applied every 8 hours. The data were processed by using the PDS2000 software (Reson-Thales), according to the IHO standard [IHO 1998], with a real time acquisition control and partial beam exclusion filtering applied to the bathymetric data directly onboard. Consequently, the offline swath editing and de-spiking have been carried out. The DTM (Digital Terrain Model) generation and rendering of the whole dataset was subsequently reorganized in a MXN matrix (DTM) having a grid cell of 20x20 metres [Aiello et al. 2012; in press].

4.3. Salerno Valley

Seismo-stratigraphic and morpho-bathymetric data on the Southern Campania continental margin, between the Sorrento Peninsula-Capri island elongment, to the north, and the Salerno offshore, to the south, have been collected during the oceanographic cruise SisterII (December 2004). The geophysical data were acquired at water depths ranging between 100 m and 1000 m. The Multibeam acquisition was carried out by using the Reson Seabat 8160 deep-towed Multibeam, whose calibration was capable of surveying sea bottoms at water depths ranging from 5 m to 4000 m [Aiello et al., 2009].

The acquisition of Multibeam lines has been achieved by using a coverage of 50% and following navigation lines parallel to the isobaths. The Multibeam line spacing, varying as a function of the sea bottom water depths, is comprised between 500 m ca for water depths of

100 m and 1 km for water depths of 800 m. The visualization of the bathymetric data during the acquisition was made possible by a colorimetric scale, in which the colours correspond to different bathymetric belts. During the Multibeam acquisition the calibration of bathymetric data was allowed by CTD profiles.

Subbottom Chirp profiles have been contemporaneously recorded with the aim of calibrating the morphological setting of the sea bottoms. The post-processing of the Multibeam data has enabled the construction of detailed bathymetric data, following the standards of the National Hydrographic Bureau [IHO 1998].

Multichannel reflection seismic profiles have been recorded according to the acquisition parameters reported in the Table 3.

The pre-processing of seismic data has been carried out through the editing and assignment of the field geometry of seismic dataset, the reduction of random noise in the data and the reduction of spatial aliasing by means of trace interpolation on common shot gathers. Pre-stack and post-stack data migration allowed for a better localization of the reflectors on the seismic sections.

Cycles of velocity analysis and residual static corrections improved the quality of the velocity function and, therefore, the NMO correction.

Pre-stack spiking deconvolution widened the frequency spectra of the signal and boosted data resolution. FK filtering on NMO corrected data, CDP gathers and pre and post stack predictive deconvolution weakened multiple reflections.

4.4. Agropoli Offshore

The data acquisition has been realized during the oceanographic cruise GMS03-01 (October 2003) by using a Subbottom Chirp profiler, suitable for geological mapping. The navigation map of the study seismic sections is reported in the Figure (Figure 8). The data processing has been realized through the software Seisprho, dedicated to the interactive elaboration and the geological interpretation of high resolution seismic reflection profiles [Gasperini and Stanghellini 2009]. The program processes files recorded in a SEG-Y format and produces, as a final result, seismic sections as bitmap images. Algorithms of seismic elaboration are included in the program, as the filtering, the deconvolution and several other basic modules. Seisprho realizes several interactive functions for the analysis of the seismic signal and the geometric control of the geological characteristics through a combined visualization of seismic sections and morphological maps.

Table 3. Acquisition parameters of the seismic survey Sister2

Seismic source and acquisition system	G/I Airguns, SSI Sodera Geometrics Stratavisor 24 bit seismograph 48-channel seismic streamer
Sample interval	0.5 milliseconds
Windows time	5 seconds
Receive interval	6.25 meters
Shot interval	25 meters

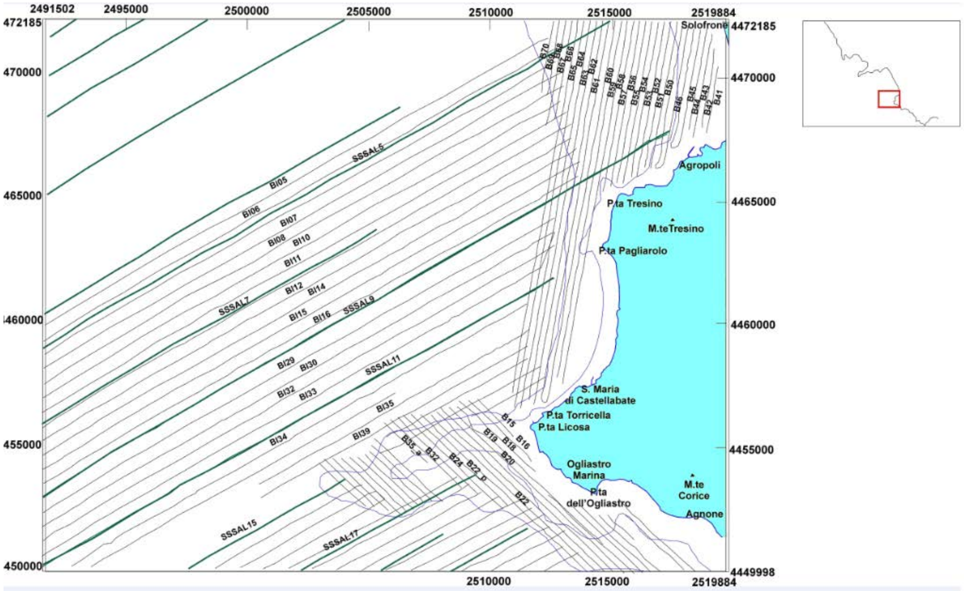


Figure 8. Navigation map of the seismic sections (Subbottom Chirp) recorded in the Agropoli offshore.

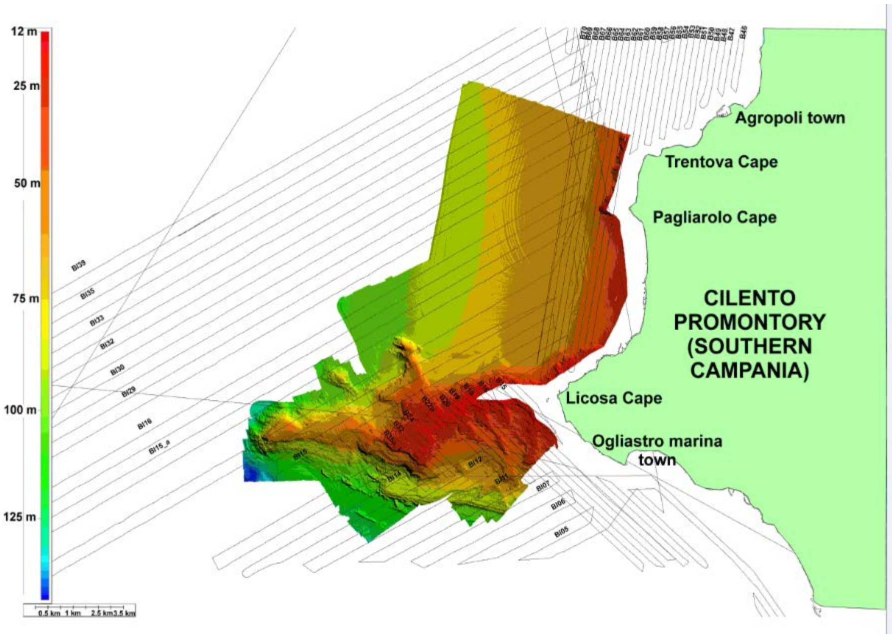


Figure 9. Digital Elevation Model (DEM) offshore the Punta Licosa morpho-structural high with superimposed Subbottom Chirp seismic sections.

The use of the software has allowed the elaboration, the filtering and the cartographic restitution of a grid of more than 100 Subbottom Chirp seismic sections. The most used filters are the Time Variant Gain (TVG) in an interval varying between 0.0035 and 0.01 db and the Linear Gain (L'Gain) in an interval varying between 1.2 and 5.6 db.

High resolution seismic data analyzed in this chapter are located on the continental shelf surrounding the Cilento Promontory, between 10 m and 160 of water depth. The grid of seismic sections is densely spaced (line spacing of 250 m), as a function of a contemporaneous acquisition of Sidescan Sonar and magnetic profiles. The Digital Elevation Model of the Tyrrhenian offshore surrounding the Punta Licosa morpho-structural high, on which the Chirp profiles have been superimposed is reported in the Figure (Figure 9).

4. 5. Maratea Valley

High resolution seismic profiles were acquired during the oceanographic cruise GMS00-05 (October-November 2000), using a Watergun 15 c.i. seismic source coupled to an acquisition system for multichannel seismics Stratavisor (Geometrics Inc.).

Subbottom lines have been recorded on the same navigation lines of seismics [Aiello et al. 2010a]. The recorded seismic profiles have provided interesting evidence of the offshore prolongation of the Maratea Valley [Rizzo, 1997]. The study sections are located in the Policastro Gulf; two profiles run perpendicularly to the Tyrrhenian coastline (seismic profiles S120 and S130b), the other runs parallel to the coastline (seismic profile S130) [Aiello et al. 2010a]. Multichannel seismic profiles have allowed to study the tectono-stratigraphic framework of continental shelf and slope successions; on the other side, the geological interpretation of Subbottom Chirp lines, recorded on the same navigation lines of multichannel data, has allowed a detailed stratigraphic study of the first sub-bottom (several tens of meters under the sea bottom). Multichannel data have been processed through the Seismic Unix software [Colorado School of Mines, 2000] and involved the extraction of the first channel from the shot gathers and subsequent application of filtering Automatic Gain Control; the spectral analysis of seismic traces by using the Fourier Transform and the application of time variant gain (TVG) in order to reduce the seismic noise on the sections.

The acoustic data collected by Subbottom Chirp profiles were also processed through the Seismic Unix software [Aiello et al., 2010a]. Scale changes due to water depth in the SEG-Y format subbottom data were eliminated, with the modified data then plotted graphically. This allowed the cartographic representation of profiles, with a uniform vertical scale. Seismic sections were integrated with a time-variant gain, uniform with increasing depth, which allowed to increase the resolution of the seismic signal on the sections. This improved their quality and facilitated the geological interpretation.

4. SEISMIC STRATIGRAPHY OF CONTINENTAL SHELVES OF SOUTHERN ITALY: SELECTED EXAMPLES OF CAMPANIA AND BASILICATA OFFSHORE

4.1. Seismic Stratigraphy of the Volturno Basin (Northern Campania Continental Margin)

A deep seismic profile recorded in the Volturno basin and presented in this chapter outline a geological picture of the deep structures of the investigated area, with particular reference to the stratigraphic relationships between the Meso-Cenozoic acoustic basement and the Quaternary basin filling. Deep exploration wells in Campania and Latium of the Tyrrhenian margin [Ippolito et al., 1975]; [Ortolani and Aprile, 1978] have supplied litho-stratigraphic data that have been used to define the commercial seismic profiles.

The stratigraphic and structural data collected in the Volturno basin have been compared with commercial seismic data of “Zone E” (AGIP), with particular attention to the Terracina and Gaeta basins, which are examples of half-graben basins and are located on the Campania-Latium Tyrrhenian margin [Aiello et al., 2000]. This has allowed a better geological interpretation of the deep seismic line, which has been put into a regional geological context through the re-interpretation of some of the profiles from the commercial seismic data. All the three basins (Volturno, Terracina and Gaeta) show the formation of wide deltaic systems on the Pleistocene continental shelf that are genetically related to the rivers that crossed the adjacent coastal belt and formed the alluvial plains of Latium (Pontina and Fondi Plains) and Campania (Garigliano and Volturno plains).

The main regional morpho-structures of the northern Campania continental margin recognized by the reflection seismic profiles and desumed from the commercial seismic data of Zone E have been represented in a sketch map (Figure 10); [Bartole, 1984]; [Aiello et al., 1996]; [Aiello et al., 2000]; [Bruno et al., 2000]; [de Alteriis et al., 2006]. These structures are the following:

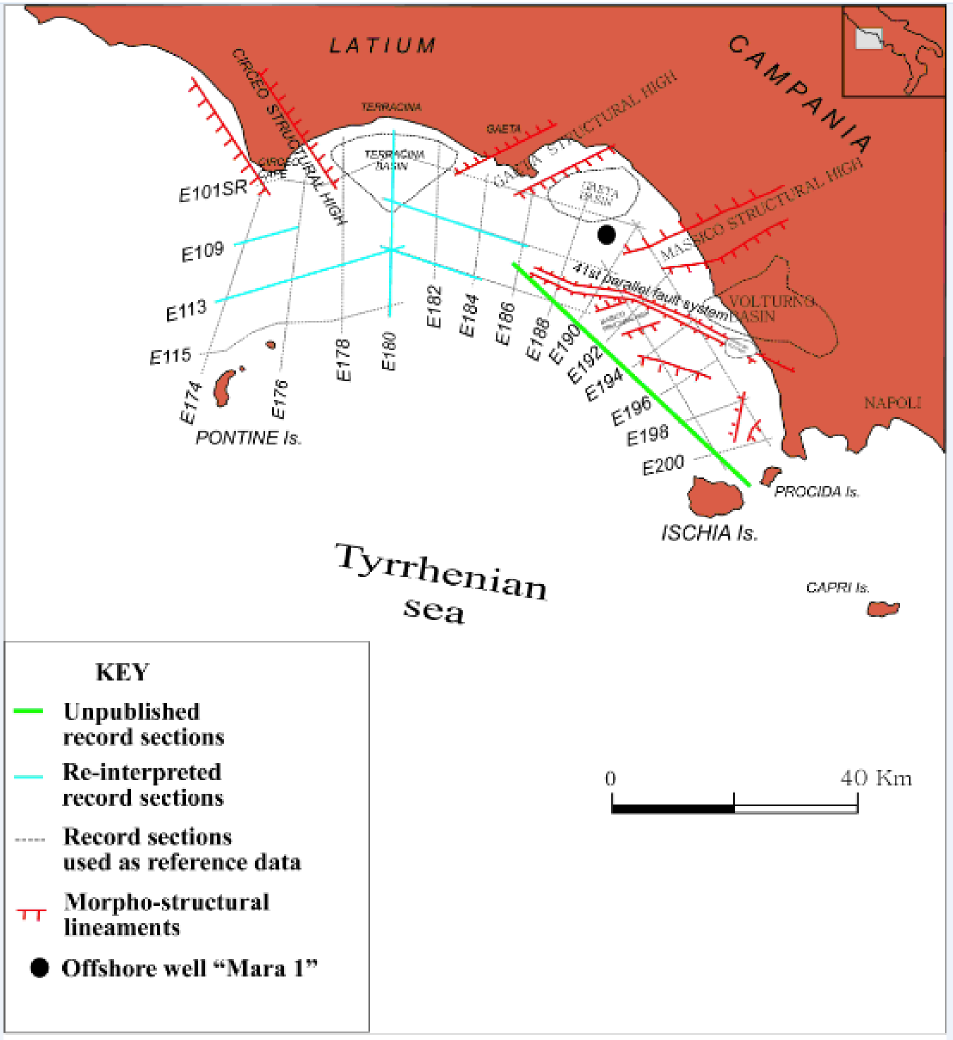
- the Circeo structural high, with a NW-SE trending, which represents the seaward prolongation of the Circeo Promontory;
- the Terracina basin, a N-S trending half-graben basin, which widens seaward and laterally joins with the Gaeta basin;
- the Terracina-Gaeta structural high, a wide belt of structural highs outside of the Gaeta town, which represents the physiographic separation between the Terracina and Gaeta basins;
- the Massico structural high, a NE-SW trending structural high, which represents the seaward enlargement of the Massico Mount structural high;
- the Volturno basin, where the basin filling reaches a thickness of 2.5 sec.

The Volturno basin takes up the northern sector of the Campania Plain, which underwent pronounced tectonic subsidence during Quaternary times.

It is bounded to the north-northwest by the NE-SW trending Massico Mount structural high, to the east by a series of NW-SE striking normal faults, down throwing the platform carbonates that crop out in the Caserta Mountains.

The Volturno basin has a volcanic body that is genetically related to the Villa Literno volcanic complex [Baldi et al., 1976]; [Barbieri et al., 1976]; [Di Girolamo et al., 1984]; [Rosi and Sbrana, 1987]. To the west, in the surrounding offshore, it is limited by a volcanic structural high that runs parallel to the shoreline and represents a buried volcanic edifice at the mouth of the Volturno river [de Alteriis et al., 2006].

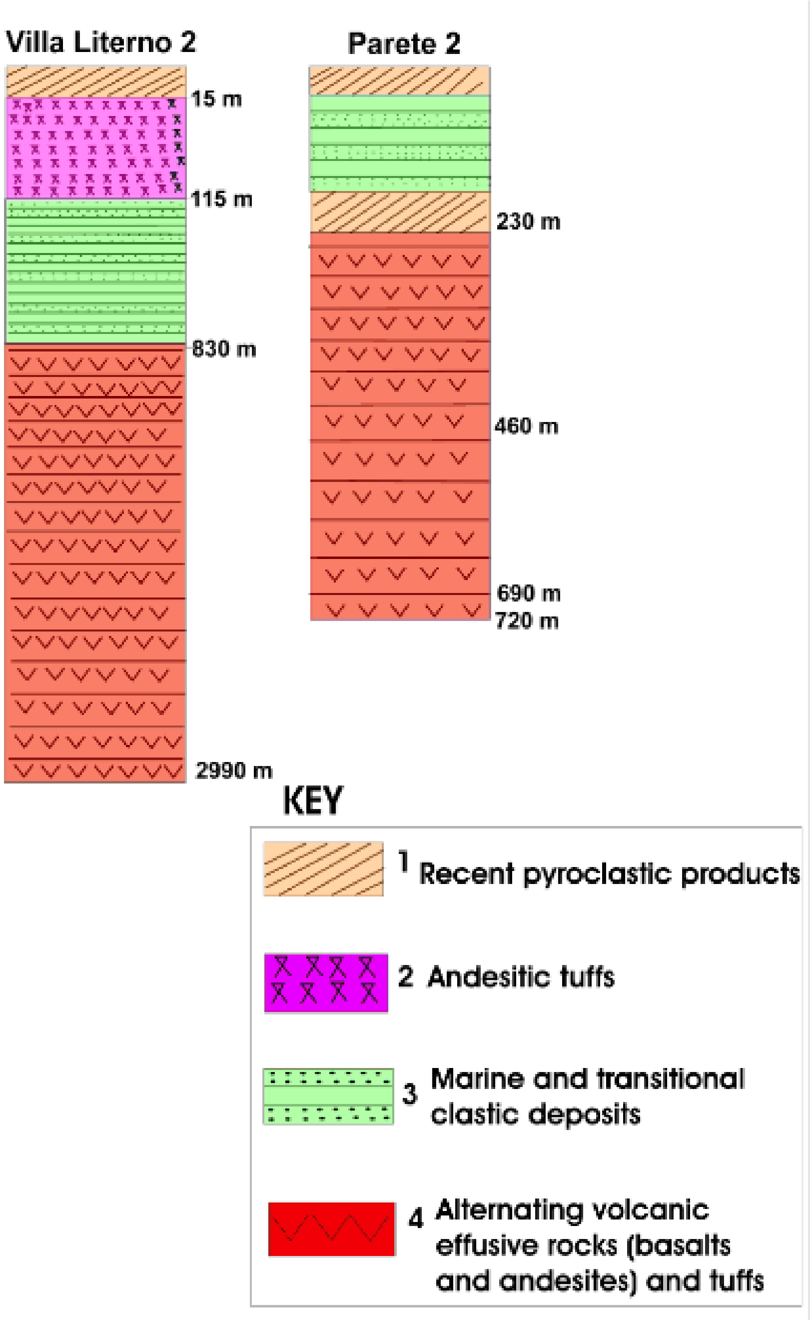
The litho-stratigraphic attribution of the Parete and Villa Literno volcanic complexes has been described by several authors [Ortolani and Aprile, 1978], showing the stratigraphy of the corresponding wells (Figure 11).



(after Bartole 1984; Bruno et al. 2000; Aiello et al. 2000; de Alteriis et al. 2006).

Figure 10. Sketch map of the interpreted seismic sections in the Volturno Basin (modified after Aiello et al. 2011). Unpublished record sections, re-interpreted record sections and record sections used as reference data are indicated. The regional morpho-structures on the Northern Campania Tyrrhenian continental margin detected through reflection seismic profiles are also shown.

In the Villa Literno 2 well, west of Parete (Campania), below recent pyroclastic products the drill site encountered andesitic tuffs (about 150 m thick) overlying marine and transitional clastic deposits (about 650 m thick). Alternating basalts-andesites and tuffs were encountered at depths between 830 m and 2980 m. The borehole reached a maximum depth of 2990 m, crossing lava products about 2150 m thick that probably continue at increasing depths. In the Parete 2 drill site (Figure 11), located in the Parete area, which is characterized by positive magnetic and gravimetric anomalies, the borehole was drilled through alternating basaltic and andesitic lavas below recent pyroclastic products and clastic deposits that are about 300 m thick [Baldi et al., 1976]; [Ortolani and Aprile, 1978].



(modified after Ortolani and Aprile, 1978).

Figure 11. Schematic stratigraphy of the “Villa Literno 2” and “Parete 2” lithostratigraphic wells.

The maximum development of the sedimentary bodies in the Volturno basin is conditioned by the Massico structural high, which forms the boundary of the basin towards the north-west. This produces depositional geometries typical of a NE-SW trending fan complex. Qualitative calibration of the seismic sequences that fill the sedimentary basin were carried out through the lithostratigraphic data of the “Castelvolturno 2” deep borehole, near the town of Cancello Arnone [Ippolito et al., 1973]. The well was drilled through alternating pyroclastic levels and conglomeratic deposits of lagoon and deltaic environments, which evolve upwards to marine sediments.

The seismo-stratigraphic analysis of the Sister4_2 seismic profile has shown the depositional geometries of the filling of the Volturno basin, which overlies an acoustic basement that probably corresponds to the top of Meso-Cenozoic carbonates and at depths between 1800 m and 1950 m (Figure 12). The geological interpretation of the deep seismic line has been constrained by well data and scientific literature on this argument. In particular, the lithology of the seismic units was inferred from the lihostratigraphic data of the "Castelvolturno 2" and "Villa Literno 2" boreholes and defined by additional seismo-stratigraphic data [Mariani and Prato, 1988].

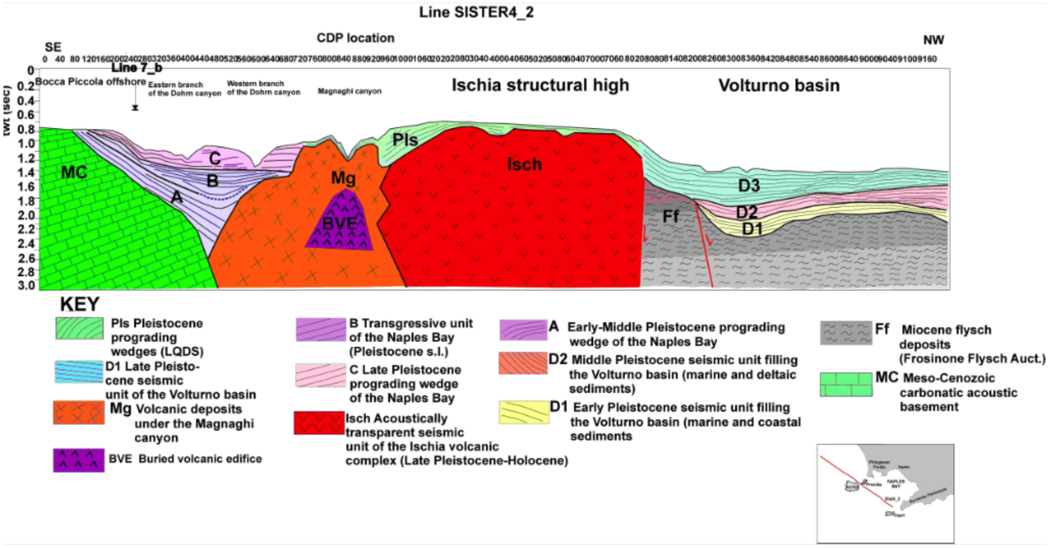
A deep seismic unit has been related to the Meso-Cenozoic carbonates ("Campania-Lucania carbonate platform"; Figure 12); [D'Argenio et al., 1973].

The carbonatic basement is overlain by a thick seismic sequence that is characterized by a chaotic seismic facies with scattered discontinuous reflectors, showing an evident structure with faulted blocks. The top of this seismic sequence is at depths from 1125 m to 1350 m. It probably correlates with the Miocene flysch deposits ("Flysch di Frosinone" *Auct.*), which widely crop out in the adjacent emerged sectors of the Latium-Campania Apennines [Parotto and Praturlon, 1975]; [Accordi and Carbone, 1986].

Relatively complex depositional geometries have been observed in the Volturno offshore through seismo-stratigraphic interpretation. An acoustically-transparent seismic sequence has been interpreted as volcanites (VC; Figure 12), which is Quaternary in age and genetically related to the Villa Literno volcanic complex ("Villa Literno 2" well); [Ippolito et al., 1973]; [Mariani and Prato, 1988].

The filling of the Quaternary basin is composed of four main seismic sequences. The first of these, constituted of shales of coastal environment (Pleistocene) is a seismic unit with parallel to subparallel seismic reflectors, from discontinuous to continuous. It shows an evident wedging, which testifies to its deposition during the tectonic activity of normal faults that involved the underlying acoustic basement. On the continental shelf, the second seismic sequence shows evident progradational geometries, which overlies a downlap surface with a low angle (Figure 12). This has been interpreted as a relic prograding wedge downlapping on volcanic rocks that are genetically related to the Villa Literno volcanic complex (VC; Figure 12). In the basin, the second seismic sequence is characterized by discontinuous, parallel-to-sub-parallel seismic reflectors, which were probably deposited in a deltaic depositional environment. Both the third and fourth seismic sequences are organized in parallel-to-sub-parallel seismic reflectors, which are from discontinuous to continuous. There are unfilled distributor channels in the uppermost sequence.

The new seismo-stratigraphic data collected for the Volturno Basin confirm that it represents a half-graben (accordingly to Mariani and Prato [1988]), that is characterized by blocks that are down thrown along normal faults, and which mainly affect the top of the Miocene siliciclastic sequences. Seismo-stratigraphic evidence suggests that the activity of these normal faults probably lasted during a time interval spanning from the end of the Late Miocene (the assumed age of the Frosinone Flysch) [Parotto and Praturlon, 1975] to the Early Pleistocene (the assumed age of the first seismic sequence of the basin filling) [Mariani and Prato, 1988]. Indeed, the basal sequence shows an evident wedging geometry, which indicates its synsedimentary nature.



(modified after Aiello et al., 2011).

Figure 12. Geological interpretation of the Sister4_2 seismic profile. The lithology was inferred from the lithostratigraphic data of the "Castelvolturno 2" and "Villa Literno 2" boreholes and defined by additional seismo-stratigraphic data.

Similar to other sedimentary basins offshore of Campania, the volcanic deposits are well developed and interstratified in the sedimentary filling of the basin. This is also the case for a volcanic body that is genetically related to the Villa Literno volcanic complex (Figure 12) and correlates with the Quaternary volcanites drilled by the Villa Literno 2 well [Ippolito et al., 1973]; [Ortolani and Aprile, 1978]. The emplacement of this volcanic body appears to be successive to the main part of the tectonic extension in the sedimentary basin. However, we cannot exclude that the normal faults represented the preferential route for the magma uprising of the VC volcanic complex. Here, direct evidence of normal faulting corresponding to these volcanites is difficult to assess, as is their detailed relative chronology with the fault systems and their stratigraphic relationship with the filling in the basin, due to the large scattering of the volcanic sequence.

In the Table 4 the main characteristics of the seismic units of the Volturno basin are reported.

4.2. High Resolution Seismic Stratigraphy of the South-Eastern Ischia Island (Naples Bay)

Some concepts of the seismic stratigraphy and applications to the Ischia volcanic complex (Naples Bay) are herein resumed before to show the regional example of the Ischia island based on high resolution (Sparker) seismic profiles.

The seismic stratigraphy is a methodology of geological survey of the subsurface, typically developed on the marine sequences of Atlantic-types passive continental margins, starting from the end of 70th (Vail et al., 1977; Mitchum et al., 1977).

Table 4. Table reporting the main characteristics of the seismic units in the Volturno Basin

Seismic unit	Lithology	Seismic facies
4 (Volturno basin filling)	Shales of coastal environment (Pleistocene)	Parallel to sub-parallel seismic reflectors, from discontinuous to continuous
3 (Volturno basin filling)	Alternating sands and shales of deltaic environment (Pleistocene)	Parallel to sub-parallel seismic reflectors with high amplitude
2a/2b (Volturno basin filling)	Alternating sands and shales of deltaic environment (Pleistocene)	(a) Relic prograding wedge downlapping on volcanites genetically related to the Villa Literno volcanic complex (b) Seismic unit with discontinuous, parallel to subparallel seismic reflectors
1 (Volturno basin filling)	Sands, conglomerates and shales with levels of pyroclastites	Parallel to sub-parallel seismic reflectors, from discontinuous to continuous
VC	Volcanic deposits, genetically related to the Villa Literno volcanic complex	Acoustically-transparent
FLS	Miocene flysch deposits (“Flysch di Frosinone” *Auct.*)	Chaotic seismic reflectors
MC	Meso-Cenozoic carbonates (“Campania-Lucania carbonate platform”)	Chaotic seismic reflectors with some intercalated continuous reflectors

Its basic principle is that the reflectors visible on the seismic reflection profiles (corresponding to contrasts of acoustic impedance, product of the seismic velocity for the density) match to the stratal plans and consequently, the geometries visible on the seismic profiles match to the depositional geometries. The seismic sections offer then the possibility to investigate the subsurface through realistic stratigraphic sections of sedimentary sequences.

The seismo-stratigraphic analysis, based on recognition of lower and upper terminations of seismic horizons (onlap, erosional truncation, downlap, toplap) with respect to main unconformities bounding the depositional sequences (Type 1 or Type 2 sequence boundaries; Vail et al.., 1984) offers the opportunity to reconstruct the tectono-stratigraphic evolution of a sedimentary basin in terms of sea level eustatic oscillations.

Sequence stratigraphy models find an easy application in relatively undeformed areas, characterized by a normal marine sedimentation, although seismic models have been largely applied on structured tectonized regions. In the Ischia island it is worth noting the occurrence of isolated volcanic bodies, as intrusions, domes, volcanic necks and tabular, acoustically transparent seismic units. This makes the sequence stratigraphic approach particularly complex to the geological interpretation of seismic profiles. On the contrary, the pyroclastic edifices and/or the buried pyroclastic deposits may be well detected, due to their internal stratification. As a consequence, the seismic stratigraphy of the Ischia offshore is more complex and difficult to interpret with respect to the stratigraphy of the eastern sector of the Naples Bay, where sedimentary seismic units prevail, apart from the Dohrn canyon morpho-structural lineament [Aiello et al., 2001]; [D'Argenio et al., 2004].

The marine sedimentation include both the contribution of alluvial and marine sediments (for instance supplied by the Volturno river in the Gaeta Gulf) and the input of volcanites and volcaniclastic deposits originated by the eruptions of Ischia and Procida volcanic complexes, which, starting from 55 ky B.P., have generated pyroclastic flux and/or fall deposits.

In the Ischia offshore the thickness of Pleistocenic-Holocenic marine sediments varies from 0.4-0.5 sec twt (corresponding to about 340-425 meters) to the north of the Ischia and Procida islands, to 0.2-0.3 sec twt (corresponding to about 170-255 meters) in the western Ischia offshore. Along all the southern continental slope of the island the sedimentary cover is very reduced and sedimentary drapes, several tens of meters thick, are widespread.

The Ischia island and its submerged sectors show many hints concealing the relative sea level oscillations, resulting from the interactions among the eustatic sea level oscillations and the volcano-tectonic soil movements during the Late Pleistocene, before and after the eruption of the Epomeo Green Tuffs, both in the sense of down throwing and of uplift of sectors of the island. These hints are of a geomorphological nature (for instance marine terraces uplifted above the sea level, rapid incisions, fossil beach deposits), of a biostratigraphic and paleontological nature (fossil remnants of malacofaunas and benthic micro-organisms, rhyzoms of *Posidonia oceanica* in beach deposits), radiometric (for instance fragments of the hermatipic coral *Cladocora coespitosa*), historical and archaeological (Roman walls, now submerged) [Buchner, 1986], more than geophysical (geodetical measurements with DGPS) [Del Gaudio et al., 2011].

It is worth noting that the average rates of uplift/subsidence, deduced with completely different geological and geophysical methods, converge on values in the order of 5-10 mm/year. However, these values are compatible both with the post-glacial sea level rise curve during the last 18 ky B.P. [Shackleton et al., 1986] and with the soil deformations (bradyseisms) on the island measured through topographic levelling or GPS thresholds [Del Gaudio et al., 2011]. Then the eustatic component may be unlikely discriminated from the volcano-tectonic one.

As a consequence, the application of sequence stratigraphy concepts, which define the depositional tracts (system tracts, corresponding to associations of depositional systems laterally coeval, corresponding to single tracts of the glacio-eustatic curve successive to the isotopic stage 5e [Martinson et al., 1987] based on the sea level glacio-eustatic curve is difficult, if not impossible to apply in many marine sectors surrounding the island.

The seismic interpretation has allowed to observe that in the Maronti offshore the sub-actual terrace, coincident with a progradational wedge deposited during the last 5-6 ky B.P. should coincide, in terms of relative age dating, with the Holocene highstand wedge. This attribution is not confirmed both by the thickness of the sequence, which is exceptionally high due to the high sedimentary supply coming from the Serrara-Fontana basin, nor by the internal geometry of the analyzed sedimentary sequence [Marsella et al., 2001]. In particular, Sparker seismic lines recorded in the Maronti offshore and on the slope of the "Scarrupata di Barano" during a geological survey preliminary with respect to the beach nourishment [Marsella et al., 2001] have shown the occurrence of several superimposed prograding wedges, a more recent one (CA in Figure 13) and a relic one (CR in Figure 13), not linked to glacio-eustatic oscillations (Figure 13).

A regional geological section along the south-eastern and eastern sectors of the Ischia island has been constructed based on seismic interpretation (Figure 14). In particular, the section runs along the volcanic structure of the Ischia Bank through the Ischia Channel. Here it crosses the relic volcanic edifice named "Il Pertuso" and arrives up to the continental shelf of the Procida island, in correspondence to the tuff coastal cliff of Punta Solchiaro (Procida). This section documents the stratigraphic relationships among the volcanic units of the acoustic basement and the Quaternary deposits.

The Ischia Bank is a flat troncho-conycal volcanic edifice, having steep slopes, which terminates with a regular continental shelf at a water depth of – 30 m.

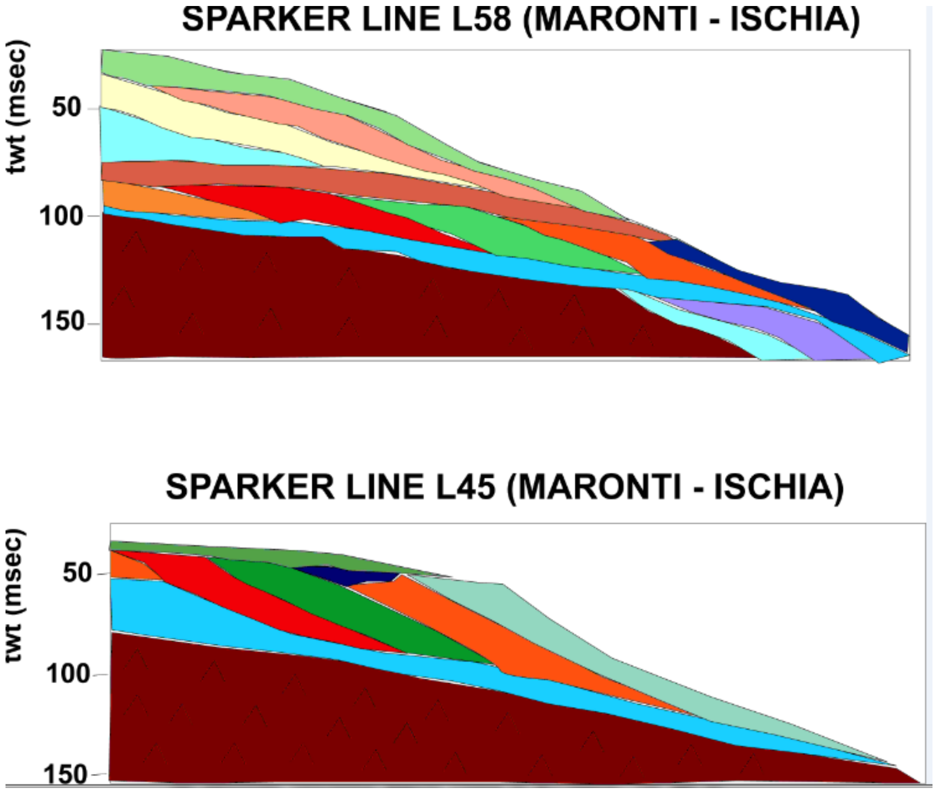


Figure 13. Sparker seismic lines recorded offshore the Maronti and the Scarrupata di Barano (southern Ischia). It is worth noting several depositional wedges (CA=actual wedge; CR=relic wedge), not obviously linked to glacio-eustatic fluctuations.

A parasitic vent on the flank of the main edifice has been evidenced by the Multibeam bathymetric analysis [Aiello et al., 2009a]. The age of formation of this monogenic volcano is unknown through direct age dating, i.e. through absolute dating. [Vezzoli et al., 1988] have indicated the Ischia Bank as the eruptive center of some pyroclastic fall and flux deposits localized in the eastern sector of Ischia, having a recent age (Piano Liguori Formation, age < 6-8 ky B.P.). Several relic volcanic edifices have been detected in the Ischia Channel (eastern Ischia offshore).

These edifices (“I Ruommoli”, “La Catena”, “Le Formiche di Vivara”, “Il Pertuso”) are constituted of the remnants of hydromagmatic volcanic edifices, mainly composed of hialoclastites, indicating their emplacement in a subaqueous environment. “Le Formiche di Vivara” volcanic structure is a saddle composed of the remnants of a downthrown volcanic edifice, whose age of formation is probably older than that one of the Vivara volcano [Di Girolamo and Rolandi, 1976]; [Di Girolamo et al., 1984]. The volcanic products cropping out in correspondence to the saddle are composed of yellow tuffs, overlying on a base of volcanic breccias. The saddle is characterized by the occurrence of different submerged cavities, having variable dimensions. The cave studied with a greatest detail has been named “Grotta Grande delle Formiche” and is located on the eastern side of the saddle. The genesis of the main cavity (“Grotta Grande delle Formiche di Vivara”) has been favoured by the morpho-selective action exherted on the breccias underlying the stratified tuffs [de Alteriis et al., 1994]; [Ferranti et al., 1994].

The seismic profile L57 crosses the south-eastern and the eastern sector of the island of Ischia (Figure 14). The seismo-stratigraphic analysis has allowed the identification of volcanic and sedimentary seismic units. A volcanic acoustic basement (unit V2-BI, Figure), characterized by an acoustically-transparent seismic facies, indicates the occurrence of lavas and pyroclastites genetically related with the main morpho-structure of the Ischia Bank. FST deposits have been identified on both the slopes of the bank (Figure 14). The top of the volcanic structure is overlain by a thin drape of bioclastic sands and gravels, cropping out at the sea bottom.

The unit of Ischia Channel (unit V3-CI, Figure 14) is constituted of pyroclastites and lavas genetically related to relic hydromagmatic volcanic edifices of eastern Ischia, presumably older than the Vivara volcano [Scandone et al., 1991]; [De Alteriis et al., 1994]. Another volcanic seismic unit, probably pyroclastic in nature, underlies the marine deposits of the Ischia Channel (volcanic unit, uncertain attribution, Figure 14). In correspondence to il Pertuso volcanic edifice the unit is put in lateral contact with the volcanic sequence of the Ischia Channel (unit V3-CI, Figure 14). Proceeding towards the Procida shelf, the V3-CI volcanic sequence grades laterally into a relic prograding wedge, probably Pleistocene in age, characterized by prograding clinoforms (Figure 14). This wedge is overlain by a pyroclastic unit, onlapping into depressions and channel erosional morphologies, genetically related to the last eruptive phases of the Procida island.

4.3. Seismic Stratigraphy of the Capri Basin and the Salerno Valley (Southern Campania Continental Margin)

The seismic stratigraphy of the Capri Basin and of the Salerno Valley is here shown based on the seismo-stratigraphic analysis of deep multichannel seismic profiles.

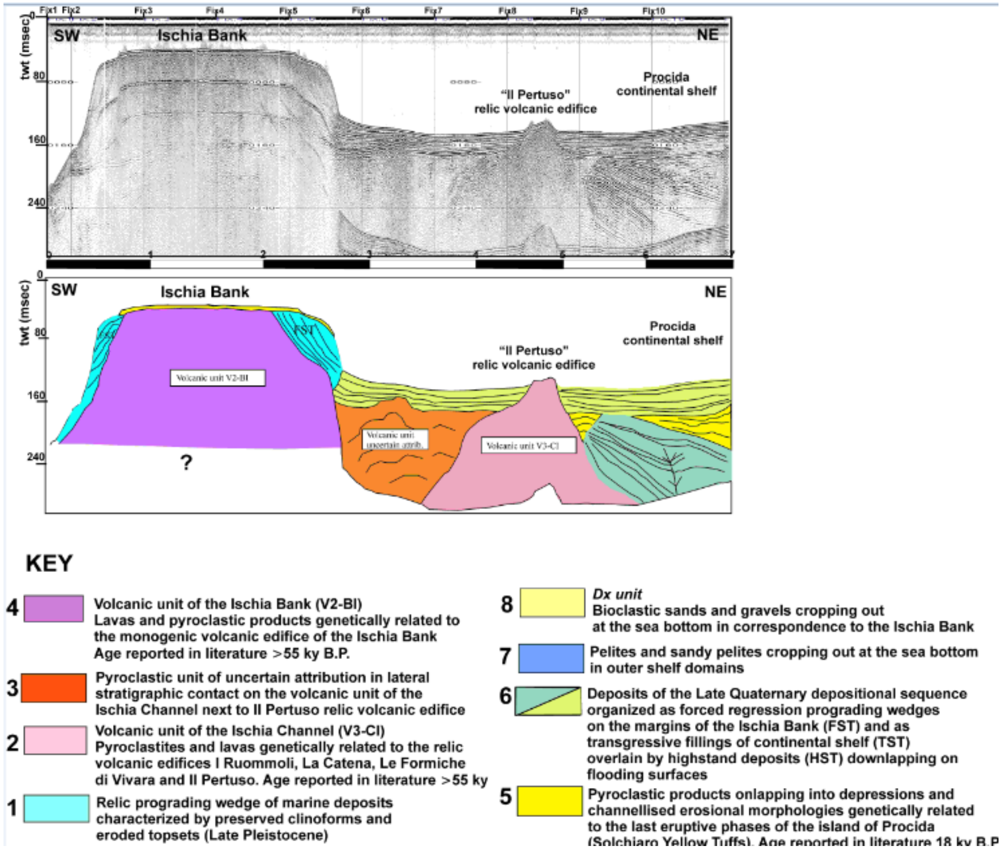


Figure 14. Seismic profile L57 located in the south-eastern and eastern sectors of the Ischia island (Ischia Bank – Il Pertuso volcanic edifice – Procida continental shelf) and corresponding geologic interpretation.

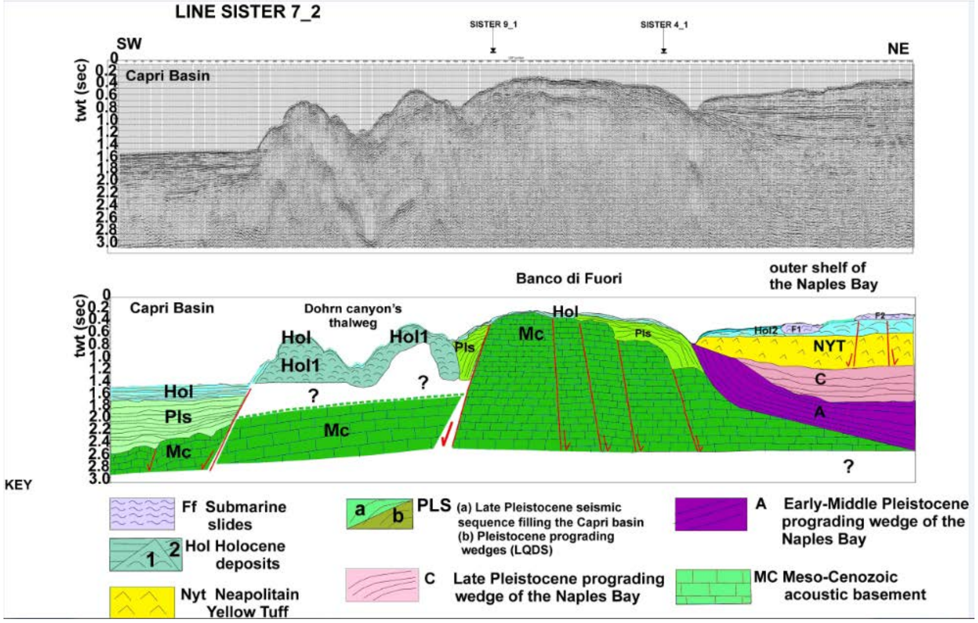
New insights on the deep regional geological structure of the Naples Bay have been recently proposed through the constraints of seismic interpretation [Aiello et al., 2011b].

The main regional morpho-structures of the Ischia-Capri-Volturno alignment of the Campania continental margin have been singled out at a regional scale. These morpho-structures are the following: (a) the "Banco di Fuori", a morpho-structure high of Meso-Cenozoic carbonates, bounding southwards the Naples Bay; (b) the Dohrn canyon, separating the eastern side of the Bay, where sedimentary seismic sequences crop out, from the western one, where volcanic seismic units prevail; (c) the Capri structural high, a sedimentary high related to regional uplift of Meso-Cenozoic carbonates along the Capri-Sorrento alignment; (d) the Magnaghi canyon, eroding the Mg volcanic seismic unit southwards of the Procida island; (e) the Capri basin, a deep basin located south of the Naples Bay, filled by Pleistocene-Holocene sediments overlying a Meso-Cenozoic carbonatic unit; (f) the Salerno Valley, a half-graben filled by three seismic units corresponding to Quaternary marine deposits, overlying chaotic sequences related to the Flysch del Cilento *Auct.*; (g) the Volturno Basin, filled by four marine to deltaic seismic sequences, frequently alternating with volcaniclastic levels, overlying deep seismic units, correlated with Miocene flysch deposits (sands and shales) and Meso-Cenozoic carbonates.

The seismic stratigraphic setting of the Capri Basin is shown by the geological interpretation of the seismic profile Sister7_2 (Figure 15). The Capri Basin has a close spatial relationship to the Dohrn canyon’s thalweg, bounding its north-eastern flank and to the Banco di Fuori structural high, joining the Dohrn canyon’s thalweg to the outer shelf of the Naples Bay (Figure 15).

The Capri Basin develops in the Naples Bay at water depths of about 1125 meters. Seismic data have shown that the individuation of the Capri basin has been probably controlled by a master fault bounding the Dohrn canyon thalweg (Figure 15). From the top the most recent seismic unit (Hol Figure profilo sismico) is characterized by strong reflectors, parallel and laterally continuous. The latter are related to Holocene marine sediments, overlying Late Pleistocene marine sediments, showing reflectors with the same seismo-acoustic characteristics (Pls Figure 15). These two units stand for the filling of the Capri Basin, probably ranging in age from Middle-Late Pleistocene to Holocene.

The lower seismic unit (MC unit; Figure 15) shows an acoustically transparent seismic facies due to poor penetration of the seismic signal.



(modified after Aiello et al. 2011).

Figure 15. Seismic profile Sister 7_2 and corresponding geologic interpretation. Mc: Acoustic basement. Meso-Cenozoic carbonates cropping out offshore the Sorrento Peninsula and the Capri island. A: Early Pleistocene relic prograding wedge, representing the lower unit in the stratigraphic architecture of the Naples Bay, characterized by obliquous prograding clinoforms and parallel reflectors (perpendicularly to the direction of progradation). B: Late Pleistocene prograding wedge representing the upper unit in the stratigraphic architecture of the Naples Bay, characterized by low angle sigmoidal to obliquous clinoforms and parallel reflectors (perpendicular to the direction of progradation), supplied by the palaeo-Sarno river mouth. Pls: Late Pleistocene seismic sequence representing the basin filling of the Capri Basin. Hol: Holocene deposits, characterized by parallel and continuous seismic reflectors in the Capri Basin. Hola: Holocene deposits on the outer shelf of the Naples Bay, characterized by alternances of marine and volcaniclastic sediments; interlayered slide deposits (Bb). Holb Holocene deposits, characterized by an acoustically transparent seismic facies in correspondence to channel-levee complexes in the Dohrn canyon’s thalweg.

It is correlated to the Meso-Cenozoic carbonates, representing the rock bodies which extensively crop out in the Capri island [Barattolo and Pugliese, 1987]; [De Castro, 1991]. This deep seismic unit relates to thick carbonatic succession of the Campania-Lucania carbonate platform margin [D'Argenio et al., 1973]. The MC unit has been recognized under the Capri Basin, where it appears downthrown at depths between 2.6 – 2.8 sec twt, corresponding to about 2800 – 3000 meters. The same carbonatic unit has been hypothized as continuing also below the Dohrn canyon thalweg at depths between 2.0 and 1.8 sec twt, corresponding to about 2000 – 2200 meters.

The shallow stratigraphy of the Dohrn canyon's thalweg is characterized by Holocene deposits, characterized by an acoustically-transparent seismic facies and organized as channel-levee complexes. The north-eastern flank of the canyon seems to be tectonically-controlled in correspondence to a normal fault, strongly downthrowing Meso-Cenozoic carbonates from the Banco di Fuori structural high, where the MC unit is uplifted and crops out at the sea bottom (Figure 15). The description of the seismic units recognized in the Capri Basin, in the Dohrn canyon thalweg and in the Banco di Fuori structure has been resumed in the table 5.

The Capri Basin is a deep basin localized in the Tyrrhenian bathyal plain southwards of the Dohrn canyon.

Table 5. Sketch table of the seismic units recognized in the Capri Basin and in the adjacent lineaments of the Dohrn canyon's thalweg and of the Banco di Fuori structural high

Capri Basin	Dohrn canyon's thalweg	Banco di Fuori structural high
Hol–Holocene deposits characterized by parallel and continuous seismic reflectors in the Capri Basin	Hol/Holb – Holocene deposits, characterized by an acoustically-transparent seismic facies in correspondence to channel-levee complexes in the Dohrn canyon's thalweg	Hol – Holocene deposits, characterized by parallel and continuous seismic reflectors
Pls – Late Pleistocene seismic sequence representing the basin filling of the Capri Basin	Pls – Late Pleistocene prograding sequence at the north-eastern flank of the canyon thalweg, at the boundary with the Banco di Fuori structure	Pls – Late Pleistocene prograding sequences on both the flanks of the Banco di Fuori structural high
MC Acoustic basement – Meso-Cenozoic carbonates cropping out offshore the Sorrento Peninsula and the Capri island.	MC Acoustic basement – Meso-Cenozoic carbonates cropping out offshore the Sorrento Peninsula and the Capri island.	MC Acoustic basement – Meso-Cenozoic carbonates cropping out offshore the Sorrento Peninsula and the Capri island.

It is filled by Pleistocene-Holocene sediments thick about 0.7 s (twt), unconformably overlying the Meso-Cenozoic carbonates. The basin filling is characterized by parallel and laterally continuous seismic reflectors, overlying an acoustically transparent seismic facies, interpreted as the Meso-Cenozoic carbonates. A few studies deal with the seismic stratigraphy of the Capri Basin, which is relatively unknown, excluding the paper of [Milia and Torrente, 1999]. They have identified seven depositional sequences in the basin filling. Two lowstand units have been related to main tectonic pulses. Mass flow deposits that flowed into the basin directly from the contiguous narrow shelf and steep slope have also been recognized.

The Salerno Valley represents a half-graben sedimentary basin, whose identification has been controlled, during the Early Pleistocene, by the master fault Capri-Sorrento Peninsula, showing vertical throws of 1500 metres, which downthrows the Meso-Cenozoic carbonatic acoustic basement under the sedimentary basin. The geologic interpretation of multichannel seismic profiles has enabled the identification of a main unconformity, located at depths ranging from 3000 to 3500 metres under the sea bottom and correlated to the top of the Meso-Cenozoic carbonatic sequence, extensively cropping out onshore in the Sorrento Peninsula structural high. This unconformity bounds upwards the carbonatic acoustic basement, strongly deformed by normal faulting, and represents the base of the Pleistocene basin filling, the Salerno Valley. The basin filling, with an overall thickness exceeding 1000 metres, is characterized by parallel and continuous seismic reflectors alternating with chaotic intervals, having acoustically-transparent seismic facies.

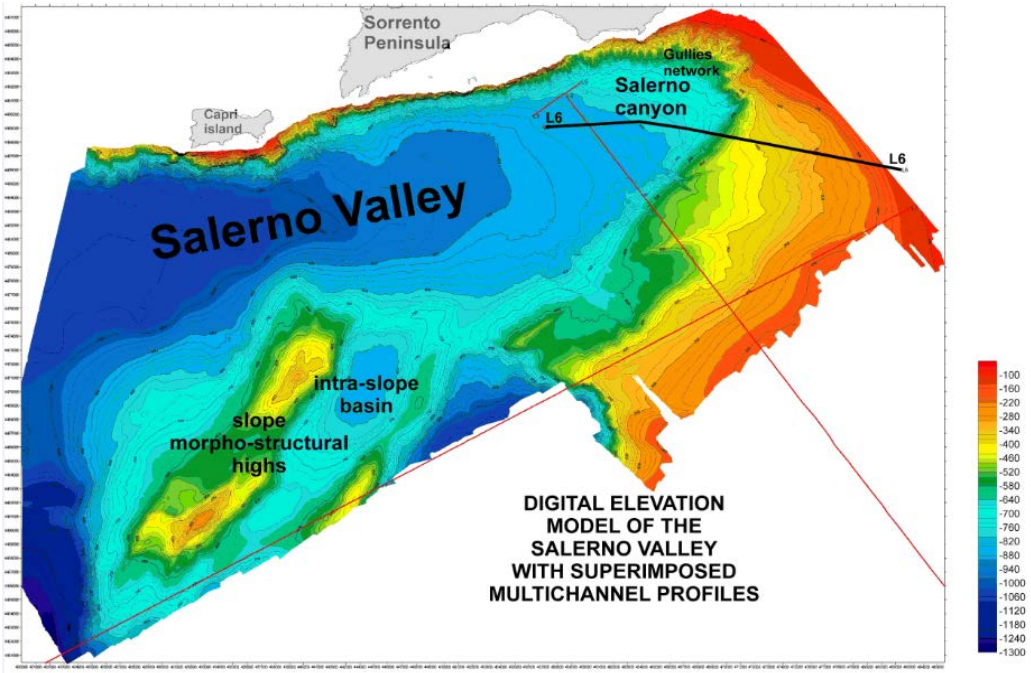
The strong synsedimentary tectonics lasting up to Late Pleistocene times in correspondence to NNW-SSE trending listric normal faults triggered gravity mass instability processes, evident as chaotic acoustic intervals intercalated at various stratigraphic levels in the stratigraphic record shown by the multichannel seismic profiles.

Strong seismic reflectors inclined towards SSE with apparent angles of 10°-15° appear on seismic profiles, indicating the occurrence of detachment levels in the carbonatic multilayer [Aiello et al., 1997a; 1997b]. The extension in the Salerno basin is due to groups of listric normal faults converging on low-angle detachment levels. Another preferential detachment level is located on top of the Miocene flysch terrains [Sacchi et al., 1994].

Bathymetric and high resolution reflection seismic data previously collected in the Salerno Valley [Aiello et al., 1997a; 1997b] indicate that the depositional processes and overfilling of the basin prevail on the continental shelf to the east, while the western sector of the half-graben is the site of erosional and sedimentary processes still active in a canyon (the Salerno canyon), with depths ranging from 600 to 1000 m. The occurrence of wedging geometries in the sedimentary successions, of tectonic unconformities, of hummocky reflectors and seismic facies intercalated at several stratigraphic levels in the basin filling are hints of strong synsedimentary tectonics and of a strong uplift of the adjacent onshore areas of the southern Apennines during the Pleistocene.

In the Salerno offshore, anticlines with ENE-WSW axes suggest roll-over mechanisms, resulting from the envelopment of listric normal faults of from a tectonic inversion of the half-graben, according to a N-S trending compression or to a transpression along the master fault Capri-Sorrento Peninsula [Aiello et al., 1997a; 1997b]; [Sacchi et al., 1994].

Two regional seismic lines have been recorded in the Salerno Valley. The sketch map of Figure 16 shows the Digital Terrain Model (DTM) of the Salerno Valley, on which the location of multichannel seismic profiles recorded in the study area has been superimposed.



(modified after Aiello et al., 2009).

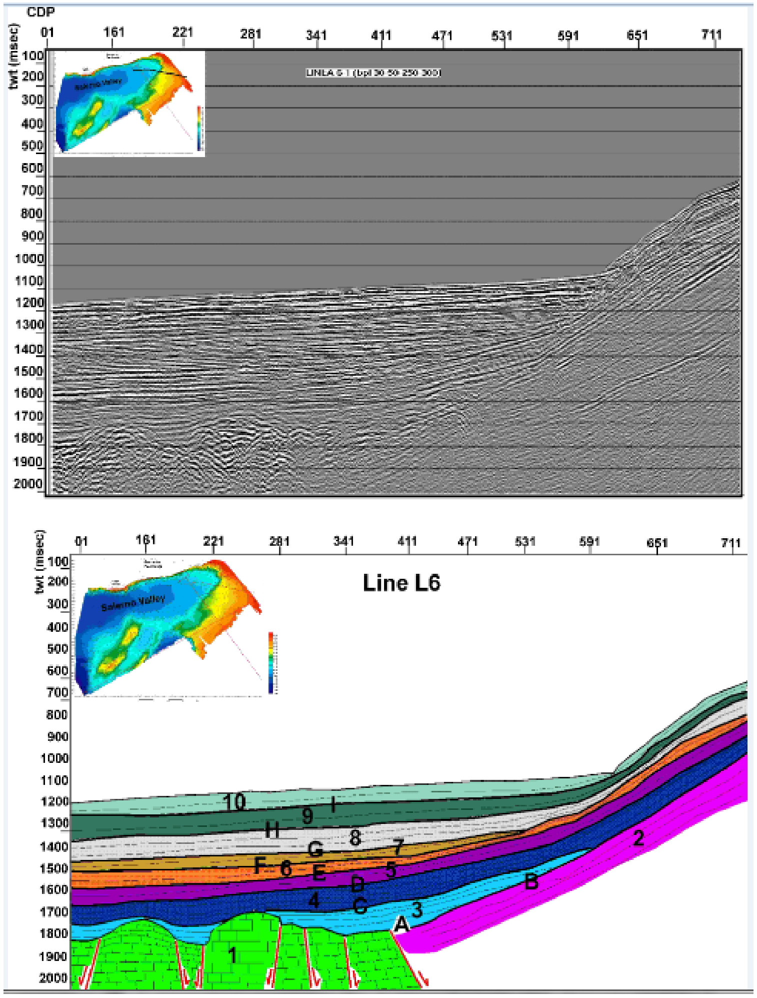
Figure 16. Digital Terrain Model of the Salerno Valley and superimposed location of multichannel seismic profiles recorded in the study area.

The Salerno Valley shows an example of complex Quaternary filling of a tectonically-controlled sedimentary basin, recording the interactions between the effects of the glacio-eustatic sea level fluctuations, the tectonic activity in the source region and the tectonic deformation in the depositional area, lasting up to recent times. High sedimentary supply, combined with a restrict sediment dispersal, have enabled the deposition of a thick sedimentary succession, locally exceeding 3000 m of thickness.

The basin filling is composed of marls and marly clays with intercalations of sands and conglomerates and then of marly clays with intercalations of thin sands (Pleistocene). The overall thickness of the Pleistocene filling of the Salerno Valley based on the offshore wells ranges between 1500 and 2000 m (Mina 1 exploration well); [Agip, 1977]. In the Cilento offshore, a regional unconformity, probably related to a non-depositional and/or erosional hiatus (Pliocene is completely missing), characterizes the base of the Pleistocene sequences. The seismo-stratigraphic interpretation of the L6 seismic profile shows the stratigraphic architecture of the Salerno Valley, showing a E-W trending (in its first part), passing to a NNW-SSE trending (in its second part). The profile crosses the Salerno Valley at water depths ranging from – 900 m to – 500 m. It shows a first part depicting the basin (i.e. the Salerno Valley) at water depths of about – 900 m, rising in corresponding to a break in slope located at about – 825 m to – 525 along the flank of the slope surrounding the western sector of the Salerno Gulf (Figure 17).

The geological interpretation of the multichannel profile L6, carried out based on seismo-stratigraphic criteria has enabled the identification of several seismic horizons, corresponding to significant unconformities (Figure 17).

In particular, an important unconformity, located between 1.7 and 1.8 sec of depth (two-way travel times) has been correlated with the top of the Meso-Cenozoic carbonatic acoustic basement, widely cropping out in the Sorrento Peninsula structural high.



(modified after Aiello et al. 2009).

Figure 17. Geologic interpretation of multichannel seismic profile L6. Key. 1: Meso-Cenozoic platform carbonates. 2: Early Pleistocene marine deposits, which can be probably attributed to relic prograding wedges. 3: First seismic sequence of the basin filling, onlapping the B unconformity (located at the top of the seismic sequence 2) and unconformably overlying the unit 1, with parallel and subparallel reflectors. 4: Second seismic sequence of the basin filling, characterised by inclined reflectors on the slope and by parallel reflectors in the basin. 5: Third seismic sequence of the basin filling, characterised by inclined reflectors on the slope and by parallel reflectors in the basin. 6: Fourth seismic sequence of the basin filling, characterised by inclined reflectors on the slope (where it is relatively thinner) and by parallel reflectors in the basin. 7: Fifth seismic sequence of the basin filling, characterised by a wedge-shaped external geometry, onlapping the F unconformity (located at the top of the seismic sequence 6). 8: Sixth seismic sequence of the basin filling, characterised by inclined reflectors on the slope and parallel reflectors in the basin. 9: Seventh seismic sequence of the basin filling, characterised by inclined reflectors on the slope and parallel reflectors in the basin. 10: Eighth seismic sequence of the basin filling, characterised by inclined reflectors on the slope and parallel reflectors in the basin.

Table 6. Seismic units in the Salerno Valley, a sedimentary basin located southwards of the Sorrento Peninsula (Naples Bay)

Salerno Valley	Seismic facies and description of the seismic unit
1 MC	Meso-Cenozoic carbonates – Acoustically-transparent seismic facies with scattered and discontinous seismic reflectors
2 Seismic sequence 2	Old sedimentary drape, overlying the continental slope, which bounds the eastern sector of the Salerno Gulf; parallel reflectors, with high amplitude and continuity; its top corresponds to an unconformity (reflector B) identified by the onlap of the overlying seismic sequence (sequence 3).
3 Seismic sequence 3	Seismic sequence corresponding to the earliest phases of the basin filling; characterized by wedge-shaped external geometries overlying the A unconformity and characterized by onlap terminations on the unconformity B.
4, 5, 6 Seismic sequences 4, 5, 6	Seismic sequences showing seismic horizons with high amplitude and lateral continuity and overall geometry corresponding to vertically aggrading infill, both in the basin and in the continental slope. Stratigraphic relationships among the three sequences of paraconcordance, also in relation to the bounding unconformities. The unconformity F, at the top of the seismic sequence 6, indicates a main variation in the aggradational geometries of the basin filling, indicating a probable variation in the depositional conditions in the sedimentary basin, probably accompanied by submarine erosion.
7 Seismic sequence 7	Seismic sequence characterized by parallel and continuous seismic reflectors, alternating with transparent intervals.
8 Seismic sequences 8, 9 and 10	Seismic sequences characterized by a pronounced vertical aggradation. The blanking of the acoustic signal in correspondence to localized seismic intervals indicates the occurrence of chaotic intervals, probably corresponding to resedimented deposits, triggered by submarine instabilities and occurring in the sedimentary filling of the Salerno Valley

This unconformity is strongly downthrown by normal faulting and marks the top of the Meso-Cenozoic acoustic basement and the base of the Pleistocene basin filling of the Salerno Valley. The corresponding seismic horizon lacks in lateral continuity and grades towards parallel seismic reflectors, which form a thick sedimentary package along the slope. The Pleistocene basin filling of the Salerno Valley is organized in eight seismi sequences (3 to 10 in Figure 17) separated by unconformities (B to I in Figure 17), for an overall thickness of about 600 msec (corresponding to about 510 m). The acoustic basement is represented by Meso-Cenozoic carbonates (1 in Figure 17).

The description of the seismic units recognized in the Salerno Valley has been resumed in the table 6.

4.4. High Resolution Seismic Stratigraphy of the Agropoli Continental Shelf

A densely-spaced grid of Subbottom Chirp seismic sections has been recorded and interpreted in the Agropoli offshore, in correspondence to the seaward elongment of the Punta Licosa morpho-structural high (Figure 8). The geological structures and the related seismic sequences, unconformably overlying wide outcrops of the acoustic basement, have been studied in detail. This has allowed to reconstruct the stratigraphic architecture of the Quaternary marine deposits, well developed in the depocenter located between the mouth of the Solofrone river and the town of Agropoli. In the Punta Licosa morpho-structural high the rocky outcrops result from the seaward prolongation of the stratigraphic-structural units, widely cropping out onshore in the adjacent emerged sectors of the Cilento Promontory ("Flysch del Cilento" *Auct.*); [Ciampo et al., 1984]; [Bonardi et al., 1988].

The stratigraphic units individuated in the Agropoli offshore through the seismo-stratigraphic analysis belong to the Late Quaternary Depositional Sequence; in this sequence, the space and time evolution and the lateral and vertical migration of marine coastal, continental shelf and slope depositional environments of the Late Pleistocene to Holocene glacio-eustatic cycle have been recognized. The stratigraphic succession records the variations of the accommodation space of the Late Quaternary deposits during the last 4th order glacio-eustatic cycle, ranging between 128 ky B.P. (Tyrrhenian stage) and the present-day (isotopic stage 5e). Several local unconformities overlie coarse-grained deposits, filling intra-basinal depressions or palaeo-channels located at the top of the acoustic basement. It is worth noting the polycyclic nature of these unconformities. Several lines of evidence suggest that the acoustic basement is involved in several phases of erosion/emersion, development of marine terraces and successive transgression, a a consequence of both Late Quaternary glacio-eustatic fluctuations and of Pleistocene tectonic uplift.

The geological interpretation of seismic reflection profiles localized in the morpho-structural high of Punta Licosa has evidenced the occurrence of the acoustic basement (unit S), cropping out at the sea bottom nearshore and dipping seawards under the Quaternary deposits, which form the recent sedimentary cover. Remnants of terraced surfaces located at several water depths have evidenced the complex morpho-evolution of the acoustic basement during the Late Quaternary. In particular, four main orders of terraced surfaces have been recognized. The oldest ones are located at water depths ranging between – 50 m and – 43 m and are genetically related with the terraced surfaces disposed at water depths ranging between – 46 m and the – 44 m in the Capo Palinuro area.

The second order of terraced surfaces has been identified at water depths ranging between – 27 m and – 17 m and is genetically related with the terraced surfaces located at water depths ranging between – 18 m and – 24 m in the Capo Palinuro area. The third order of terraced surfaces has been recognized at water depths ranging between – 10 m and – 14 m in the Palinuro Cape. Finally, the terrace rims occurring at – 8 m are coeval. On the basis of high resolution reflction seismics is has not been possible to recognize the Eutyrrhenian paleo-sea level mark on related deposits. Number and water depths of the terraced surfaces associated to seismic profiles in the Agropoli offshore are reported in the Table 7.

A geological interpretation of the seismic sections recorded in the Punta Licosa morpho-structural high based on the criteria of seismic stratigraphy has been carried out, with the aim to carry out the recognition of the main marine terraced surfaces and to furnish an interpretative correlation with the curves of the isotopic stratigraphy.

Table 7. Water depth and number of the terraced surfaces related to the seismic profiles in the Agropoli offshore

Seismic profile	Number of terraced surfaces	Water depth of terrace rims
B50, B50_1	1	- 17 m
B51	2	- 18 m, - 21 m
B52	2	- 18 m, - 21 m
B55	3	- 8 m, - 18 m, - 21 m
B56	2	- 10 m, - 17 m
B61a	2	- 14 m, - 24 m
B61b	3	- 10 m, - 18 m, - 27 m
B62	3	- 10 m, - 20 m, - 50 m
B15	3	- 5 m, - 19 m, - 31 m
B19	3	- 44 m, - 47 m, - 50 m
B20	3	- 10 m, -21 m, - 43 m
B22	3	- 15 m, - 25 m, - 47 m

The approach to the seismic stratigraphy is based on the principle of the seismic reflectors, determined by contrasts of acoustic impedance (product of the seismic velocity for the density of the crossed grounds) correspond to stratal plans. Perhaps, the geometry of the reflectors individuated on seismic profiles correspond, as a general rule, to the depositional geometries [Vail et al., 1977]; [Mitchum et al., 1977]; [Anstey 1982].

The geological interpretation of the seismic reflection profiles has allowed to distinguish the main seismo-stratigraphic units occurring in the marine subbottom, separated by significant reflectors, corresponding to notable surfaces of conformity or unconformity. The interpretation of the seismic sections has allowed to carry out a distinction among the acoustic basement, cropping out in wide sectors of the nearshore area, for an extension greater than that one singled out by previous papers [Coppa et al., 1988]; [Ferraro et al., 1997] and the zones of accumulation of sediments.

Some of the most significant seismic profiles have been selected, focussing, in particular, on the research theme of the marine terraces in the Agropoli offshore. The selected profiles show the outcrops of rocky acoustic basement, incised by terrace rims located at several water depths.

The seismic profile B50 is composed of two successive acquisitions (B50 and B50_1; Figure 18) and has been recorded with a NNW-SSE trending in water depths ranging between – 18.75 m (beginning of the acquisition) and the – 16.5 m (end of the acquisition). The vertical penetration is of 100 msec (about 62 m). The sea bottom is covered by grasses at marine Phanerogams, particularly abundant in this bathymetric belt.

The seismo-stratigraphic analysis has allowed to recognize three main units, separated by significant seismic reflectors, corresponding to erosional or paraconformity surfaces. Moreover, it has been identified the acoustic basement (unit S), dipping under the A reflector. Its top is characterized by the occurrence of a marine terrace, located at about – 17 m of water depth (Figure 18). The first seismic unit (unit 1) is characterized by parallel seismic reflectors and shows an average thickness of 44 msec (about 37.5 m). It is bounded at its top by a main seismic reflector, which seems in stratigraphic continuity (reflector A).

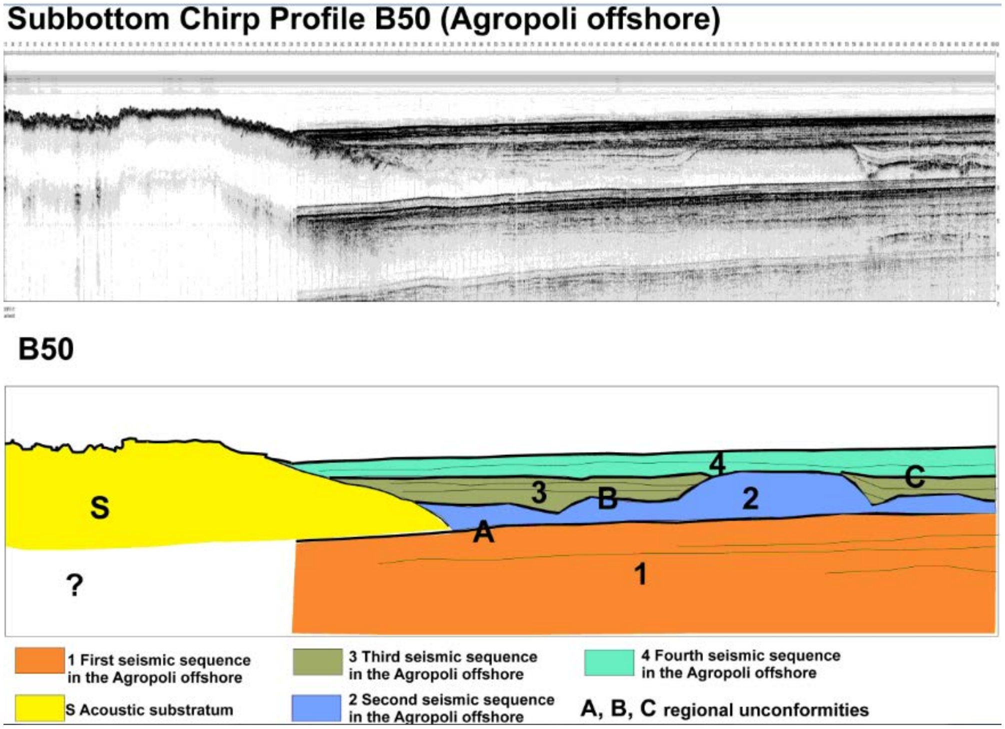


Figure 18. Seismic profile B50 in the Agropoli offshore and corresponding geologic interpretation.

The second seismic unit (unit 2) is characterized by an acoustically-transparent seismic facies and shows an average thickness of about 10 msec (about 8.5 m). This is characterized by a wedge-shaped external geometry, thinning towards the end of the first profile (B50) and at the beginning of the second profile (B50_1), up to close completely for the occurrence of a wide palaeo-channel.

The unit is bounded by two seismic reflectors: at its base, by the unconformity A, having onlap stratigraphic relationships and by the unconformity B, corresponding to a main erosional surface. The external geometry of the seismic unit and its acoustic facies suggest that it should represent a sandy body having a coarsed grain size.

The third unit (unit 3) is characterized by an acoustic facies with discontinuous reflectors having a high amplitude, alternating with acoustically-transparent intervals. It shows an average thickness of 20 msec (about 17 m). The unit fills a palaeo-channel, intercalated in the stratigraphic succession. It is probably composed of alternating sands (transparent intervals) and shales (continuous reflectors).

The seismic profile B51 (Figure 19) shows a length of about 6.1 km and has been recorded with a NNE-SSW trending at water depths ranging between – 19.5 m (at the beginning of the acquisition) and – 12 m (at the end of the acquisition). The vertical penetration of the study profile is of about 100 msec (about 64.5 m). In correspondence to the nearshore outcrops of the rocky acoustic basement (unit S) two terraced surfaces have been singled out, respectively localized at water depths of – 18 m and of – 21 m.

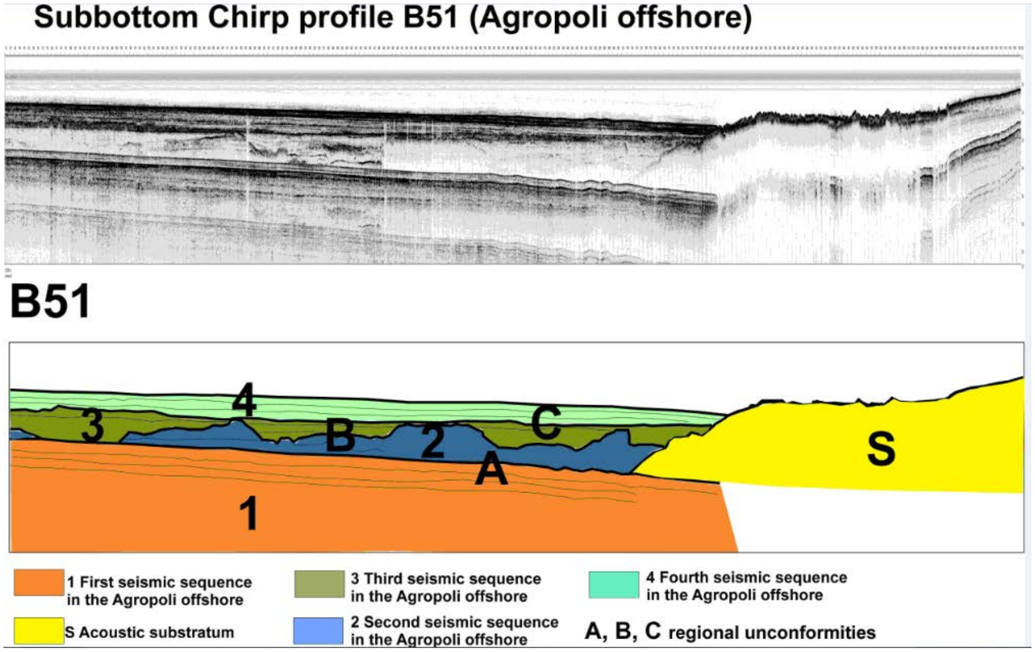


Figure 19. Seismic profile B51 in the Agropoli offshore and corresponding geologic interpretation.

The seismo-stratigraphic analysis has allowed the recognition of three units, separated by significant seismic reflectors, corresponding to erosional surfaces or paraconformities (Figure 19). The first unit (unit 1) is composed of marine sediments and characterized by parallel seismic reflectors, having an average thickness of 44 msec (about 37.5 m).

The second unit (unit 2) shows an acoustically-transparent seismic facies and a lenticular external geometry. Its thickness is of about 10 msec (8.5 meters). The unit demonstrates at its base an unconformity surface (A reflector) and at its top a main erosional surface. The acoustic facies and the stratigraphic relationships suggest that the unit 2 is composed of coarse-grained sands, forming the infilling of palaeo-channels.

The third unit (unit 3) is characterized by an acoustic facies with discontinuous reflectors having a high amplitude, alternating to acoustically-transparent seismic intervals and showing an average thickness of about 20 msec (about 17 m). Moreover, a shallow gas pocket crossing the three seismic sequences has been identified (Figure 19).

The geological interpretation of the seismic profiles B55 and B56 (Figure 20) has evidenced the occurrence of the acoustic basement (unit S), cropping out at the sea bottom in the nearshore area and dipping seawards under the Quaternary marine deposits.

Rims of terraced surfaces disposed at several water depths (- 8 m, - 18 m, - 21 m on the seismic profile B55; - 10 m and – 17 m on the seismic profile B56) have evidenced the complex morpho-evolution of the acoustic basement.

Quaternary marine deposits are organized in three main seismic units (units 1, 2 and 3), separated by two erosional surfaces and/or paraconformity (A and B seismic reflectors). The unit 3 has been furtherly subdivided into two sub-units (respectively named 3a and 3b), based on the occurrence of a local unconformity. In fact, the unit 3a represents the filling of a wide channellised structure, probably representing a palaeo-channel (Figure 20).

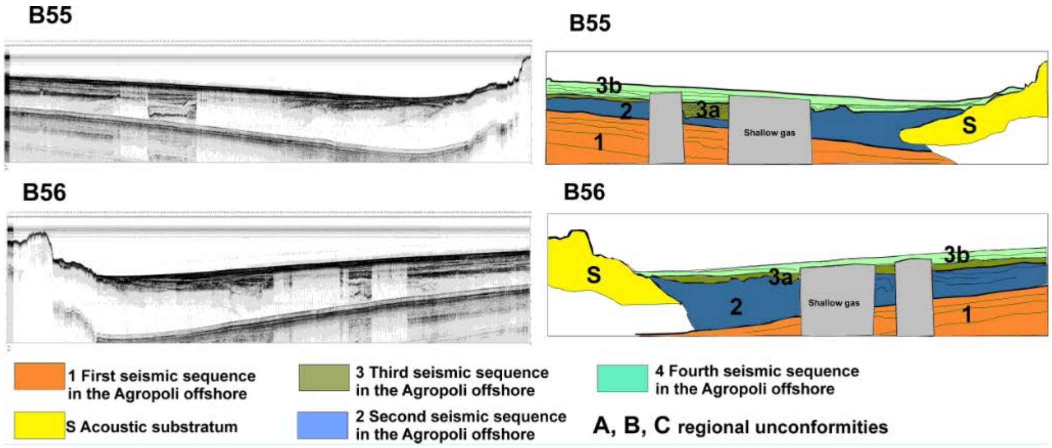


Figure 20. Seismic profiles B55 and B56 in the Agropoli offshore and corresponding geologic interpretation.

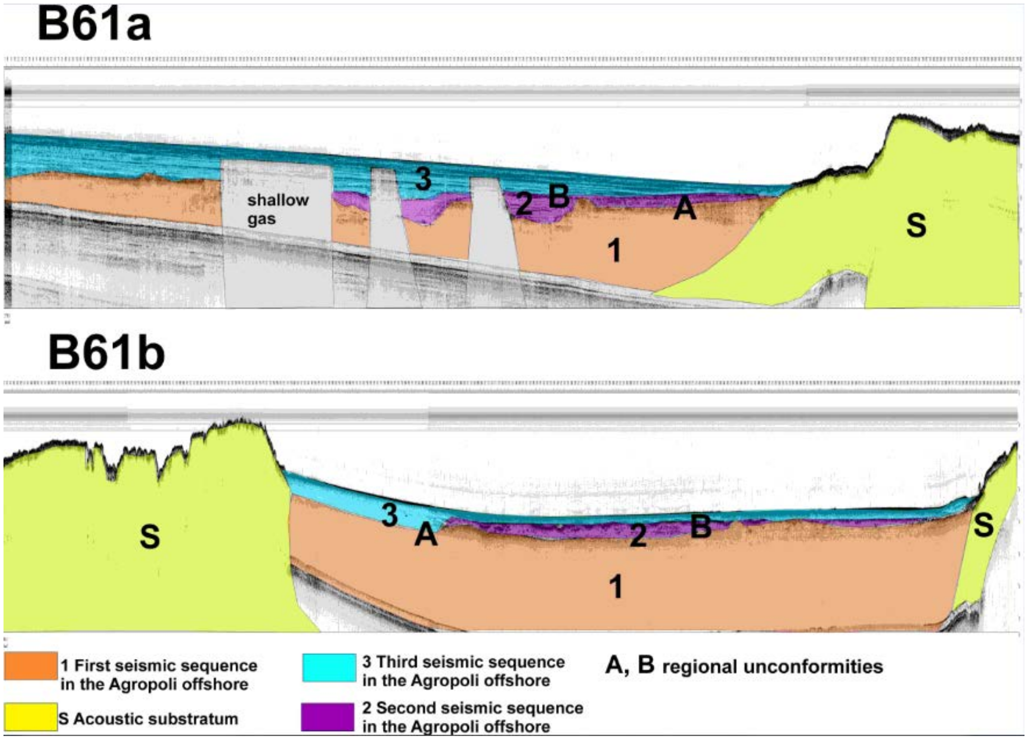


Figure 21. Seismic profile B61 in the Agropoli offshore and corresponding geologic interpretation.

The seismic profile B61 is composed of two successive acquisitions (B61a and B61b; Figure 21) and has been recorded at water depths included among – 21 m at the beginning of the acquisition and – 16 m at the end of the acquisition, having a NNE-SSW trending.

The vertical penetration of the study profile is of 69 msec (about 59 m of sediments). The top of the acoustic basement (unit S) shows several rims of terraced surfaces, respectively localized at – 24 m and at – 14 m (in the first line of the section) and at – 18 m, - 10 m and – 27 m (in the second line of the section).

Moreover, a sector of the sea bottom in active erosion has been identified, evidenced by the occurrence of channellized areas. The acoustic basement crops out in correspondence to a main morpho-structural high located at the center of the study area, probably tectonically controlled due to the occurrence of normal faults. Quaternary marine deposits are organized in three main seismic sequences (1, 2 and 3), separated by significant seismic reflectors, corresponding to erosional surfaces or paraconformities and showing a stratigraphic architecture similar to the previously described one.

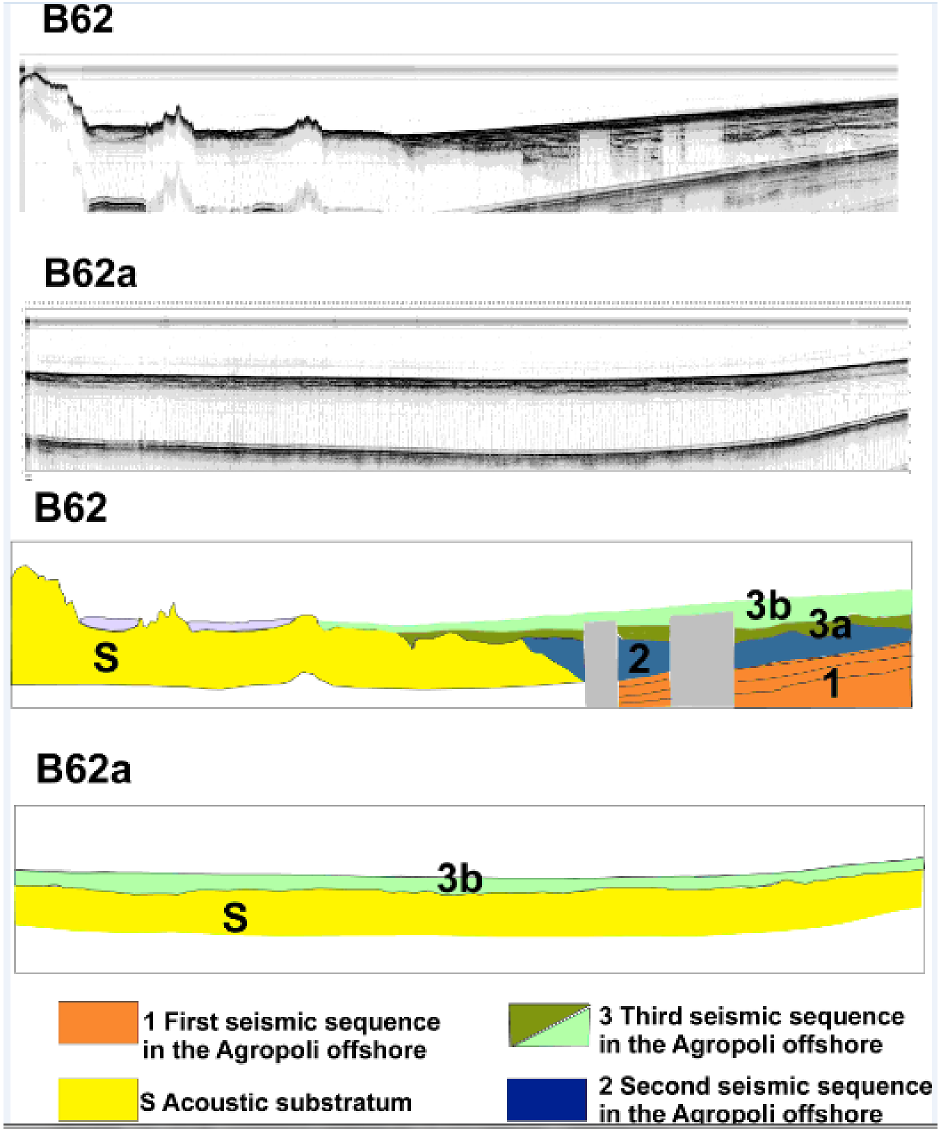


Figure 22. Seismic profile B62 in the Agropoli offshore and corresponding geologic interpretation.

At the same time, the seismic profile B62 (Figure 22), distinguished into two main successive acquisitions (B62 and B62a) is characterized by an acoustic basement (unit S), widely cropping out in the nearshore area, where it is down thrown by normal faults. Three orders of marine terraces have been individuated, respectively localized at – 10 m, - 20 m and – 50 m of water depth.

The sea bottom shows hints of a still active erosion, which is evidenced by carving channels (Figure 22). Moreover, fillings composed of recent marine sediments with a wedge-shaped external geometry have been identified.

4.5. High Resolution Seismic Stratigraphy of the Maratea Valley

The geological framework of the Maratea Valley on land is connected with the Late Pleistocene-Holocene evolution of the surrounding continental platform and slope and with the significant glacio-eustatic fluctuations during the late Quaternary.

Near the shoreline the bathymetric setting of the area is characterized by steep and articulated sea bottoms, resulting from the seaward elomgment of the rocky coastal cliffs, up to the – 30 m isobaths, where the continental shelf starts [Colantoni et al., 1997]. From the – 30 m water depth the sea bottom is more regular up to the shelf break, located at about 2 kilometres from the coastline, at an average water depth of 100-120 meters. In correspondence to the Maratea valley the shelf break retreats up to 900-1000 m from the shoreline, reaching a water depth of -70/80 meters. Here it is articulated and incised by deep channels linked to a submarine canyon’s head (the Maratea canyon), involved by active regressive erosion.

High resolution seismic profiles have provided new evidence on the offshore prolongation of the Maratea Valley. As a general rule, the deep gravitational movements already described in the Maratea Valley have influenced the geological setting of the surrounding continental shelf and slope. The continental slope is characterized by deformed sequences, involved by NE-SW normal faults and by slumpings. Normal faulting has also controlled the development of the Maratea canyon itself. The occurrence of the Maratea canyon is significant because the canyon undermines the instable masses of the Maratea valley and induces the development of submarine slides through regressive erosion.

The multichannel seismic profile S130bis crosses the Policastro Gulf with a NW-SE trending (Figure 23). The seismo-stratigraphic analysis has evidenced a narrow continental shelf, whose stratigraphic architecture is characterized by the occurrence of a prograding sedimetntary succession, probably Pleistocenic in age (Figure 23). The prograding sedimentary wedge is characterized by preserved clinoforms and by eroded topsets and is truncated at the sea bottom by an erosional unconformity.

The slope gradients appear quite high (ranging from 30° and 45°), according to a hypothesis of a structural control from a normal fault in correspondence to the shelf break.

At the foot of the slope the development of the Maratea canyon is evident.

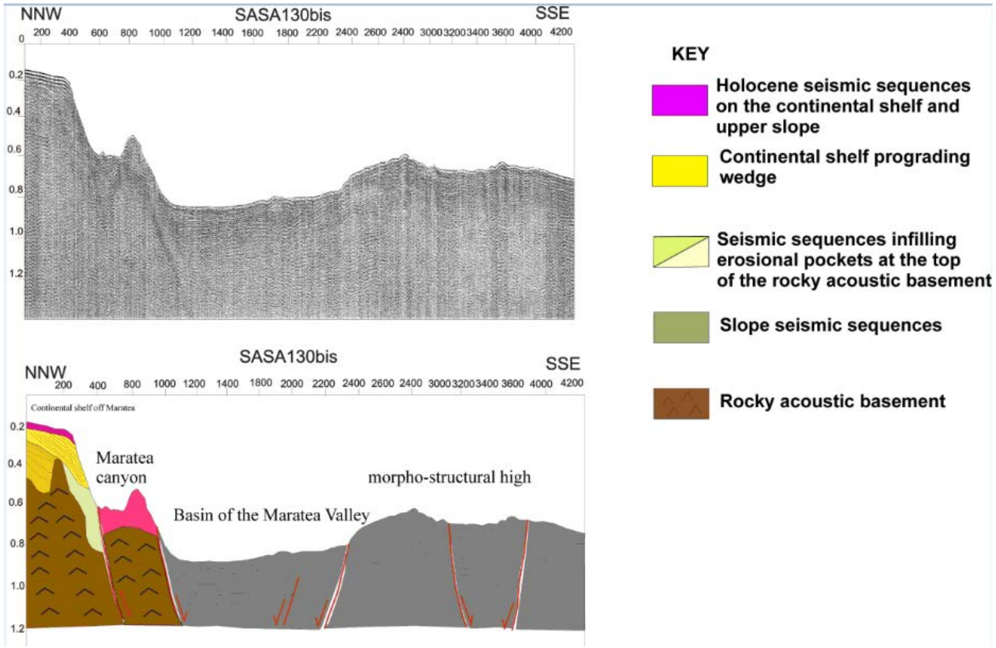
The time to depth conversion carried out on the seismic profile has shown water depths at about 450 m for the canyon’s thalweg. It is evident that the canyon occurrence is also clearly recognizable from the trending of the isobaths, showing a curved shape in plan view in correspondence of the canyon.

The slope sequences, upper Pleistocene to Holocene in age, deposited in an intra-slope sedimentary basin (Figure 23), are located at water depths ranging from – 600 m and – 675 m. After the basin, the sequences are tectonically uplifted in correspondence to a morpho-structural high (Figure 23), bounded by two normal faults, localized in water depths ranging between – 562 m and – 487 m.

The high is interpreted as a slope ridge [Trincardi and Zitellini, 1987]; it represents a complex morpho-structural high, controlled by normal faults. The occurrence of these kinds of highs on the continental slope off the Calabria region has already been documented [Pennetta et al., 1996a; 1996b].

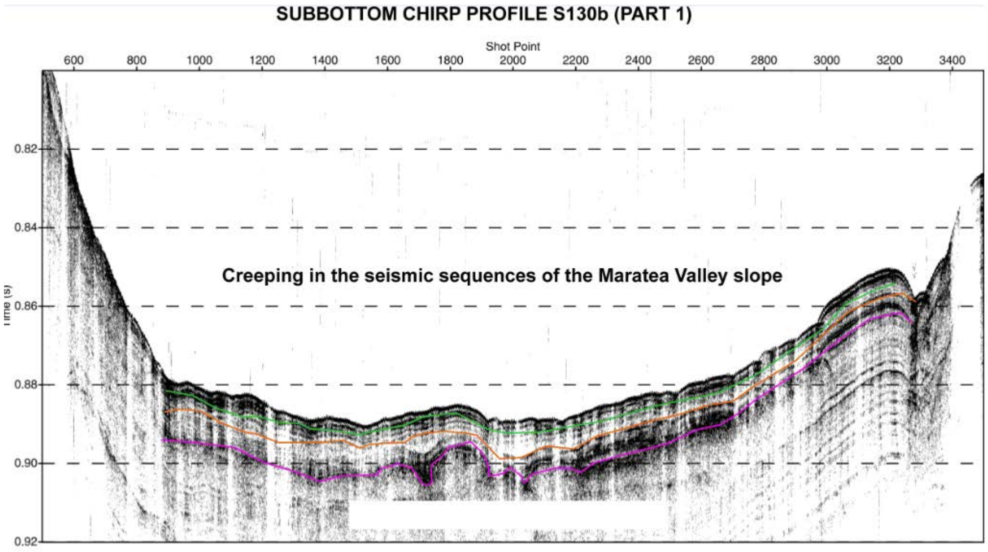
The intense synsedimentary tectonics, which characterizes the slope successions and the erosional processes, still active in correspondence to the Maratea canyon, have controlled the development of submarine gravity instabilities. The latter are suggested both by rapid thickness variations in the seismic sequences and by the occurrence of several chaotic intervals intercalated at several stratigraphic highs in the recent deposits.

The Subbottom Chirp profile S130bis, running on the same navigation line of the Watergun profile, shows a detailed image of the first few meters below the sea bottom. In particular, in the first part of the profile (Figure 24) a steep slope revals the occurrence of the Maratea canyon, reaching in this area water depths of more than – 600 m. At the foot of the canyon, the sea bottom, running at water depths of more than 650 m appears quite articulated, as the seismic units identified in the first subbottom.



(modified after Aiello et al., 2010).

Figure 23. (A) Multichannel seismic profile S130bis recorded offshore Maratea; (B) Interpreted seismic profile offshore Maratea. Note the occurrence of several seismostratigraphic units overlying an acoustic basement. Late Pleistocene progradational deposits occur on the continental shelf off Maratea. Tectonically-controlled shelf break occurs at water depth of about – 30 m. Slope sequences appear to be deformed by NE-SW trending normal faulting.



(modified after Aiello et al. 2010).

Figure 24. Subbottom Chirp profile S130 bis (part 1), showing a detailed, highly resolutive image of the first meters under the sea bottom along the same navigation line of the Watergun profile. Note that the sequences cropping out at the sea bottom are affected by creeping.

A first seismic unit, about 10 meters thick, shows more or less regularly stratified seismic horizons. This is probably composed of fine-grained marine sediments and corresponds to highstand deposits deposited during the last important transgressive phase (Flandrian transgression).

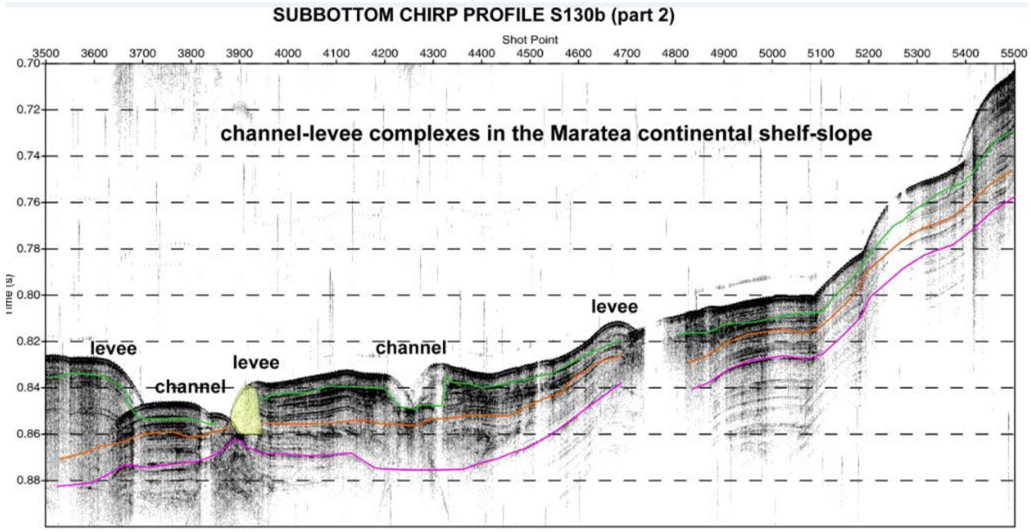
The high penetration of acoustic energy in these strata suggests that the unit is composed of under-consolidated or normally consolidated sediments. Gravitational movements and internal detachments are often present in these kinds of deposits, as confirmed also by the creeping involving recent sediments.

Under this unit a second seismic sequence, with an average thickness of about 20 m, shows less penetration of acoustic energy and is probably composed of coarser lithologies.

The second part of the section S130bis (Figure 25) is characterized by the occurrence of channel-levee complexes and by the occurrence of many channels, showing the recent activity of erosional processes. A sandy levee, located at water depths of – 625 m, is localized in correspondence of several lobes of minor extension.

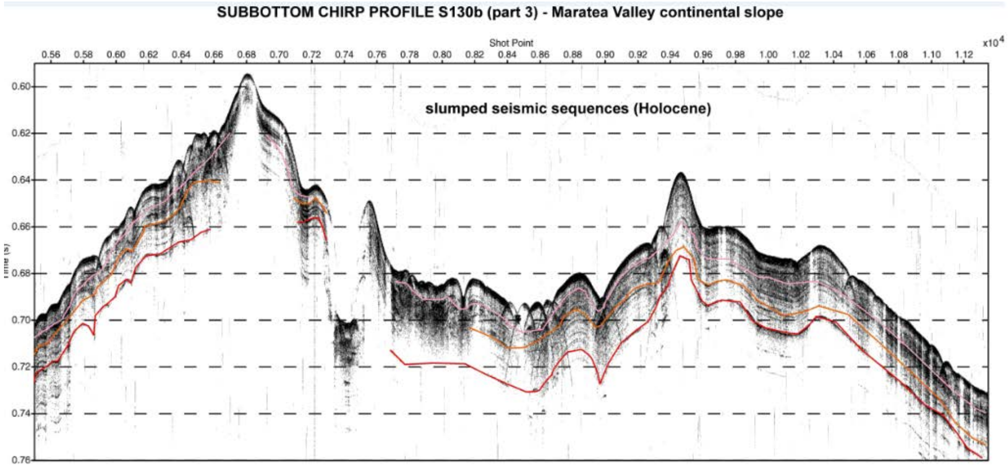
In the last part of the seismic profile S130bis (Figure 26) Holocene sedimentary sequences are spotted with slumpings, resulting from gravity instabilities, which characterize the entire study area. The seismic profile Subbottom Chirp S130b (Figure 27), perpendicular to the Tyrrhenian shoreline, runs along the continental shelf surrounding northern Calabria. Seismo-stratigraphic analysis allowed to distinguish, on the continental shelf, an acoustic basement characterized by low-angle prograding clinoforms.

The progradations recognized in the acoustic basement show depositional geometries with preserved clinoforms and eroded topsets. This indicates the occurrence of a wide prograding succession, which, during the Pleistocene, widened the continental shelf of the northern Calabria. The shelf break, of a gradual type, is located at water depths of about – 150 m. An erosional unconformity is located at the top of the prograding deposits.



(modified after Aiello et al. 2010).

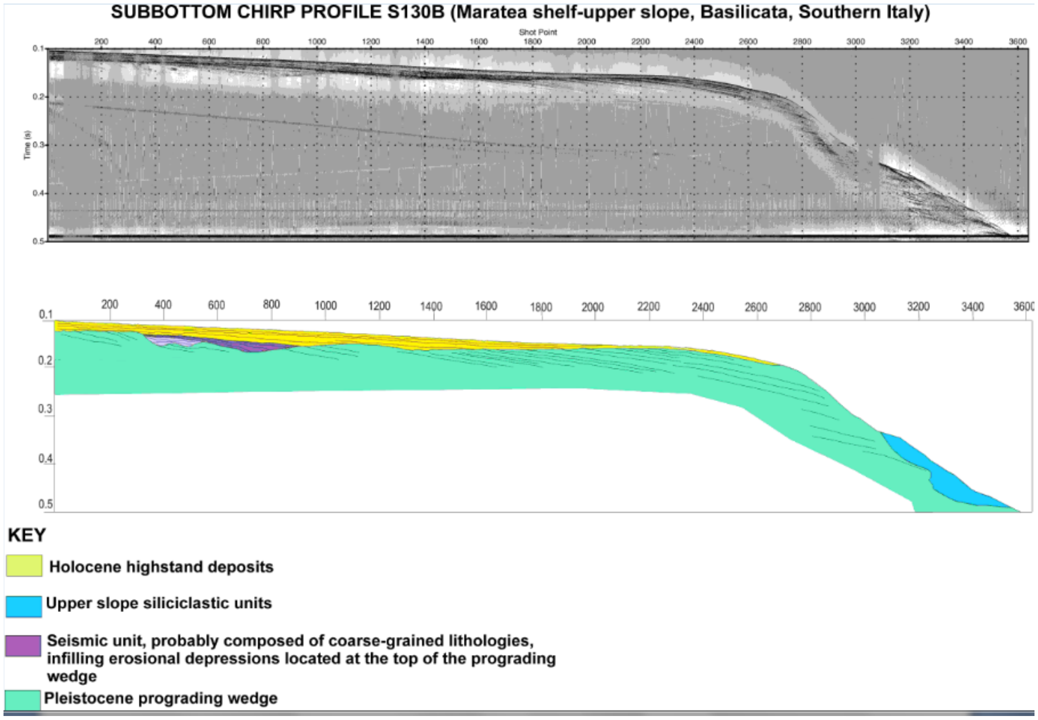
Figure 25. Subbottom Chirp profile S130 bis (part 2;). Main morphological and depositional units distinguished in this area are the channel-levee complexes, often present in the areas surrounding the submarine canyons.



(modified after Aiello et al. 2010).

Figure 26. Subbottom Chirp profile S130 bis (part 3;). Holocene sedimentary sequences appear to be clearly affected by slumpings, as a result of submarine instability processes in the area surrounding the Maratea Valley.

Coarse-grained wedge-shaped seismic units deposit in the deep channels of the unconformity, forming infillings characterized by bidirectional onlaps. Proceeding upwards we can observe a succession of marine deposits characterized by parallel seismic reflectors of high amplitude and continuity. The thickness of this succession is about 60 meters near shore. The deposits progressively decrease proceeding seawards, eventually thinning towards the shelf break.



(modified after Aiello et al. 2010).

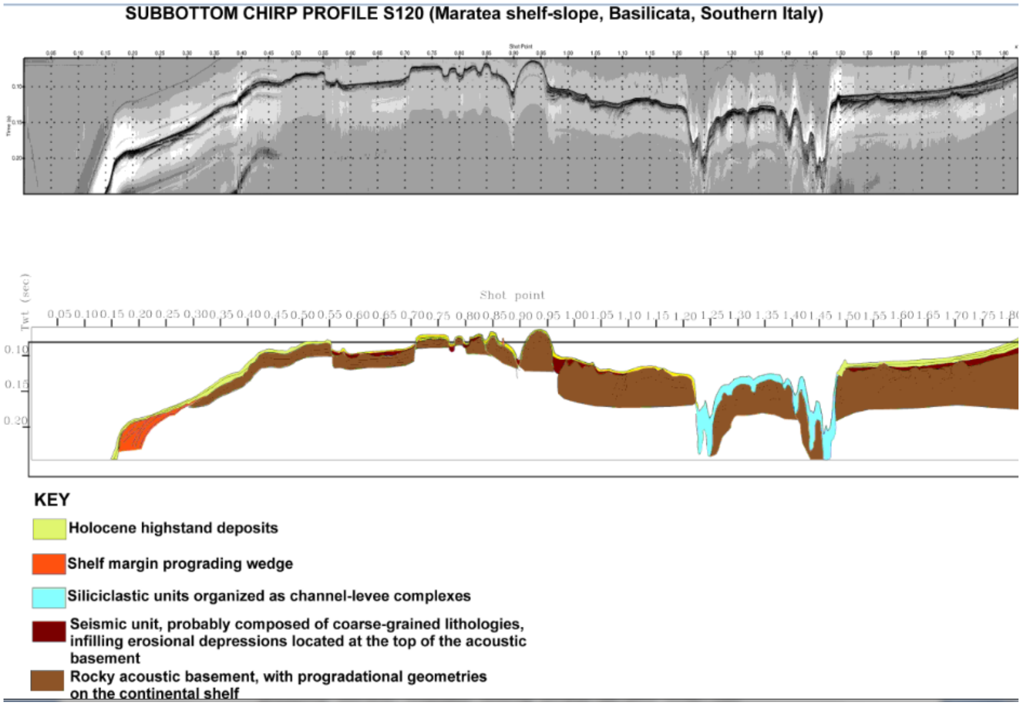
Figure 27. Subbottom Chirp profile S130b. On the continental shelf note the occurrence of a wide prograding succession, characterized by clinoforms prograding seawards, with eroded topsets and non-preserved offsets. Note the occurrence of a lenticular unit, filling the incisions and the valley depressions which form in correspondence to the wide erosional surface bounding the acoustic basement at the top. Holocene highstand wedge tends to decrease in thickness towards the shelf break.

This succession is composed of coastal and marine depositional systems that formed during the progressive retreating of the shoreline induced by the late Quaternary sea level rise, allowing for an overall vertical aggradation of the continental shelf.

The seismic profile Subbottom Chirp S120 (Figure 28) runs perpendicularly to the shoreline in the sector surrounding the Maratea offshore. The geological interpretation of the profile has allowed the occurrence of several seismo-stratigraphic units, which characterize the architecture of the continental shelf and slope.

This section has clearly crossed the Maratea canyon system, characterized by two main axes, separated by a morphological threshold and by some secondary drainage axes, genetically related to the canyon system. The first sector of the continental shelf (shot points 1.80-1.50) is distinguished for the occurrence of an acoustic basement (represented in brown in the section).

It corresponds to the Pleistocene prograding succession, already identified on the section and interpreted as the relic of a prograding wedge genetically linked to upper Pleistocene lowstand stages. Seismo-stratigraphic evidence suggests that this succession also extends under the system of the Maratea canyon and up to the successive sector of the continental shelf. The Maratea canyon deeply incides the continental shelf, allowing the formation of two morphological breaks in slope, bounding the canyon system (Figure 28).



(modified after Aiello et al. 2010).

Figure 28. Subbottom Chirp profile S120. Note the occurrence of an acoustic basement characterized by a wide prograding succession, which deposits on the whole continental shelf surrounding the Maratea offshore. The Maratea canyon deeply erodes the continental shelf succession and is characterized by a double culmination. Note the occurrence of a shelf margin prograding wedge.

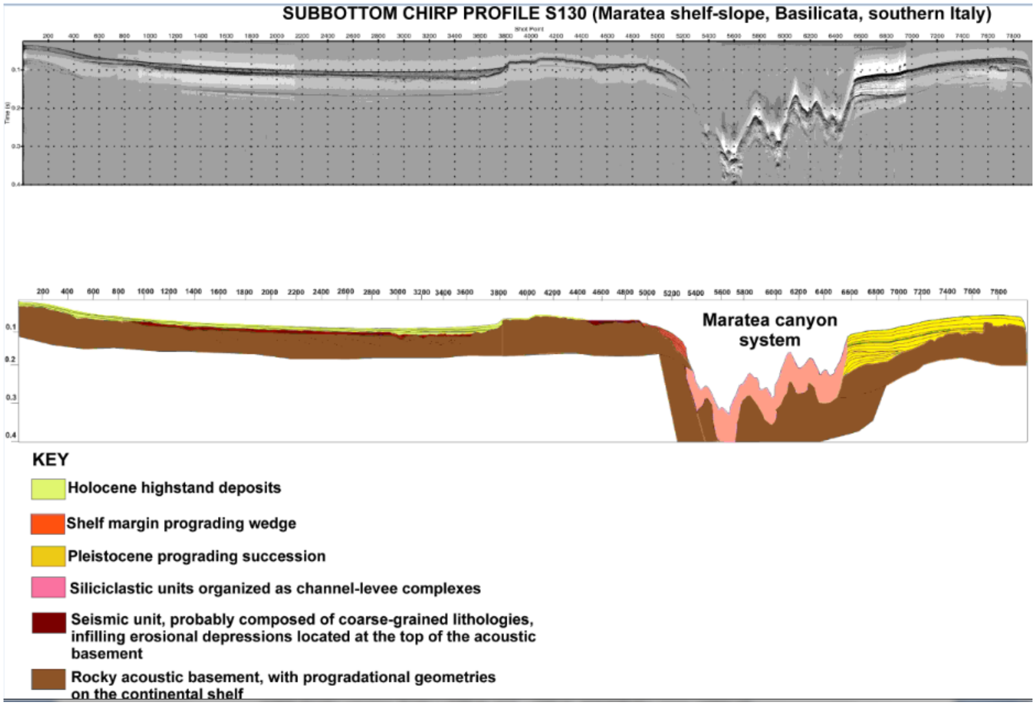
In correspondence to the shelf break, localized about at – 150 m of water depth, a shelf margin prograding wedge develops (represented in orange on the section) characterized by a sigmoidal progradation, which appears draped by the Holocene highstand deposits of the late Quaternary sequence (reported in yellow on the seismic profile).

Coarse-grained deposits are frequent and are probably composed of sands and gravels, infilling erosional channels localized in correspondence to the wurmian erosional surface (18 ky B.P.).

The Subbottom Chirp profile S130 runs parallel to the Tyrrhenian shoreline from the Policastro Gulf towards Northern Calabria (Figure 29). The geological interpretation of the section has revealed an acoustic basement on the continental shelf, characterized by prograding deposits. The prograding succession is truncated by an erosional surface, probably subaerial, which in some points crops out at the sea bottom.

In the first part of the seismic profile (shots 0-5200) the Holocene highstand deposits (reported in yellow on the section) occur as a thin drape, which tends to close southwards. In correspondence to the break in slope which marks the passage to the Maratea canyon, a recent prograding wedge with sigmoidal progradations has been observed.

The Maratea canyon system is articulated in four main axes, localized at water depths ranging from – 150 m and – 230 m, towards the inner sector of the continental shelf. The Pleistocene prograding succession was observed at more elevated water depths towards the second break in slope bounding the canyon.



(modified after Aiello et al. 2010).

Figure 29. Subbottom Chirp profile S130. Note the occurrence (on the left of the profile) of a wide depression at the top of the acoustic basement, representing the seaward prolongation of the Maratea Valley. In this depression a seismic unit, characterized by a wedge-shaped external geometry and coarse-grained lithology deposits. The Maratea canyon system is characterized by three axial culminations and by delineated breaks in slope at its margins.

The recent marine deposits show high thickness, probably due to high sedimentary supply in correspondence to the Bussento river mouth; moreover, the onlap of the first reflectors of the Holocene sequence appears above the Pleistocene acoustic basement.

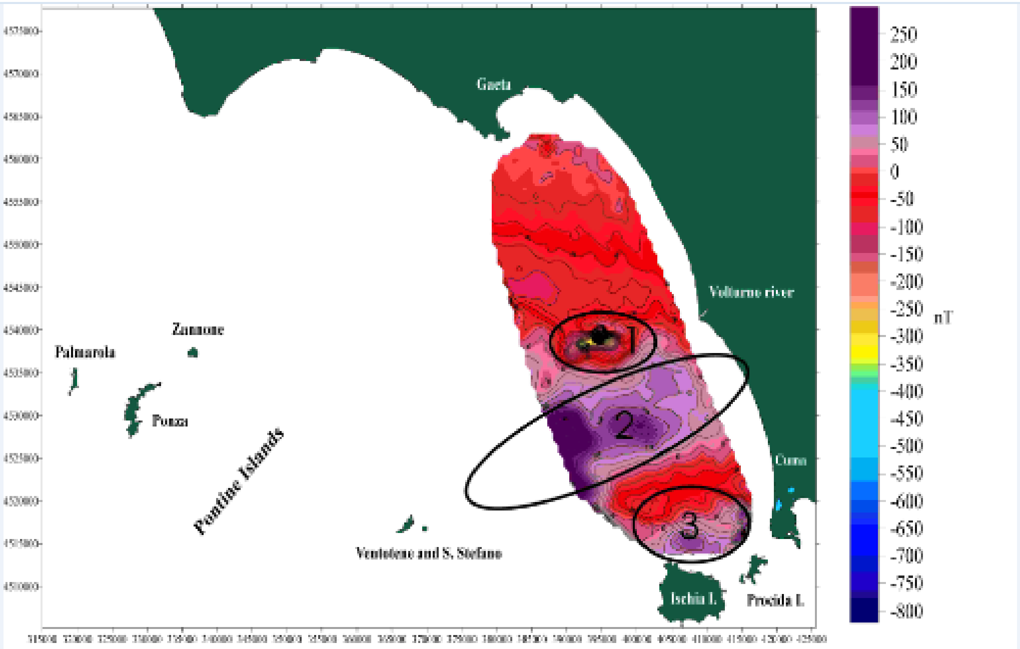
CONCLUSION

Volturno Basin

In this chapter we focused on the Volturno Basin, confirming the regional geological structure of the Campania-Latium continental margin, which is characterized by a series of structural highs and intervening basins, matching the main structures of the mainland. The implications for the tectono-stratigraphy of the other basins of the Campania and Latium margin (the Terracina and Gaeta basins) have also been analyzed.

The present study long-establishes the important role played by the Quaternary volcanic eruptions and demonstrates the incidence of sedimentation of thick, acoustically transparent volcanic seismic sequences under the basin that are interconnected with the Villa Literno and Parete volcanic complexes. A qualitative correlation of the seismic and magnetic data has also been carried out, which was aimed at confirmation of the volcanic nature of the seismic units that have been predicted through geological interpretations (Figures 30 and 31). The regional tectonic lineaments of the Campania-Latium Tyrrhenian margin are here summarized, as reported in Figure 10: the NW-SE trending Circeo structural high, which represents the seaward extension of the Circeo Promontory; the Terracina Basin, which is a N-S trending half-graben that enlarges seawards and laterally joins the Gaeta Basin; the Terracina-Gaeta structural high, which is a wide belt of structural highs outside Gaeta town that indicate the physiographic separation of the Terracina and Gaeta basins; the Massico Mount structural high, a NE-SW trending structural high that is indicative of the seaward prolongation of the Mount Massico structure; and the Volturno Basin, which is characterized by a depocenter that corresponds with the mouth of the Volturno river.

The Plio-Pleistocene basin fill of the Terracina and Gaeta Basins constitutes siliciclastic deposits of marine, coastal and deltaic environments (conglomerates, sands and shales), which sometimes has intercalations of volcaniclastic levels, as documented by the offshore well stratigraphy [Aiello et al., 2000]; (Figure 10). These deposits overlie a succession that is about 1000 m thick, of alternating sands, shales and alluvial conglomerates, at the offshore well “Mara 1”. The conglomerates are probably Late Pliocene – Early Pleistocene in age and correspond to a seismic facies characterized by prograding clinoforms that are erosionally truncated at their top.



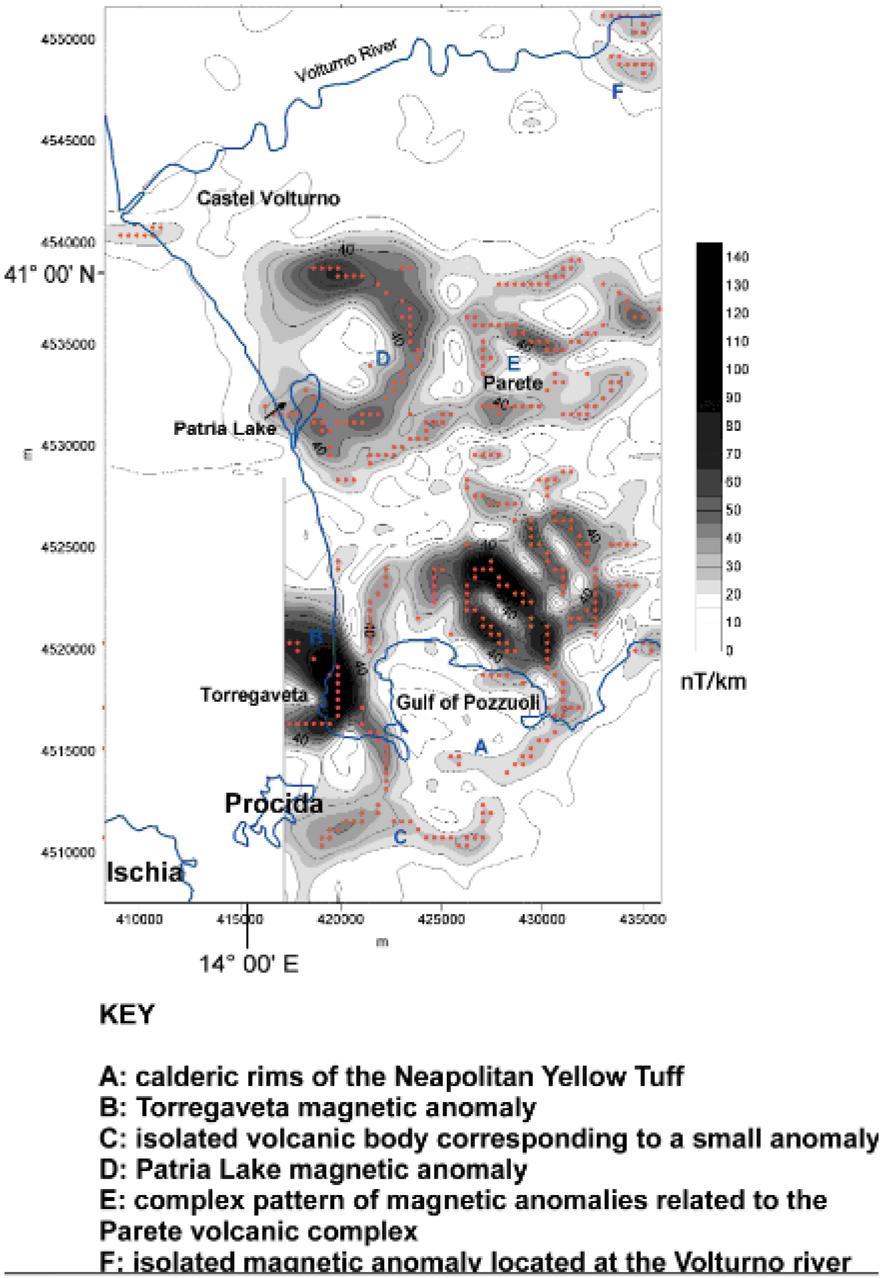
MAGNETIC ANOMALY FIELDS BETWEEN THE GAETA GULF AND THE ISCHIA ISLAND (CAMPANIA-LATIUM TYRRHENIAN MARGIN, ITALY)

1: magnetic anomaly field located on the continental shelf in correspondence to the Volturno river mouth, having a complex shape, E-W elongated, with a central minimum at 700 nT and inverted minimum-maximum magnetic axis;
2: magnetic anomaly field located in the Castelvolturno-Mondragone offshore, having a magnetic maximum at 200 nT, NE-SW oriented, probably related to a depocenter of the Volturno Basin, including in its filling reworked pyroclastic products drained by the Volturno river; its NW-SE trending seems to be controlled by counter-Apenninic (NE-SW) trending normal faults;
3: magnetic maximum of about 200 nT northwards of the Procida Island, related with the volcanic structures of the Phlegrean Fields and of the Ischia and Procida islands.

(reported from Ruggieri, 2006).

Figure 30. Anomaly map of the total magnetic field offshore between Gaeta Gulf and Ischia island.

These correlate with a similar succession that crops out onshore near Scauri and Minturno ("Conglomerati di Scauri" *Auct.*) [Parotto and Praturlon 1975]; [Accordi and Carbone 1986].



(reported from Paoletti 2004).

Figure 31. Map of the horizontal derivative plotted in the gray scale of the southern Volturno Plain. The letters A-F indicate the main magnetic anomalies recognized in the area. A: calderic rims of the Neapolitain Yellow Tuff; B: Torregaveta anomaly; C: magnetic anomaly corresponding to an isolated volcanic body; D: Patria Lake anomaly; E: complex pattern of magnetic anomalies coinciding with the Parete volcanic complex; F: isolated anomaly corresponding with the Volturno river.

The structural setting of the Terracina Basin is controlled by NNE-SSW trending normal faults that are mainly at its north-western margin. These faults spread to the west of the sedimentary basin, and only down throw the basin filling locally, and they border the southern flank of the Circeo structural high.

The same basin is bounded eastward by a structural high that is immediately offshore the Gaeta area (the Gaeta Promontory), which marks the shift to the Gaeta Basin. The extensional deformation was probably active up to the early stages of the filling of the basin, as indicated by the wedging and growth of the basal seismic sequences. The Gaeta Basin is E-W oriented and is characterized by two main depocenters. It is bounded to the north and to the south by E-W striking normal faults [Aiello et al. 2000]; [Bruno et al. 2000], and to the east by a NW-SE trending normal fault. At the northern margin of the basin there is a system of normal fault that are E-W oriented and that reach a throw of < 1 s. The acoustic basement ranges in depth between 300 ms and 1 s in correspondence to the Gaeta structural high (Figure 10) and is composed of siliciclastic deposits ("Flysch di Frosinone" *Auct.*) [Parotto and Praturlon 1975] and Jurassic-Cretaceous basinal carbonates; it is strongly affected by extensional tectonics. The eastern-most depocenter of the Gaeta Basin is enclosed towards the east by a NW-SE trending normal fault.

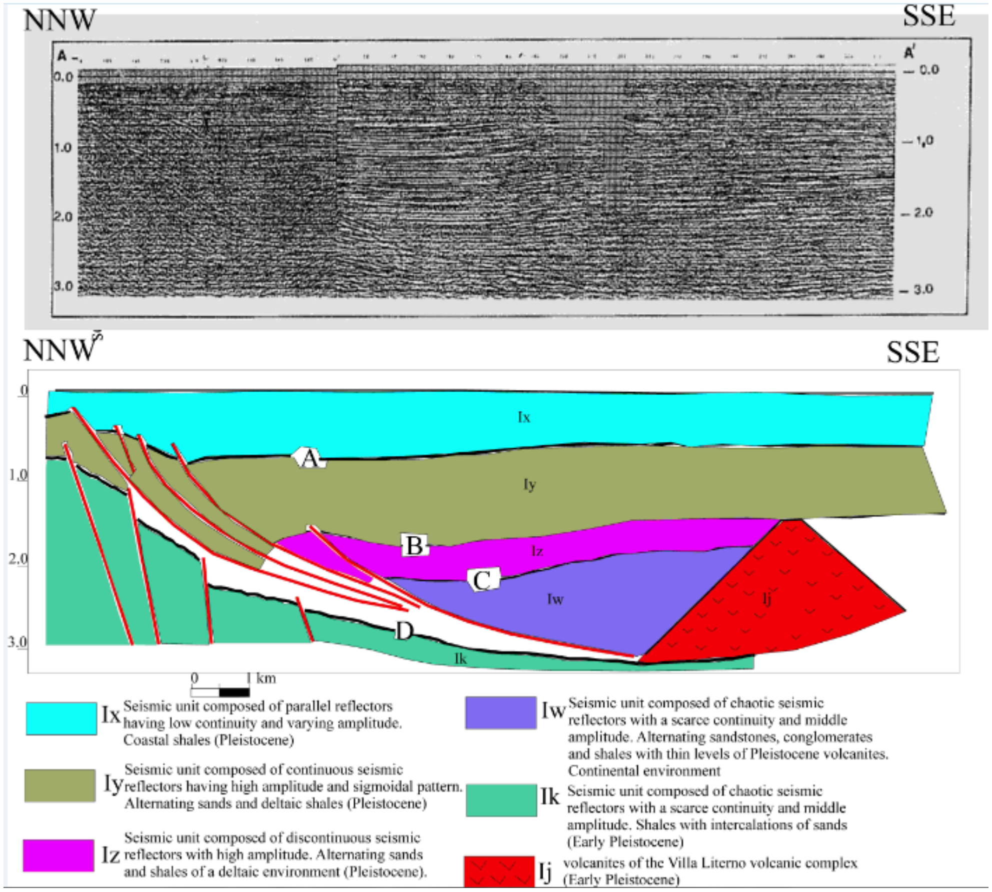
The Volturno Basin is bordered to the north-north-west by the NE-SW trending Massico Mount Structural High, to the east by NW-SE trending normal faults that down-throw the platform carbonates that crop out in the Caserta Mountains. It is also defined by volcanic rock that is genetically related to the Villa Literno volcanic complex, and to the west in the surrounding offshore by a volcanic structural high that is parallel to the shoreline and which represents a buried volcanic edifice at the mouth of the Volturno river [de Alteriis et al., 2006].

The Plio-Pleistocene basin fill (Castelvolturno 2 well) [Ippolito et al. 1973] is composed of marine deposits, with frequent pyroclastic levels and lagoon and deltaic conglomerates, which evolve upwards into marine sediments. The seismic interpretation of the onshore reflection seismics [Mariani and Prato 1988] allowed the identification of five seismic sequences, which include the volcanic seismic sequence related to the Villa Literno volcanic complex (Figure 32). The upper sequence (Ix Figure 32) is Pleistocene in age and is branded by parallel and discontinuous reflectors with low amplitudes, and is composed of clays of coastal environments. It is underlined by an erosional unconformity that grades into another Pleistocene seismic sequence (Iy Figure 32), which is characterized by continuous seismic reflectors with progradational (sigmoidal) geometry, and is constituted by alternating sands and shales of deltaic environments. The underlying Pleistocene sequence (Iz Figure 32) is distinguished by discontinuous and parallel seismic reflectors, and it is composed of sands that alternate with shales of deltaic environments.

The lowest sequence (Iw Figure 32) is identified by discontinuous seismic reflectors with poor continuity, and it is constituted by thin alternating sandstones, conglomerates and shales, with levels of Pleistocene volcanites. It was deposited in continental environments.

The geological interpretation of the Sister4_2 seismic profile has highlighted the relationships between the Meso-Cenozoic acoustic basement and the Quaternary basin filling, which include significant volcanic terms.

The Meso-Cenozoic acoustic basement is composed of two main seismic facies, which are interpreted as Meso-Cenozoic carbonates (MC Figure 15) and the overlying siliciclastic (flysch) deposits (FLS Figure 15).



(modified after Mariani and Prato 1988).

Figure 32. Interpreted seismic section onshore in the Volturno basin. Note the occurrence of four main onshore seismic sequences identified based on the seismo-stratigraphic analysis of the Sister4_2 seismic profile. Key. Ix: Seismic unit composed of parallel reflectors having low continuity and varying amplitude. Coastal clays (Pleistocene). Iy: Seismic unit composed of continuous reflectors having high amplitude and sigmoidal patterns. Alternating deltaic sands and shales (Pleistocene). Iz: Seismic unit composed of discontinuous reflectors with high amplitude. Alternating deltaic sands and shales (Pleistocene). Iw: Seismic unit composed of discontinuous chaotic reflectors with middle amplitude. Shales with intercalations of sands (Early Pleistocene). Ij: Volcanic rocks (Villa Literno volcanic complex; Early Pleistocene).

The Meso-Cenozoic carbonates show a seismic facies with scattered and discontinuous seismic reflectors, which is of high amplitude. Their top is marked by a strong erosional unconformity, at depths between 1800 m and 1950 m. The overlying Cenozoic deposits show a chaotic seismic facies and are intensively deformed by normal faulting. Their top is marked by a strong erosional unconformity, at depths between 1125 m and 1350 m. This sequence correlates with the Miocene deposits of the “Flysch di Frosinone” *Auct.* [Parotto and Praturlon, 1975].

A thick, acoustically transparent, seismic sequence overlying the unconformity located at the top of the Miocene flysch deposits is interpreted as volcanites that are genetically related to the volcanic deposits of the Villa Literno volcanic complex. The average thickness of this sequence has been estimated at about 400 m.

The considerable amount of lava drilled by the “Parete 2” and “Villa Literno 2” lithostratigraphic wells (Figure 11), along with the buried volcanic complexes seen on the Sister4_2 seismic section (Figure 15), suggest the occurrence of volcanic complexes that are now fossilised and buried, with their probable effusive centers completely covered by recent alluvial and pyroclastic deposits. These volcanic complexes also extend seawards, and they were probably located between the low course of the Volturno river and the northern margin of the Phlegrean Fields.

The stratigraphy of the Campania Plain can be summarized as follows [Ortolani and Aprile, 1978]: alluvial deposits and volcanites thick 3000-3500 m (in the central sector), Tertiary terrigenous deposits, thick several hundred of meters, ranging in age from the late Miocene to the Pliocene, carbonatic units of the Campania-Lucania Carbonate Platform at depths from 4000 m to 4500 m down to 6500 m to 7000 m, and finally carbonatic units of the Abruzzi-Campania carbonate platform.

The main conclusions are here summarized. Four main seismic sequences that correspond to the seismic units recognized onshore by [Mariani and Prato 1988], have been distinguished in the Volturno Basin, based on seismo-stratigraphic analysis of the Sister4_2 seismic profile (Figure 12). The lithology of the seismic units of the filling of the Quaternary basin has been inferred both from the litho-stratigraphic data of the “Castelvolturno 2” deep borehole and from the geological interpretation of [Mariani and Prato 1988].

The first seismic sequence (Figure 12) is characterized by discontinuous to continuous seismic reflectors that are from parallel to sub-parallel. They are probably composed of sands, conglomerates and shales, with levels of pyroclastites, and their age is probably Early Pleistocene [Mariani and Prato 1988]. The sequence onlaps onto the flank of the VC volcanic seismic unit (Figure 12), which represents volcanites genetically related to the Villa Literno volcanic complex. It is characterized by wedging geometries, which suggests its emplacement during the activity of synsedimentary tectonic extension. The intrusion of the VC volcanic unit is probably older than the deposition of seismic unit 1, as is suggested by the onlap of the above mentioned unit on the flanks of the volcanic rock.

The second seismic sequence (Figure 12) has been subdivided into two main seismic facies that have been identified on the continental shelf (seismic sequence 2a, Figure 12) and the basin (seismic sequence 2b, Figure 12). The sequence 2a is characterized by prograding clinoforms and has been interpreted as a relic prograding wedge that downlaps onto volcanites. Seismic unit 2b is characterized by parallel to sub-parallel seismic reflectors and it is probably constituted by alternating sands and shales of deltaic environments (Pleistocene).

The third seismic sequence (Figure 12) is identified by parallel to sub-parallel seismic reflectors with high amplitude and it is formed by alternating sands and shales of deltaic environments.

Finally, the fourth seismic sequence (Figure 12) shows discontinuous to continuous and parallel to sub-parallel seismic reflectors. It is probably composed of clays of coastal environments (Pleistocene).

The seismic interpretation of the Sister4_2 multichannel profile has contributed to our knowledge of the stratigraphic and structural relationships between the Meso-Cenozoic acoustic basement and the filling of the Quaternary basin in the Volturno Basin, on the northern Campania continental margin. The overall seismo-stratigraphic data is in agreement with [Mariani and Prato, 1988] and confirms that the Volturno Basin is a half-graben structure that is characterized by down-thrown blocks along normal faults that affect mainly the top of the Miocene acoustic basement.

As in the other sedimentary basins offshore of the Campania region [see also Aiello et al. 2005b], the volcanic deposits appear to be well developed as offshore buried volcanic complexes. This is the case for the volcanic bodies identified on the Sister4_2 seismic profile that are genetically related to the Villa Literno volcanic complex. The filling of the Quaternary basin is composed of thick sediments of delta, lagoon and marine environments. It shows stratigraphic relationships of facies hetheropy with pyroclastic and lavic complexes. As a general rule, the depositional geometries of the filling of the sedimentary basin often appear to be conditioned by the buried volcanic complexes, especially at the contact between the acoustically transparent volcanites and the marine sediments. This had already been suggested in the case histories of the Bay of Naples [Aiello et al., 2005] and of the mouth of the Volturno river [de Alteriis et al. 2006], where buried volcanic complexes have been identified and studied in detail through seismic interpretation.

The comparison of the data from the Volturno basin with the commercial seismic data of "Zone E" (AGIP) has been already carried out. This refers in particular to the Terracina and Gaeta basins, which represent further examples of half-graben basins on the Campania-Latium Tyrrhenian margin [Aiello et al. 2000].

The tectonic extension is revealed by NE-SW (counter-Apenninic) and E-W trends of normal faults that control the formation of N-S to E-W oriented half-graben structures on the Campania-Latium Tyrrhenian margin (Terracina, Gaeta and Volturno basins), accordingly to [Oldow et al., 1993] and [Ferranti et al. 1996]. The older extensional phase, which is Pliocene in age, acted through NW-SE (Apenninic) normal faults, which controls the structural setting of the investigated area. In correspondence with the Tyrrhenian coastal belt, NW-SE trending sedimentary basins and intervening ridges distinguish the physiography of the Campania continental margin. Lastly, the Pleistocene extensional phase acts through high-angle normal faults with counter-Apennine trends, and it is responsible for the most recent deformations and for the general down-throwing of the western Apenninic margin towards the central Tyrrhenian sea.

A semi-quantitative kinematic model explaining the relationships between the extension in the Tyrrhenian sea, the basin formation, the migration of the Apenninic arcs, and the geotectonic setting of the volcanism has been recently elaborated by [Turco et al. 2006]. The extension directions in various sectors of the Apennine chain have been compared with the results of the morpho-structural analysis. Two distinct kinematic elements, the Northern Apennine Arc and the Southern Apennine Arc, have moved independently and have undergone two stages of rotation. During the first stage, ranging in age between 3.5 My and 0.78 My, the two arcs migrated independently; in the second stage, ranging in age from 0.78 My to the present, the Northern Apenninic Arc stopped its migration, while the Southern Apenninic Arc continued moving toward the SE. The N-S extension in the Campania Plain was a consequence of the motion of the Northern Apenninic Arc during the first stage of rotation, while the NW-SE extension is related to the south-eastwards migration of the Southern Apennines with respect to the Northern Apennines.

The obtained results well agree with those shown by some previous geological sections carried out on the Campania continental margin, both at a crustal [Milia et al. 2003]; [Sartori et al. 2004] and at intermediate [Aiello et al. 2009a] scales. The structure of the continental margin is controlled by asymmetric-linked fault systems, which are characterized by a main detachment level, listric normal faults, and roll-over anticlines. Deep seismic reflection data collected during the Ocean Drilling Program cruises [Sartori et al. 2004] have revealed the conjugate structure of the Campania and Sardinia passive continental margins. Plio-Quaternary depocenters (more than 1.4 s twt) occur close to the base of the continental margin, and are in small half-graben basins that are bounded by faults that trend from N-S to NW-SE.

The continental margins of the southern Tyrrhenian basin are highly asymmetric because the rifting processes were overcome by a low-angle, easterly dipping, and crustal detachment fault [Trincardi and Zitellini, 1987]; [Kastens et al., 1988]. The geological transects have confirmed the asymmetric nature of the conjugate margin pairs of Sardinia-Campania, which extend down to the Moho depth [Sartori et al. 2004].

Although the scale of the multi-channel profile analyzed here did not allow for the identification of deep detachment levels, which are usually identified on seismic reflection or refraction profiles recorded at a crustal scale, we can hypothesize that the portion of the continental margin investigated shows only the upper part of listric normal faults [Bally et al. 1985; high-angle normal faults], while the low-angle normal faults and the sole faults might be located at greater depths. Therefore, the nature of the growth faults [Bally et al. 1985] of the interpreted structural lineaments is suggested by the wedging and growth of the basal sequences of the Quaternary filling.

South-Eastern Ischia Island

The main seismic sequences of the south-eastern Ischia offshore have been restored through the geological interpretation of high resolution (Sparker) seismic reflection profiles. Regional seismic sections have been assembled based on their geologic interpretation to improve the understanding of the structural and stratigraphic characteristics of the island offshore and taking into account the volcanology and the stratigraphy of the onshore sequences [Vezzoli 1988]; [Orsi et al. 2004]; [Brown et al. 2008] for a coherent geological interpretation.

The south-western Ischia offshore, between Punta Imperatore and Sant'Angelo promontories, has been investigated analyzing five seismic sections, perpendicular to the shoreline and one tie section [Aiello et al. 2012; in press.]. Here the Ischia continental shelf is very narrow and the late Quaternary deposits are thin and restricted sideway. The shelf break, however, seems to be depositional. The most important seismic unit detected in this sector is the volcanic acoustic basement, cropping out on the slope below a thin Holocene sedimentary drape, genetically corresponding to the Punta Imperatore lavas [Aiello et al., 2012; in press.]. Continental slope deposits, ranging in age from the Late Pleistocene to the Holocene, have also been recognized.

Based on the most recent literature the following sequence of events may be restored, at Punta Imperatore promontory. Alkalitrachytic lavas (117 ky B.P.) cover pyroclastic breccias emplaced before the Mt. Epomeo Green Tuff [Brown et al. 2008]. The above breccia is overlain by thick pumice-fall breccias, with several intercalated scoria layers. A white ignimbritic deposit, related to the Epomeo Green Tuff eruptions, follows and fills a small valley cut into thick fall deposits [Orsi et al. 2004]. On the southern slope of the promontory this sequence is unconformably covered by the volcanic products of the Scarrupo di Panza eruption, and by the pyroclastic units of the 28-18 ky period of Ischia volcanic activity.

A new pyroclastic stratigraphy by [Brown et al. 2008] for the Ischia island covers the period from 75 to 50 ky B.P. Their volcanological data indicate that during this period the largest eruptions recorded on the island occurred. In particular, the stratigraphy of the volcanic sequences cropping out at Punta Imperatore has been deeply revised [Brown et al. 2008]. In the basal part of these sequences outcropping in the coastal cliffs, lavas aged about 118 ky B.P. [Vezzoli 1988] have been identified. They are overlain by undifferentiated pumice fall deposit, uncertain in age.

These latter deposits are in turn unconformably overlain by the following terranes: the Monte Epomeo Green Tuffs [MEGT in Brown et al. 2008] consisting of heterolithic pyroclastic breccias and ignimbrites; the La Roia Tephra, consisting of well-sorted, graded pumice lapilli, overlying a paleosol developed in the above extracaldera MEGT lithic breccia and passing up into a paleosol overlain by distal ashfall deposits of the Chiummano Tephra. They are covered, in turn, by the Schiappone Tephra, consisting of pumice fall deposits covered by ignimbrites, which in turn are overlain by the Citara-Serrara Fontana Formation (45 ky B.P.); [Vezzoli 1988].

The Maronti area has been investigated through Sparker profiles (Figure 13). Here the continental shelf is narrow with respect to the adjacent areas. The TST and HST deposits are thin and restricted. The volcanic acoustic basement is thick and continuous from the shelf towards the slope. The Maronti beach extends between Punta della Signora and Sant'Angelo promontories. Coastal outcrops are the product of the dismantling of the M.te Epomeo structure, that recently originated landslides and mud flows, covering older debris avalanches. At the base of the Sant'Angelo promontory an alkalitrachytic lava dome (100 ky B.P.); [Orsi et al. 2004] is overlain by ash flows, pyroclastic flows and fall deposits. They belong to the explosive volcanism that preceded the Epomeo eruption [Brown et al. 2008]. These deposits are overlain by pyroclastic deposits dated at about 55 and 20 ky B.P.

The stratigraphic relationships with the Banco di Ischia volcanic structure have been shown by the regional seismic section L57 and corresponding geologic interpretation (Figure 14). In particular, this section has crossed the volcanic structure of the Ischia Bank through the Ischia Channel, where it crosses the relic volcanic edifice named “Il Pertuso” and arrives since to the Procida continental shelf (Figure 14).

The Ischia Bank is a flat tronco-conycal volcanic edifice, having steep slopes, ending into a regular continental shelf at water depths of – 30 m. The age of formation of this monogenic volcano is not directly known, i.e. based on direct datations. [Vezzoli 1988] has indicated the Ischia bank as the eruptive centre of pyroclastic fall and flux deposits localized onshore in the eastern Ischia island (Piano Liguori Formation; age less than 6-8 ky B.P.).

Several relic volcanic edifices occur in the Ischia Channel (“I Ruommoli”, “La Catena”, “Le Formiche di Vivara”, “Il Pertuso”), composed of remnants of hydromagmatic volcanic features, mostly composed of hialoclastites, indicating an emplacement in a subaqueous environment. The saddle named “Le Formiche di Vivara” is composed by the remnants of a volcanic edifice partially down thrown, probably older than the Vivara volcano [Di Girolamo and Rolandi 1976]. The volcanic products cropping out in correspondence to the saddle are composed of yellow tuffs, overlying on volcanic breccias. The saddle is characterized by the occurrence of several submerged cavities, having varying dimensions. One of the most important caves is named “Grotta Grande delle Formiche” and is located on the eastern side of the saddle. The birth of the main cavity culmination (Grotta Grande delle Formiche di Vivara) has been favoured by the morpho-selective action exercised on the volcanic breccias underlying the stratified tuffs [de Alteriis et al. 1994; Ferranti et al. 1994].

Capri Basin and the Salerno Valley

The regional geological interpretation of the seismic profiles comcurred to obtain new data on the structural and stratigraphic setting of the Naples Bay along the Ischia-Capri alignment and its relationships with the Campania-Latium margin and the Salerno Gulf [Aiello et al. 2011d]. The study sections are all localized in the Naples Bay; two of them end up in correspondence to the Campania-Latium Tyrrhenian margin (Sister4_2 and Sister7_2; Figures 12 and 15), while the third one end up in correspondence to the Salerno Gulf (Sister 9_1) [Aiello et al. 2011d].

The main regional morpho-structures of the Campania continental margin along the Ischia-Capri alignment have been already discussed [Aiello et al. 2011b]. Here they are recalled to clarify the stratigraphic relationships with the Capri basin and the Salerno Valley, included in this segment of the Campania continental margin .

1. The “Banco di Fuori” is a morpho-structure high of the Meso-Cenozoic carbonatic substrate, bounding the southern sector of the Naples Bay. Its flanks and top are overlain by the Pleistocene deposits of the Late Quaternary depositional sequence. It is characterized by an acoustically transparent seismic facies, related to the Meso-Cenozoic carbonates.

Regional geological evidences and seismic interpretation have confirmed that the Banco di Fuori represents a major morpho-structure high, which separates the Dohrn canyon from the Magnaghi canyon. It is formed by a Mesozoic carbonate block that resulted from the regional uplift and tilting of the carbonatic substrate. Its carbonatic nature is suggested by the location along the Capri-Sorrento structural alignment and confirmed by the lack of significant field anomalies [Aiello et al.., 2001; 2005].

The interpreted seismic data agree with previous structural interpretations [Milia and Torrente 1999]. The Banco di Fuori high is bounded southward by a normal fault swarm, showing a change of trend from N56E to N33E that down throws the Meso-Cenozoic substrate many hundred of meters to the south-east and is characterized by variable cross-section geometries. The top of the substrate is down faulted to the south-east. The appraisal of the corresponding fault is ca. 1300 and 1000 m, while the eastern profile of ca. 600 m. The displacement changes of the Banco di Fuori normal fault are interpreted according to the model of [Walsh and Watterson 1988], which document that the fault displacement changes along the strike. It is commonly greatest at the centre of the fault, decreasing to zero at the eastern fault tip in the central part of the Bay of Naples, where this structure is buried by younger sediments.

2. The Dohrn canyon is a main morpho-structure of the Naples Bay, separating the eastern sector, where the sedimentary seismic units crop out, from the western one, where the volcanic seismic units prevail. It is articulated into two branches, the eastern one and the western one, merging in a thalweg having a NE-SW (counter-Apenninic) direction, bounded southwards by the Capri Basin [Aiello et al. 2011b]. It erodes the Pleistocene relic marine units of the prograding wedges (A and C in the interpreted seismic sections) overlying the Meso-Cenozoic carbonates. The new seismo-stratigraphic data have suggested the occurrence

of Meso-Cenozoic carbonates under the canyon thalweg, in the bathyal plain westwards of Capri island, as evidenced by the stratigraphic relationships of the carbonatic unit along the Banco di Fuori-Salerno Valley alignment. The carbonatic unit below the Banco di Fuori-Dohrn canyon-Salerno Valley alignment has not been previously pointed out by seismostratigraphic papers on the Naples Bay, suggesting its distribution only in the eastern continental shelf of the Naples Bay, as offshore prolongation of the NW dipping Capri-Sorrento monoclinalic structure [Fusi 1996].

3. The Capri structural high, whose stratigraphic bulk is constituted by two relic prograding units (A and C seismic units). The structural high is bounded by the Dohrn canyon structure to the north-west and by the Salerno Valley to the south-east. Its regional structure is related to the Capri-Sorrento Peninsula structural alignment [D'Argenio et al. 1973]; [Perrone 1988]. The southern flank of the structural high is controlled by the Capri-Sorrento master fault.

4. The Magnaghi canyon drained the volcanic and volcaniclastic input coming from the eruptive activity of the Ischia and Procida islands during the Late Quaternary. It carves the sediments of the Mg unit, characterized by reflectors having a chaotic distribution. Based on regional seismo-stratigraphic evidences, a volcanic nature of the Mg unit, genetically related to the Procida volcanic complex, may be assumed [Aiello et al. 2011b].

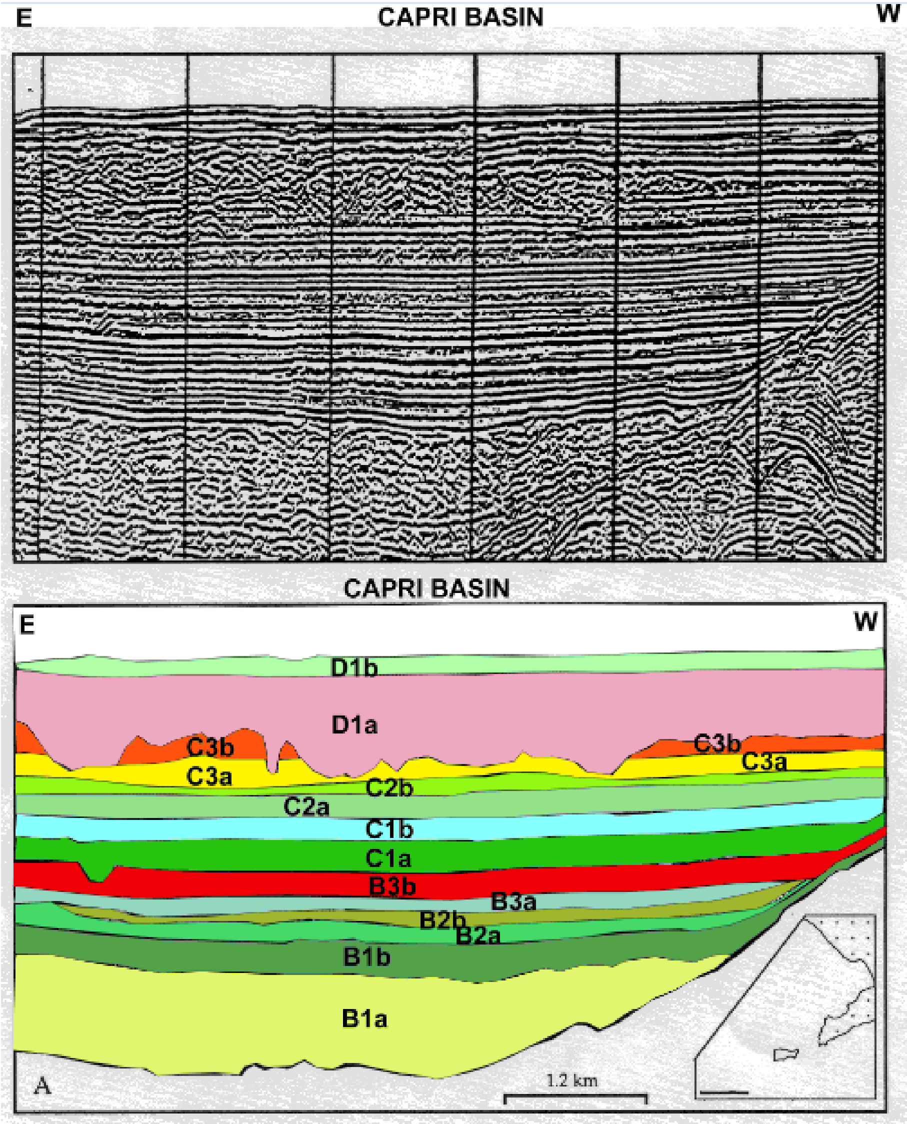
5. The Magnaghi canyon basin is a sedimentary basin located adjacently to the Magnaghi canyon and representing a depositional area, where Pleistocene-Holocene deposits drained by the canyon in its initial thalweg accumulated. It has been not previously mentioned by papers dealing on seismic stratigraphy of the area [Fusi et al. 1991]; [Milia and Torrente 1999].

6. The buried volcanic edifice localized between the Dohrn and Magnaghi canyons (BVE) represents another important morpho-structure of the Naples Bay detected through seismic interpretation. The volcanic edifice has been identified for the first time by [Secomandi et al. 2003] based on magnetic anomaly maps of the Naples Bay and is confirmed by the seismic interpretation of the seismic profile Sister4_2. The volcanic structure, interstratified in the volcanic deposits of the Mg unit, shows a mounded-shaped external geometry and is buried below a volcanic sequence about 720 m thick. It should be genetically related to the oldest phases of eruptive activity of Ischia and Procida volcanic complexes due to its stratigraphic location in the basal part of the Mg volcanic unit [Vezzoli 1988]; [De Astis et al. 2004].

7. The Capri Basin is a deep basin localized in the Tyrrhenian bathyal plain southwards of the Dohrn canyon. It is filled by Pleistocene-Holocene sediments thick about 0.7 s (twt), unconformably overlying the Meso-Cenozoic carbonates. The basin filling is characterized by parallel and laterally continuous seismic reflectors, overlying an acoustically transparent seismic facies, interpreted as the Meso-Cenozoic carbonates.

A few study deals with the seismic stratigraphy of the Capri Basin, which is relatively unknown, excluding the paper of [Milia and Torrente 1999], identifying seven depositional sequences in the basin filling. Two lowstand units have been related to main tectonic pulses. Mass flow deposits that flowed into the basin directly from the contiguous narrow shelf and steep slope have also been recognized. Sparker seismic line and corresponding geological interpretation (Figure 33); [Milia and Torrente 1999] has shown the deep basin succession, consisting of seven depositional sequences (B1, B2, B3, C1, C2, C3, D1). Two thick seismic units (B1a, D1a), interpreted as LST, were associated with the two main tectonic pulses. The seismic sequence B1a is interpreted as a mass flow deposit that reached the Capri basin directly from the adjacent narrow shelf and steep slope, whereas D1a is interpreted as a submarine fan that reached the basin through the Dohrn canyon.

The geologic evolution of the Capri Basin has also been resumed [Milia and Torrente 1999]. In the basinal area the seismic unit B1a, characterized by a chaotic seismic facies overlies the seismic unit A (Figure 33).



(modified after Milia and Torrente 1999).

Figure 33. Sparker seismic line in the Capri Basin and corresponding geologic interpretation. The deep basin succession shows seven depositional sequences (B1, B2, B3, C1, C2, C3, D1). Two thick units (B1a, D1a), interpreted as lowstand deposits, are associated with the two main tectonic pulses. B1a is interpreted as a mass flow deposit that flowed into the basin directly from the contiguous narrow shelf and steep slope, whereas D1a is interpreted as a submarine fan that reached the basin through the Dohrn canyon.

This unit, whose thickness has been estimated in about 100 m, has been interpreted as a debris flow and corresponds to the basinal depositional counterpart of the unconformity U1, located in the shelf.

Indeed, the erosion of the crest of the fault block, which gave rise to the unconformity U1, furnished sediments (probably coarse grained detritus) that were deposited directly into the deep basin west of Capri. These sediments reflect the collapse of the basin during the rifting related to the Banco di Fuori and Sorrento Peninsula normal faults. The unit B1a can be interpreted as the lowstand system tract of the B1 depositional sequence and is associated with the tectonically-enhanced unconformity U1. The upper part of the sequence B1 is made up of a few continuous reflectors, characterized by high amplitude and good continuity, corresponding to the unit B1b. The latter is covered by two depositional sequences named B2 and B3 (Figure 33). The base of each one features reflectors with variable amplitude and low continuity, onlap and downlap terminations (units B2a; B3a), followed by parallel reflectors with high amplitude and good continuity onlapping the basin flank (units B2b, B3b). These different seismic facies reflect lithologic variations present in the deep water environment. In particular, the units B2a and B3a can be interpreted as debris flow deposits intercalated in the lowstand deposits; by contrast, the units B2b and B3b show a high stratal continuity. The latter seismic facies commonly correspond to hemipelagic and/or pelagic sediments, which usually characterize these deep water environments during the transgressive and highstand system tracts. The seismic sequence C has an average thickness of 140 m. This high value of sedimentation in the deep basin is in accordance with the high sediment supply and regressive trend in the shelf-slope area. The horizontal stratal terminations of these units indicate a period of tectonic stability in the basin. By concluding, the depositional sequence D1 rests above an erosional surface and shows an average thickness of about 100 m. It consists of a submarine fan located at the mouth of the Dohrn canyon. The source area of these deposits corresponds to the shelf and they were transported to the deep basin through the Dohrn canyon. This deep sea fan has been interpreted as the lowstand system tract of the depositional sequence D1 [Milia and Torrente 1999].

8. The Salerno Valley is a half-graben basin filled by three main seismic units corresponding to Quaternary marine and continental sediments. These units grade laterally into the chaotic deposits related to the “Flysch del Cilento” *Auct.* [Bonardi et al. 1988]. The deepest seismic unit has been interpreted as Meso-Cenozoic carbonates due to poor penetration of seismic signal. The tectonic setting of the valley is controlled by the Capri regional fault, downthrowing the Meso-Cenozoic carbonates from the Capri structural high under the basin itself.

9. The Volturno Basin, hosting the northern sector of the Campania Plain and the surrounding offshore, shows a sedimentary filling consisting of four marine and deltaic seismic sequences, alternating with volcaniclastic levels and overlying deep seismic units, related with Miocene flysch deposits (sands and shales) and Meso-Cenozoic carbonates.

The seismo-stratigraphic data have evidenced that the Volturno Basin represents a half-graben, characterized by blocks down thrown along normal faults, involving the top of the Miocene acoustic basement. Similarly to other sedimentary basins offshore of Campania, the volcanic terms are particularly developed with proper terms (i.e. a volcanic body genetically related to the Villa Literno volcanic complex). The basin filling is composed of thick coastal and deltaic sediments interstratified with pyroclastic and lavic complexes, often conditioning their depositional geometries.

Agropoli Continental Shelf

The elaboration and the interpretation of a detailed grid of high resolution seismic reflection profiles recorded in the offshore of the Campania continental shelf between the Solofrone river mouth and the Agnone town (Cilento region) have allowed to carry out a study of the geomorphological hints of relative sea level variations in an area of inner continental shelf. One main aim of this interpretation was the identification of geologic and morphologic lineaments occurring at the sea bottom and in the first marine subbottom. The seismic profiles, recorded through the Chirp Subbottom profiler, have been processed through the use of a software of reading and data elaboration, the Seisphro [Gasperini and Stanghellini, 2009].

The geologic interpretation of seismic sections has been carried out according to the criteria of seismic stratigraphy; this has allowed to distinguish the main seismo-stratigraphic units occurring at the sea bottom, separated by significant seismic reflectors, corresponding to notable surfaces of conformity or unconformity. The interpretation of the sections has allowed to distinguish among the acoustic basement, widely cropping out in the nearshore area, for an extension at the sea bottom much greater with respect to that one singled out by previous studies [Coppa et al., 1988]; [Ferraro et al., 1997] and the zones of accumulation of sediments.

The outcrops of acoustic basement, correlated with the units of the “Flysch del Cilento” *Auct.*, widely cropping out in the surrounding emerged sectors, are particularly diffused in the bathymetric belt included among the – 10 m and – 50 m of water depth (i.e. in the inner continental shelf) and form terraced surfaces having a low gradient in the nearshore area between the Solofrone river mouth and Punta Licosa.

The analysis of the seismic signal and the correlation with Sidescan Sonar sonographs recorded on the same navigation lines of the Chirp Subbottom profiler have evidenced the occurrence of wide grasses at *Posidonia oceanica* and *Cymodocea nodosa*, particularly diffused at low water depths up to the – 50 m. Proceeding seawards, the acoustic basement is down thrown by normal faults under the recent sedimentary cover, organized in three main seismo-stratigraphic units separated by unconformities. The rocky acoustic basement surveyed in this area results correlated with the rocky units of the “Flysch del Cilento” *Auct.*, widely cropping out in the corresponding emerged sector of the Cilento Promontory [Bonardi et al., 1988].

In the northern sector of the study area, i.e. in the offshore located between the Solofrone river mouth and Punta Licosa, the seismo-stratigraphic analysis has evidenced that the recent sedimentary cover, ranging in age between the Late Pleistocene and the Holocene, is organized in three main seismo-stratigraphic units (Figures 18-22).

The first unit (unit 1) is characterized by parallel seismic reflectors and shows an average thickness comprised between 40 and 50 metres; it is composed of marine sediments and is bounded at its top by a surface of paraconformity (reflector A).

The second unit (unit 2) is characterized by an acoustically-transparent seismic facies and shows an average thickness included between 7 and 10 metres; it is bounded by two seismic reflectors: at the base by the reflector A (in paraconformity) and at the top by the reflector B (corresponding to a main surface of erosion) and is probably composed of sands (Figures 18-22).

The third unit (unit 3) is characterized by an acoustically-transparent seismic facies, with seismic reflectors which have been observed mainly in the basal part of the succession, showing an average thickness of about 10 m. It is probably composed of alternating sands and shales (Figures 18-22).

In the same area, wide shallow gas pockets have been identified, having a kilometric extension, crossing the stratigraphic succession up to the sea bottom. In correspondence to these gas pockets, pockmarks structures have been identified at the sea bottom, localized in the inner part of sub-circular fields. Moreover, it must be specified that, in the area of outcrops of rocky acoustic basement the sedimentary covers, composed of Quaternary marine sediments result reduced and/or lacking.

Based on these considerations, the inner continental shelf between the Solofrone river mouth and Punta Licosa represents, in its northern sector, a depocentral area of marine sediments, as evidenced by the outcropping, at the sea bottom, of marine sediments, showing mainly sandy grain-sizes [Ferraro et al., 1997]. Coarse-grained sandy ridges, parallel to the coastline, have evidenced the probable activity of sea bottom currents, active alongshore.

This area represents the seaward prolongation of the Santa Maria coastal plain, bounded by the morphological highs of Monte Tresino to the north and of the hills of Castellabate towards south-east. Apart from the actual and recent deposits, here the Quaternary deposits of the Complex of the S. Antonio and S. Marco Sandstones and of the Comenale Complex, composed both of marine and aeolian sands [Cinque et al., 1994].

In its southern sector, the continental shelf clearly represents an area of structural high, resulting from the seaward prolongation of the Punta Licosa structural high. This is evidenced by the wide diffusion at the sea bottom of the outcrops of rocky acoustic basement, genetically related with the “Flysch del Cilento” *Auct.* The acoustic basement widely crops out in the nearshore sectors, delineating a terraced surface, which dips seawards with low gradients, up to soaking under the recent sedimentary cover, probably due to the control of normal faults. Proceeding seawards, this rocky acoustic basement newly crops out in correspondence to a wide morpho-structural high, controlled by normal faults. The geologic interpretation of seismic sections has evidenced that this high shows an overall extension of about 1.4 kilometres and its rims are controlled by normal faults. Instead, the top of the rocky acoustic basement is represented by a wide erosional surface, probably polycyclic, cropping out at the sea bottom in a nearshore area. This erosional surfaces is terraced by marine terraces at several water depths (see the Table 7).

Significant outcrops of organogenic coarse-grained sands have been singled out in this area, genetically related to the wurmian regression. Based on the data of piston cores drilled in the Punta Licosa area [Ferraro et al. 1997], these deposits are composed of organogenic coarse-grained sands, including abundant shells and fragments of Mollusks, fragments of *Arctica islandica*, remnants of Echinids and Bryozoans, passing upwards, through an abrupt contact to middle-grained sands and sandy pelites having a variable thickness, but less than 2 metres. They are represented by relic littoral deposits organized as coastal prisms overlying shelf margin progradations, representing portions of submerged beachs linked to the last sea level lowstand, in correspondence to the isotopic stage 2. The deposits have been revealed as coastal dunes having NW-SE trending, occurring in the south-western sector of the area at water depths ranging between – 140 m and – 145 m and showing an age ranging between the Late Pleistocene and the Holocene.

In the south-western sector of the study area wide outcrops of Pleistocene marine relic units have been surveyed in outcrops. These units are represented by marine deposits, from coarse to fine-grained, probably composed of well sorted sands and gravels with bioclastic fragments and middle-fine grained sands, with a pelitic cover having a variable thickness, but less than 2 meters, which constitute palinsests of beach and continental shelf environments. The deposits, stratigraphically underlying the lowstand system tract, represent the remnants of older beach systems, correlated to the isotopic stages 4 and 3 and have a probable age of the Late Pleistocene.

The distribution of the Pleistocene marine terraces has furnished absolute estimates of the vertical movements involving the coastal belt surrounding the Cilento Promontory. In the Northern Cilento area, the oldest marine terraces, Middle Pleistocene in age, have been discovered at a maximum altitude of 60 meters above the sea level [Cinque et al., 1994]. At the Bulgheria Mt. (southern Cilento) the marine terraces of the Middle Pliocene- Early Pleistocene are uplifted at 450 m above the sea level, while the terraces of the Aemilian stage reach the maximum altitude of 350 m above the sea level [Baggioni et al., 1981]; [Lippmann-Provansal, 1987]. The palaeo-strandlines occurring at 100 m above the sea level are covered by continental deposits including old manufacts of the Auchellenian [Palma di Cesnola, 1980], which supports the upper chronological boundary of these terraces to the Middle-Late Pleistocene. The palaeo-strandlines related to the palaeo-sea level of the Eutyrrhenian have been detected at a constant eustatic altitude along all the coast of the Cilento Promontory, thus suggesting that this region has acquired a tectonic stability starting from the end of the Middle Pleistocene [Romano, 1992].

In particular, in the area of Mt. Bulgheria, the different phases of uplift and tectonic fragmentation have produced different orders of erosional landforms having a low gradient, often sub-horizontal, crossing the carbonatic relief at altitudes ranging between 400 and 1000 meters. The lowest and the youngest of these orders of palaeobaselines include also the marine abrasional terraces, whose correlative deposits have been dated to the Emilian substage of the Early Pleistocene [Borrelli et al., 1988]. Along the southern coastal slope of the Bulgheria Mt. some bordering faults have been fragmented by the Emilian terrace, producing a duplication of the latter one, which has reached the present-day sea level [Antonioli et al., 1994]. Some geomorphologic and stratigraphic hints have allowed to assume that the above mentioned marginal fragmentation is happened during the tectonic uplift of the area, which has been followed by a generalized down throwing of the area, in the order of about 200 meters. Due to the lacking of datable materials, the age of the most part of the Emilian terraces (i.e. the five or six orders of terraces uplifted at altitudes among + 200 m and + 50 m) are unknown. Nonetheless this, since the lowest terrace has a continental sedimentary cover including artefacts referred to the Middle Pleistocene, the highest marine terraces have been dated to the beginning of the Middle Pleistocene or to the end of the Early Pleistocene.

Geologic and geomorphologic studies carried out on the emerged and submerged sector of Palinuro Cape [Antonioli et al., 1997], finalized to the recognition of the traces of ancient palaeostrandlines have furnished important evidences also on the submerged sector of the study area (up to 50 m of water depth), which has been surveyed through ARA dives carried out both along the coastal cliff and in many carsic cavities occurring in the calcareous promontory.

In the emerged coastal belt a succession of seven orders of marine terraces has been individuated at altitudes included among 180 and 2 m above the sea level. They cut both the

Mesozoic carbonate rocks, constituting the bulk of the Palinuro Cape and the Meso-Cenozoic terrigenous formations, cropping out in the area northwards of the cape. The first five orders of terraces (respectively located at 180/170 m, 140/130 m, 100 m, 75/65 m and 50 m above the sea level) are represented by benches of marine abrasion, which only locally preserve the remnants of an old sedimentary cover. The sixth (8-7 m above the sea level) and the seventh order (3/2 m above the sea level) are instead represented by both abrasional landforms (platform and necks of beach), found in correspondence to the carbonatic coastal cliffs of the Palinuro Cape and to the marine deposits, passing to eolic formations and to slope deposits, cropping out along the coast included among the town of Palinuro and Torre Caprioli. The recognition of some fragments of *Strombus bubonius* in the marine deposits related to the most recent palaeostrandline confirms its attribution to the Eutyrrhenian, already proposed in literature [Brancaccio, 1990] based on measurements of aminoacid racemization carried out on shells of *Glycimeris glycimeris* occurring in the same stratigraphic level.

The morpho-stratigraphic relationships among the deposits and the landforms of marine erosion dated back to the Eutyrrhenian stage and the marine landforms of the sixth order of terraces recognized at sea based on seismic interpretation has allowed to purpose for this latter marine terrace a correlation with the sea level highstand phase related to the isotopic stage 7. The oldest five orders of terraces result, in fact, chronologically limited to the beginning of the middle Pleistocene based on their physical continuity with a similar succession of palaeostrandlines, cropping out more southwards, along the southern slope of the Bulgheria Mt. (Southern Apennines) and ascribed to the Middle Pleistocene [Ascione et al., 1999]. Their genesis is contemporaneous to the last phase of tectonic uplift involving the southern Cilento Promontory and verified during periods in which the rhythm of the tectonic uplift is equal of the eustatic sea level rise and/or during periods of stands of the tectonic uplift onshore. This phase of uplift ends about the end of the middle Pleistocene, as indicated both by the altitude of the deposits tentatively ascribed to the isotopic stages 9 or 7 and by correlations with the southern Cilento Promontory. The altitude in outcrop of the Eutyrrhenian shoreline indicates, instead, a slight downthrowing of the study area, verified during the end of the Quaternary.

The geomorphologic hints related to palaeostands landforms occurring in the submerged sector are mainly represented by marine abrasional terraces cropping out along the coastal cliff, which often penetrate in the inner part of fossil karstic cavities, making plan their bottom. Other hints are instead represented by beach notches and, more rarely, by marine conglomerates. The marine terraces can be grouped into four main orders, located at the water depths of 44/46 m, 18/24 m, 12/14 m and 7/8 m [Antonioli et al., 1997]. According to the evidences presented by these authors, the traces of the palaeostrandlines occurring among 12/14 m and 7/8 m below the sea level have to be considered coeval, if not precedent, the last Interglacial period. In fact, these landforms show hints of a rielaboration in a subaerial environment, happened during a regressive phase of the sea level, which, due to the depth at which the landforms have been found, realized before or a little bit after than the beginning of the Late Pleistocene, surely not during times more recent during which the sea deepened at greater water depths. Nonetheless this, the palaeostand represented by the abrasional notches and platforms located among 7/8 m of water depth may be tentatively ascribed to one of the minor sea level stands verified during the isotopic stage 5 (sub-stage 5.1) [Martinson et al., 1987], based on the differences of altitude with the Eutyrrhenian notches and abrasional platforms, observed at water depths among 1.5 and 2 m below the sea level. The two deepest terraced surfaces have been considered in literature as chronologically better constrained [Antonioli et al., 1997]. The marine terrace located among 18 m and 24 m of water depth has been in fact attributed to the last part of the isotopic stage 3, based on the altimetric correlation with the altitudes reported on the curve of the oscillations of the sea level of the Tyrrhenian sea [Alessio et al., 1992]. The traces of sea level stand occurring at water depths among 44 and 46 m may be ascribed to a sea level lowstand verified during the last post-glacial transgression, due to their good state of conservation and to the total lacking of subaerial re-shaping.

Based on the above discussed geological and geomorphological evidences, the terraced surfaces which erode the morpho-structural high of Punta Licosa (Agropoli) are coeval with those ones recognized onshore in the adjacent emerged sector of Palinuro Cape [Antonioli et al., 1997].

The interpretation of the Subbottom Chirp seismic sections has allowed to recognize four main orders of terraced surfaces (see the table 7). The oldest terraced surfaces have been identified at altitudes included among – 50 m and – 43 m; this family of terraced surfaces is correlated with the terraced surfaces included among – 46 m and – 44 m in the offshore surrounding the Palinuro Cape [Antonioli et al., 1997]. The second order of terraced surfaces recognized in the Agropoli offshore based on high resolution seismic data has been detected at water depths comprised among – 27 m and – 17 m of water depth and is correlated with the terraced surfaces at water depths between – 18 m and – 24 m in the area of the Palinuro Cape [Antonioli et al., 1997].

The third order of terraced surfaces has been recognized at water depths between – 10 m and – 14 m and is correlated with the surfaces included among – 12 m and – 14 m in the area of the Palinuro Cape. Analogously, the terrace rims occurring at a water depth of – 8 m are coeval, if not precedent the last interglacial and are correlated with the ending part of the isotopic stage 3. Finally, the high resolution seismic data have not allowed to the recognize the Eutyrrhenian palaeostrandline.

A stratigraphic correlation among the water depth of the terraced surfaces in the morpho-structural high of Punta Licosa recognized on a significant seismic section and the curve of the isotopic stratigraphy of [Martinson et al., 1987] has been carried out with the aim of support these conclusions, (Figure 34). As already known in literature, the relative sea level rises have been quite rapid starting from the middle Pleistocene, mainly if compared with the relative sea level lowstands [Shackleton and Opdyke, 1973]; [Chappell and Shackleton, 1986]; [Martinson et al., 1987]; [Bard et al., 1990a]; [Bard et al., 1990b]; [Pirazzoli, 1993]. In correspondence to these sea level rises transgressive surfaces of erosion (ravinement surfaces) have been formed, which appear frequently intercalated in the stratigraphic record of the Italian continental margins [Aiello and Budillon, 2004]. These surfaces have been formed during time intervals corresponding, on the isotopic curve, to the transition from the even isotopic stages to the odd ones.

In fact, the isotopic curves show that, for the glacial Pleistocene, the sea level rise was very rapid and more or less comparable in width with the most recent sea level rise (about 120 m) [Bonifay, 1975], with a periodicity of about 100 ky.

According to the stratigraphic correlation shown in Figure 34, the remnants of the terraced surfaces localized at water depths included among – 50 m and – 43 m (see the seismic section in the low of the figure) probably represent a brief stand of the sea level verified during the post-glacial (Flandrian) transgression.

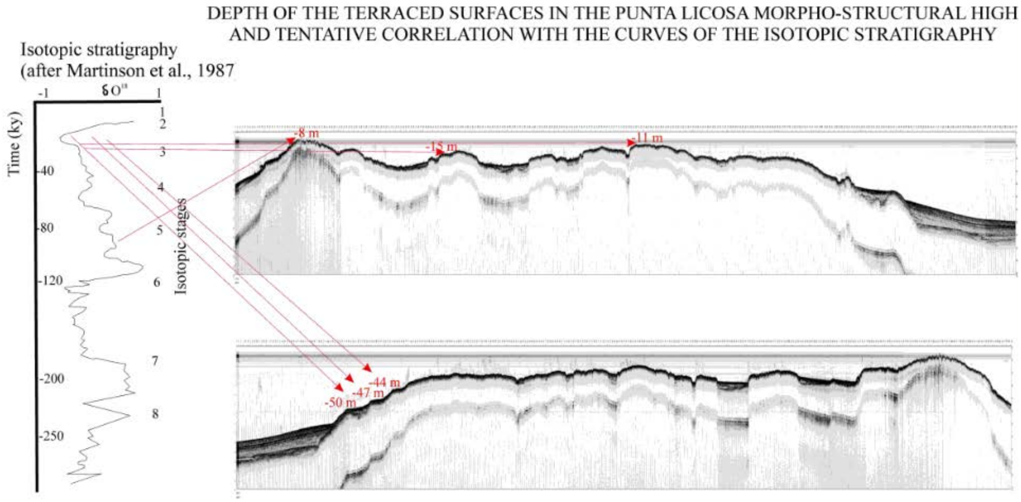


Figure 34. Depth of the terraced surfaces in the morpho-structural high off Licosa Cape and correlation with the curves of the isotopic stratigraphy. Note the occurrence of four main orders of terraced surfaces, respectively localized at water depths ranging between – 50 m and – 43 m, between – 27 m and – 17 m, between – 10 m and – 14 m and at – 8 m. These are related with the terraced surfaces recognized in the Palinuro Cape [Antonioli et al., 1997]. The oldest terraced surfaces have been identified among – 50 m and – 43 m; they are related with the terraced surfaces at – 46/44 m off the Palinuro Cape. The second order of surfaces has been identified at water depths ranging among – 18 m and – 24 m off the Palinuro Cape.

This interpretation is also confirmed by the geomorphological evidences observed by [Antonioli et al., 1997] in the marine area surrounding the Palinuro Cape (Punta Iacco), represented by corrosion notches and related rounded pebbles. There are not clear evidences of other sea level stands at lower water depths, which may be referred to the Flandrian transgression. In fact, this transgression was very fast and did not show interruptions long enough to leave marks of erosion on rocky lithologies. The geomorphological hints in the emerged sector surrounding the Palinuro Cape have instead demonstrated that this transgression has progressively provoked the erosion and the complete dismantling of the detritic fan which covered the base of the coastal cliffs during the last glacial phase, allowing for the reactivation of these old coastal structures.

A second order of terraced surfaces has been recognized at water depths ranging between – 27 m and – 17 m. A third order of terraced surfaces has been observed at water depths ranging between – 10 m and – 14 m and is probably correlated with the final part of the isotopic stage 3. To this order pertain the remnants of terraced surfaces localized at water depths among – 8 m and – 11 m. This interpretation is suggested also by the altimetric correlation of these surfaces with the altitudes reported on the curve of the sea level oscillations [Alessio et al., 1992] and by the analogy in water depth of these surfaces in conservative lithologies cropping out in the surrounding area of the Palinuro Cape [Antonioli et al., 1997].

A fourth order of terraced surfaces has been recognized at water depths of about – 8 m (see the seismic section in Figure 34). These remnants of surfaces are probably correlated to one of the minor peaks of the isotopic stage 5 and are tentatively correlated with the abrasional notches recognized at – 7 m of water depth along the coastal cliff of Palinuro

Cape, tentatively assigned to the isotopic stage 5.1 based on direct geomorphologic and stratigraphic evidences [Antonioli et al., 1997]. As evidenced by these authors, during the glacio-eustatic transgression of the isotopic stage 5 the waves have dismantled the detritic fans and cut new abrasional platforms, localized at + 1.5 and + 2 m above the sea level, at the base of the coastal cliffs. Along the coast of the Palinuro Cape, between Lido Ficocelle and Caprioli, the same transgression has cut a coastal cliff in the beach deposits pertaining to the isotopic stages 7/9 and has left at its base several meters of conglomerates and beach sands (Eutyrrhenian unit), reaching a thickness of 2.5 m above the sea level. According to the interpretation of [Antonioli et al., 1997] both these beach complexes and the landforms of abrasion/corrosion which occur among 1.5 and 2.2 m pertain to the first and highest peak of the last interglacial transgression (sub-stage 5.5). Moreover, the marks left by the same interglacial are probably localized at about 7 m on the base level along the coastal cliff of the Palinuro Cape.

5.2. Maratea Offshore

The complex and multiple instability phenomena occurring in the Maratea Valley, ascribed to typologies of *sagging, sudden spreading failure, block-slide, lateral spreads* and *translational slidings* and other plastic deformations and to plastic-gravitational type deformations such as *spreading, creep* and *squeezing* are strictly dependent on the recent and present-day seismo-tectonic activity in the area.

The measurements of soil movements, relative to the last ten years and integrated by recent geological observations have allowed to distinguish in the Maratea Valley several areas having different kinematics [Rizzo, 2001]. In particular, a wide zone of the valley is affected by slow and continuous movements (2-3 cm/year), apparently not influenced by pluviometric and hydrogeological conditions. These gravitational and rather shallow movements (≤ 50 m) underwent an acceleration during the last twenty years, presumably also in relationship to tensional states triggered by tectonics, previous to and following the seismic event of 21-03-1982 in the Policastro Gulf.

Deep movements, both tectonic and gravitational in origin, have been hypothised along the strike-slip fault bounding the right flank of the valley (0.5 cm/year).

Based on this geological framework, the Maratea Valley represents the initial stage of the opening of a pull-apart structure, generated by the Pollino strike-slip fault, with little contribution of transpressive and transtensive phenomena [Rizzo, 1997; 2001]. In the northern edge of the valley, where the fault bending has thrust the calcareous southern block against the northeastern one, there are transpressive and horse-type structures [Rizzo, 1997].

Within the valley important landslides mainly induced by seismotectonic activity can be observed; a slow and continuous flow evolves in the upper part of the valley in spreading, sackung and sagging-type phenomena, moving along the south-western limit of the valley on a substratum of plastic clay.

The geomorphology testifies the existence of quick movements and acceleration phases: trenches containing rock falls testify a sudden movement, which resulted from a strong shock, related to the upper Pleistocene tectonic activity. Roto-translational slidings, involving detrital covers observed in the central part of the valley and are due to intense seismic and rain events in historical times. Creep and other plastic deformations of shallow clayey covers (squeezing) are located in the previously described area.

The geologic framework of the Maratea Valley on land is connected with the Late Pleistocene-Holocene tectonic evolution of the surrounding continental platform and slope and with the significant glacio-eustatic sea level fluctuations during the late Quaternary. Near the shoreline the bathymetric setting of the area is characterized by ripid and articulated sea bottoms, resulting from the seaward prolongation of the rocky coastal cliff, up to the – 30 m isobath, where the continental shelf starts [Colantoni et al., 1997].

Rock lithologies (both carbonatic and siliciclastic deposits), cropping out in correspondence to the shoreline, continue along the submerged sector of the coastal cliff, up to a water depth of – 30 m. Here they interrupt, in correspondence to an abrupt break in slope, separating the steep coastal sea bottoms from the more regular ones of the continental shelf. Apart from mantaining high gradients which onland characterize the coastal belt, these rocky sea bottoms follow the trending of the coastal belt, characterized by promontories and small bays, thus demonstrating the continuity of the subaerial morphology.

Proceeding seawards, the sea bottoms, covered mainly by sands, are more regular up to the shelf break, located at about 2 km from the coastline, at an average water depth of 100-120 m. In correspondence to the Maratea Valley the shelf break retreats up to 900-1000 m from the shoreline, reaching a water depth of -70/80 m. Here it is articulated and incised by deep channels linked to a submarine canyon’s head (Maratea canyon), affected by active regressive erosion. In fact, this zone is known as “the Fossate”, because of the abrupt variations in depth linked to narrow and steep incisions which, joining seawards, form an active drainage system collecting and transporting a large part of the present-day sedimentary supply towards the basin.

High resolution seismic reflection profiles have allowed to define the subsurface stratigraphy in the outer shelf and upper slope of the Maratea Valley. The seismo-stratigraphic analysis, based on some Watergun and Subbottom Chirp seismic reflection profiles, has shown the stratigraphic architecture of the area, characterized by an acoustic basement and several main seismo-stratigraphic units, representing the sedimentary cover. In particular, the available data (Figures 23-29) show a recent sedimentary cover, ranging in age from the Late Pleistocene to the Holocene developing over the acoustic basement, with an irregular trending because of tectonic dislocation and incisions due to subaerial erosion. The sedimentary cover is composed of three main seismic units, with different depositional geometries and seismic facies, separated by regional and/or local unconformities.

The acoustic basement is truncated by a wide erosional surface, which considering its stratigraphic position and in view of previous studies carried out in the area [Ferraro et al., 1997]; [Pennetta et al., 1996a; 1996b]; [Budillon et al., 2011] is correlated to the wurmian erosional truncation, referred to the isotopic stage 5e (18 ky B.P.); [Shackleton and Opdyke, 1973]; [Martinson et al., 1987]. This evidence suggests that the overlying seismic units, which form the sedimentary cover, represent the transgressive and highstand system tracts of the Late Quaternary Depositional Sequence, widely recognized in several sectors of the Italian continental margin [Catalano et al., 1996]; [Fabbri et al., 2002]. This is confirmed by the depositional geometries identified in the seismo-stratigraphic units of the sedimentary cover.

The acoustic basement has been recognized in the continental shelf and is represented by two distinct acoustic facies. The first facies, characterized by low penetration of the acoustic energy, occurs in the near-shore sector of the inner continental shelf [Colantoni et al., 1997]. This is not documented in the seismic sections shown in this paper, which have been acquired starting from water depths of 20/30 m. This facies constitutes the seawards prolongation, along the submerged coastal cliff, of Meso-Cenozoic carbonatic and siliciclastic deposits, which form the coastal outcrops in the study area. The second facies of the acoustic basement, which was deposited seawards with respect to the rocky outcrops cropping out in the coastal belt, is characterized by a good penetration of the acoustic basement and by progradational geometries, inclined seawards (Figures 23-29). It represents a relic prograding wedge, probably deposited during the lowstand phases of the last glacio-eustatic cycle, Pleistocene to Holocene in age. This interpretation is confirmed by the stratigraphic position of the unconformity bounding the wedge at the top. This unconformity is related to the lowstand phase which, around 18-20 ky B.P. produced a maximum regression, bringing the sea level to a depth that is 110-130 m less than that of the present. This regression was followed by a rapid transgression. Subsequently, during the Holocene climatic optimum (6 ky B.P.) the sea level reached values similar to those of the present. The fast rise of sea level was not linear and various evidences, registered also on several continental margins of the Mediterranean, testify that the transgressive phase was interrupted by several stands. One of them, of about 9-11 ky B.P. (Younger Dryas) was characterized by short regressive episodes of highstands of sea level at water depths that were -40/-60 m deeper than the present day. The trending of the erosional unconformity and the top of the acoustic basement show a valley type deepening, with a U-type section, that continues seawards to the present-day bottom of the Maratea Valley. This evidences the suberial palaeotopography which characterizes the glacial maximum (Figures 23-29).

The geological interpretation of the Watergun seismic profile S130bis (Figure 23) has shown that the acoustic basement is downthrown by local tectonic deformations, controlled by NE-SW trending extensional tectonics, related to the one evident onshore, which often involves the overlying detritic cover. This tectonic framework becomes particularly relevant along the margins of the depression representing the seaward prolongation of the Maratea Valley, so enhancing the structural control, which, for the northern margin of the valley, seems to be still active [Rizzo, 1997]. Here some normal faults occur, downthrowing both the substratum and the overlying sedimentary cover. N-S trending and NE-SW trending tectonic discontinuitues presumably control the definition of the Maratea canyon. The sedimentary cover shows its maximum thickness, ranging from 30 m to 50 m in correspondence to the seaward prolongation of the Maratea Valley, while at both the margins it shows thickness less than 20 m. Towards the coast the sedimentary cover terminates in correspondence to the 20-30 m isobaths, at the contact point with the seawards prolongation of the rocky coastal cliff. Here this cover has a maximum thickness not superior to 10 m and shows typical onlap geometries.

The deepest seismic unit of the sedimentary cover is characterized by irregular, inclined and discontinuous, seismic reflectors; it is probably composed of coarse-grained siliciclastic sediments and fills the main incisions and depressions located at the top of the acoustic basement (Figures 23-28). This unit shows wedge-shaped sedimentary units and bidirectional onlaps. Its maximum thickness reaches the 10 msec reflector (at about 8 m).

The overlying seismic unit is characterized by more regular seismic reflectors, characterized by high frequency and continuity. It is composed by upper Pleistocene marine sediments, reaching about 30 m in correspondence to the seaward prolongation of the Maratea

Valley, filling the marine depression of the acoustic substratum. On the contrari, at the margins of the depression, the seismic uniti is characterized by small thickness, that is constant proceeding from land to sea.

The erosional truncation bounding the seismic units of the sedimentary cover at the top, also bounds the base of the present-day and recent marine deposits, which show an overall thickness of about 6-7 m.

In brief, the acoustic characteristics of the crossed grounds, studied through the seismic reflections and the possible correlations with the stratigraphic and structural framework of the emerged sector of the Maratea Valley, have allowed to correlate the seismic units with several depositional bodies, schematized as follows.

The first unit of the acoustic basement, not shown by the seismic profiles, but documented nearshore based on references [Colantoni et al., 1997] corresponds with the Mesozoic-Cenozoic carbonates and with the Crete Nere Formation, widely cropping out in the corresponding emerged sector. The relic prograding deposits occurring in the outer shelf may be related with the glacio-eustatic sea level fluctuations of the middle-Late Pleistocene.

The oldest unit of the sedimentary cover is deposited over a very irregular unconformity, corresponding to an emersion phase lasting for a relatively long time interval. This unit shows the characteristics of a coarse-grained facies of marine deposits. The stratigraphic relationships with the underlying seismic units suggest that they represent the highstand deposits of the Late Quaternary depositional sequence.

It is worth noting the role of the Maratea canyon as sediment collector in the continental shelf and in determining submarine gravity instability processes in the study area. These phenomena suggest the occurrence of extended creeping involving present-day and recent marine deposits and explicates with a slow movement along the slope under the action of gravity. The phenomena of gravity instability in the submarine environment are shown by the occurrence of slumpings. They appear as bodies with wedge-shaped external geometry and chaotic acoustic facies, interstratified at various stratigraphic levels in the sediments of the upper slope. These sedimentary bodies have been produced by the upwards sliding of sediments after their deposition and, specifically, by the alongslope flux of soft marine sediments, underconsolidated at the head and along the walls of the Maratea canyon.

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