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Chapter

Bioclastic Deposits in the NW Gulf of Naples (Southern Tyrrhenian Sea, Italy): A Focus on New Sedimentological and Stratigraphic Data around the Island of Ischia

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Abstract

Bioclastic deposits in the Gulf of Naples have been studied and compared based on new sedimentological and stratigraphic data, particularly referring to the rhodolith layers. They represent detrital facies deriving mainly from in situ rearrangement processes of organogenic material on rocky sea bottoms. These deposits are composed of medium-coarse-grained sands and bioclastic gravels in a scarce pelitic matrix and crop out at the sea bottom in a portion of the inner shelf located at water depths between −20 m and −50 m. Below water depths of −30 m the bioclastic deposits are rhodolith, characterized by gravels and lithoclastic sands. Rhodolith deposits are often found near the *Posidonia oceanica* meadows and/or in protected areas near the rocky outcrops. The Ischia Bank represents an excellent natural laboratory for studying the rhodolith layers. On the Ischia Bank, below the *Posidonia oceanica* meadow, both bioclastic sands immersed in a muddy matrix and volcaniclastic gravels were sampled. Both the Mollusk shells and the volcaniclastic fragments, where the contribution of the silty and sandy fractions is lower than 20%, were colonized by some species of red algae, while in the marine areas with a low gradient a maërl facies was deposited.

Keywords: bioclastic deposits, rhodolith layers, *Posidonia oceanica* meadow, sedimentological analyses, Gulf of Naples

1. Introduction

Rhodolith or maërl deposits consist of either alive or dead aggregations of coralline algae, which blanket wide coastal zones in the present-day oceans [1–3] and represent shared facies in carbonate platform settings. In some cases, the rhodolith layers indicate the transition from bioclastic-to-rocky sea bottoms, but they can form also on mobile sea bottoms [3–5]. The rhodoliths are the main components of the rhodalgal skeletal assemblage that characterizes the carbonate production in the oligophotic zone of Cenozoic and modern carbonate platforms [4, 6–10]. In

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contrast with the chloralgal and molechfor assemblages, respectively characterized by the lacking of hermatipic corals and by benthic foraminifers, mollusks, echinoids and bryozoans the rhodalgal assemblage is mainly composed of coralline algae [4]. The zonation of benthic assemblages of the Mediterranean sea performed by Peres and Picard [11] has improved the knowledge on lithology and facies interpretation of rhodolith layers (**Figure 1**). In the Mediterranean sea the bioclastic deposits occur at water depths ranging between – 40 m and – 100 m ("Détritique Cotier" of Peres and Picard; **Figure 1**) [11]. In particular, the rhodolith layers are concentrated in the marine sectors exposed to strong current regimes, such as the top of plateaus or banks. The main components of the "Détritique Cotier" are composed of the reworking and deposition of benthic communities on both mobile sea bottoms (biocoenosis of the "Détritique Cotier") and on hard sea bottoms (biocoenosis of the "Détritique Du Large"), more than the assemblages of *Posidonia oceanica* meadows and maërl deposits. As a consequence of the Holocene sea level rise the deep seafloor was covered by relict and drowned sediments ("Détritique Du Large"; **Figure 1**), characterized by low rates of sedimentation and by the occurrence of glauconite.

The global dominance of coralline algae forming the rhodalgal lithofacies from the Burdigalian to the Early Tortonian has been demonstrated based on stratigraphic data [12]. In particular, during this time interval the rhodalgal lithofacies has reached peak abundance, replacing the coral reef deposits. The prevalence of coralline algae over coral reefs was suggested as being controlled by the enhancement of the trophic resources and associated with an increase of biological productivity to a global scale [12]. This evidence was shown by geochemical data computed on carbon isotopes. During the Middle Miocene the rhodalgal lithofacies increased its extension, due to the upwelling triggered by the establishment of East Antarctic Ice Sheet led to enhanced. These stratigraphic studies performed to a global scale have confirmed the importance of rhodolith deposits as proxies of past oceanographic conditions [12].

This chapter provides new sedimentological and stratigraphic data on the bioclastic deposits and in particular on the rhodolith deposits, occurring in the offshore island of Ischia (Gulf of Naples, Italy); it is based on data coming from sea bottom samples collected during the CARG project aimed at the realization and informatization of the marine geological cartography of the geological sheet No. 464 [13]. The island of Ischia represents the emerged part of a large volcanic field, which extends from the island of Procida to the submerged volcanoes of the western offshore of Ischia [13–17].

The occurrence of rodolith deposits in the Gulf of Naples has been suggested by several studies [18–29]. The sedimentological analysis of the sea bottom samples,

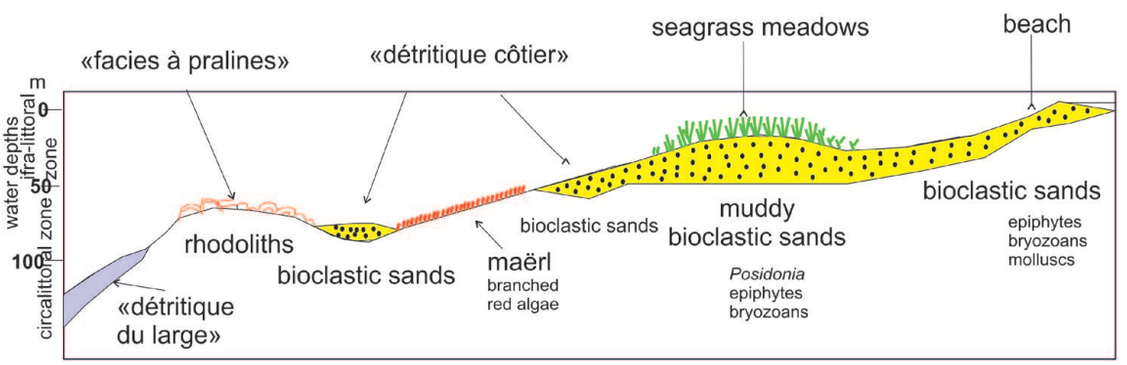

Figure 1.
Sketch diagram showing the main biocenosis of mobile sea bottoms (modified after Carannante et al. [4]).

together with the realization of geological cartography at the 1: 10.000 scale has allowed to study the bioclastic deposits and in particular, the rhodolith deposits occurring in the Ischia offshore. Moreover, the seismo-stratigraphic data have allowed for the calibration of the rhodalgal deposits on previously interpreted seismic Sparker profiles [15].

Previous studies focused on rhodolith deposits in the marine areas of the Gulf of Naples, in particular Nisida-Posillipo (Nisida Bank and La Cavallara saddle) and the Gulf of Pozzuoli (Miseno Bank), while only a single sample came from the Ischia Bank [29]. Otherwise the present work is based on a dense network of samples collected in the Ischia offshore. Moreover, the recognition of bioclastic deposits on some Sparker seismic profiles let us to perform a qualitative calibration of data coming from sampling.

Rhodolith deposits have previously been reported in the offshore of Ischia [29–31]. In particular, Toscano et al. [29] have shown the variability of the rhodalgal facies in the Gulfs of Naples and Pozzuoli, which is closely connected with the location of the platform, with the morpho-bathymetric structure, with the morphology of the sea bottom and with the hydrodynamic conditions on the submerged volcanic banks (Nisida, Miseno and Pentapalummo Banks; Ischia Bank). The top of these submerged volcanic banks is located at water depths of −28/−30 m and is overlain by the *Posidonia oceanica* meadow, growing up to water depths of −35/−40 m. In the marine areas where the *Posidonia meadow* is lacking, the action of the currents has controlled the formation of large fields of sandy ripples [32].

The rhodolith deposits form well-developed layers. They often lie on a sandy-gravelly sea bottom formed by both the shells of mollusks that live in the meadow and by the abundant pyroclastic granules, that derive from the erosion of sea bottoms on which the *Posidonia* meadow grows up [32–34]. Brandano and Civitelli [33] have analyzed the interactions between carbonate and siliciclastic sedimentation on the Pontinian shelf of the Tyrrhenian sea focusing on the relationships between the carbonate deposits and the *Posidonia* meadow. Six sedimentary facies and ten microfacies have been identified using the component analysis, the grain-size percentage, the sorting, the carbonate content and the rate of authigenic mineralization. The maërl deposits and the skeletal sands are located in the circalittoral zone (82 m to 112 m of water depth), also displaying relict facies. These authors have highlighted that the *Posidonia* meadows represent the main facies of the mobile infra-littoral substratum. In the area surrounding the Pontinian islands the *Posidonia* meadows, ranging at water depths between 30 m and 40 m water depth show a rich epiphytic flora and fauna, living on the seagrass leaves and rhizomes. The unattached coralline algal branches gravel facies indicates the environment representing the highest carbonate production rate. This facies consists of red algae (rhodalgal association) that are the main carbonate-producing biota in the Mediterranean. Brandano et al. [34] have highlighted that the seagrasses represent important carbonate factories, being characterized by important carbonate producing biota, as epiphytes on the leaves and infaunal forms. These authors have determined the skeletal assemblage of both modern (Maldivian and western Mediterranean) and fossil seagrass examples (Eocene; Apula and Oman carbonate platforms and Oligocene; Malta platform). In both Maldivian and western Mediterranean the bioclastic deposits are mainly composed of calcareous algae and foraminifera. As a difference, in the tropical setting they are represented by green algae (*Halimeda*), while in the Mediterranean they consist of red algae [34]. The performed stratigraphic study has shown that the green algae–foralgal assemblage is typical of tropical seagrass meadows. On the contrary, the red algae-foralgal assemblage is typical of tropical to subtropical seagrass meadows.

In the Gulf of Naples the red algae are widespread especially in the marine areas where the currents removing fine-grained fraction from soft sea bottom leave in place and the abundant coarse grains (lapilli in origin) become an important substratum for the growth of the coralline algae. The red algae are well developed along the western side of the Ischia bank, forming thick deposits near the tributary channel which joins the head of the Magnaghi canyon [29].

The rhodalgal deposits have their optimum bathymetric distribution between −30 m and −44 m of water depth, where a maximum biodiversity has been observed. Furthermore, Babbini et al. [30] have reported the occurrence of a maërl facies in the coastal area of Ischia, in particular in the north-western sector of Ischia, in the area between Punta Imperatore and the town of Forio and between Forio and Punta Caruso (S. Francesco). The studied sampling transects have been carried out at three different water depths (− 50 m, − 65 m, − 80 m). The taxonomic analysis of the macro-phyto-benthic component of the red coral algae has revealed well-pigmented thalli, with a various growth-form (crusty, lumpy, mammellate, arborescent). The free living branches of coralline algae have been attributed to the maërl facies [11], consisting of alive and dead thalli belonging to the species *Lithothamnion corallioides* and *Phymatolithon calcareum*.

Furthermore, the filming carried out with ROV has shown that there are areas of accumulation of calcareous algae in the ripples concavities [30]. In the same area, Gambi et al. [31] have evidenced the occurrence of rhodolith deposits between −50 m and −80 m of water depth, while the maërl facies was found in three samples, in a well-defined belt about one nautical mile long ("the pink mile") [31], located between −50 m and −65 of water depth. The identified zoo-benthic species are typical of the "détritique còtier" of Peres & Picard [11] and of muddy sea bottoms, and the rhodolith deposits of the offshore of Ischia show a very rich and diverse benthic flora and fauna, especially in the maërl facies [31].

2. Materials and methods

The geological and geophysical data were acquired in the framework of the realization of the geological map n. 464 "Ischia Island" at the 1:10.000 scale [13, 17, 35]. Detailed geological maps, showing the distribution of sea bottom sediments, were built on the basis of the previous geological survey. Furthermore, the new sedimentological analyses of sea bottom samples collected during oceanographic cruises in 2002 and in 2006 have allowed to reconstruct the facies distribution of the sea bottom and to compare the obtained sedimentological and geological results with the previous ones [29, 36]. The stratigraphic framework of the investigated area is based on both high resolution seismic profiles calibrated by cores and on high resolution sequence stratigraphy. Geological and geomorphological data collected at the 1: 10.000 and 1: 5000 scales have been reported on the 1:10.000 geological maps of Campania [35] in order to later produce national geological maps at the 1: 50.000 scale. The previously interpreted Sparker seismic profiles available around Ischia [15, 17, 35], were the subject of a new detailed interpretation focused on the Ischia Bank and Ischia Channel areas, aimed at the identification of bioclastic deposits and at the definition of their stratigraphic relationships with the volcanic and other sedimentary seismic units detected in the offshore of Ischia. The location of the samples analyzed to highlight the rhodolith deposits in the Ischia offshore was superimposed on the Ischia Digital Elevation Model (DEM; **Figure 2**).

During a first work phase, the Multibeam data processing let us to realize bathymetric maps with contour isobaths and shaded-relief maps for the geological

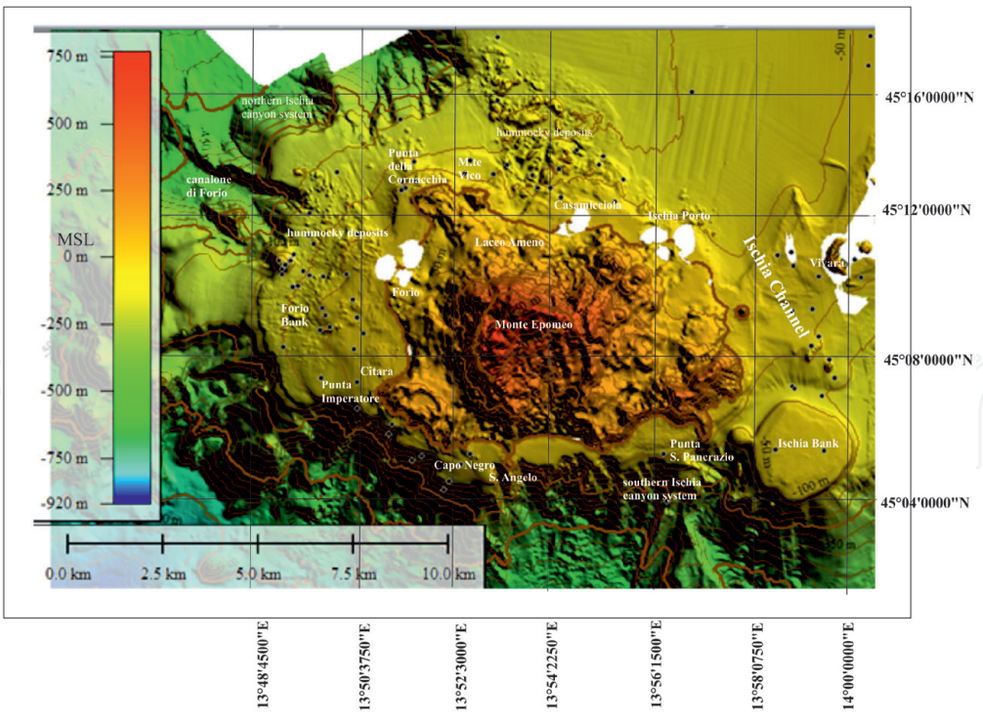

Figure 2.
Onshore-offshore DEM of Ischia reporting the sample location.

interpretation of the morpho-structural features. During a second phase of work, granulometric analyses were carried out on the sea bottom samples accordingly with the Folk classification. The geological interpretation was based on the identification of the acoustic facies, performed with the integrated interpretation of the multibeam and sidescan sonar data and through the calibration of the acoustic facies in lithological terms, using the results obtained from the granulometric analyses of the sea bottom samples (**Figure 2**; **Table 1**). The sedimentological analyses were performed at the sedimentology laboratory of the CNR-ISMAR in Naples, Italy, using a laser granulometer. The list of analyzed samples is reported in **Table 1**, including their description.

3. Results

3.1 Marine and coastal geology

The sedimentological data come from samples collected from sea bottoms located between −30 and – 200 m of water depth; they were placed in the framework of the marine geological survey at the 1: 10.000 scale (**Figure 3**). The morpho-bathymetric characteristics of the different sectors of Ischia, covered by geological survey, are highly variable (eastern, western, southern and northern offshore). The eastern offshore of Ischia, which includes the Ischia Channel, is characterized by sea bottoms with low gradients, locally interrupted by relict volcanic edifices ("I Ruommoli"; "La Catena"; "Vivara ants"). The southern offshore of Ischia is characterized by a narrow continental shelf, cut by submarine canyons and their tributary channels. Its physiography is strongly controlled by the onshore topography, characterized by alternating rocky promontories and inlets. The northern and western offshore of Ischia are characterized by a rough topography, genetically linked to the volcano-tectonic evolution of the island and to the emplacement of the debris avalanche deposits on land and in the sea [16].

Sample	Lithology	Location	Water depth	Description
B1082	Silty sands	Northern Ischia; M.te Vico promontory	–57 m	Middle-grained sand in a silty matrix. Color 5y4/2.*Posidonia oceanic* leaves, lamellibranch fragments and valves. Small pumices.
B1085	Sandy muds	Northern Ischia; Punta La Scrofa promontory	–65 m	Heterometric bioclastic sand in a silty matrix. Fragments of gastropods,bivalves,calcareous algae. Occurrence of superficial silt veil.
B1090	Sandy silts	North-western Ischia – Punta Caruso promontory	–149 m	Silty mud. Color 5y4/2. Occurrence of superficial silt veil, oxidized, thick about 1 cm.
B1094	Sands	South-western Ischia – Punta Imperatore promontory	–38 m	Medium-grained volcanic sand. Fragments of echinoids, whole irregular echinoids, lamellibranch shells. Lithic fragments.
B1096	Sands	South-western Ischia – Citara beach	–27 m	Coarse-grained volcanic sand. Scattered pebbles encrusted with worms. Fragments of calcareous algae. Small complete bivalves. Agglutinating worm tube. Pumice.
B1098	Sandy silts	Western Ischia – Punta del Soccorso promontory	–100 m	Fine-grained sand. *Posidonia oceanica* scales. Small bivalves, gastropods. Occurrence of superficial veil, thick 1 cm, composed of oxidized, fine-grained silt.
B1101	Silts	Northern Ischia – Monte Vico promontory	–95.6 m	Sandy silt with fragments of bioclasts. Color 5y 4/3. Lamellibranch valves, corals, bryozoans fragments. Occurrence of superficial veil composed of silty clay.
B1103	Silty sands	South-western Ischia – Punta dello Schiavo promontory	–88 m	Bioclastic sands in a fine-grained sandy matrix. Red algae, annelids, lamellibranch valves. *Posidonia oceanica* rhizomes. The superficial veil is covered by a net made of *Posidonia oceanica* flakes.
B1105	Silty sands	South-western Ischia – Capo Negro promontory	–74 m	Concretions of red algae, having dimensions in the order of 7–10 cm, overlying fine-grained sands. Tubes of worms, bryozoans, corals. Occurrence of a superficial veil, composed of fine-grained sand, *Posidonia oceanica* leaves, gastropods (*Turritella*), lamellibranchs, rounded pumice clasts and fragments of echinoids.
B1107	Sandy silts	South-western Ischia – Punta del Chiarito promontory	–168 m	Slightly sandy silt. Color 5y4/2. Reworked *Posidonia oceanica*.
B1111	Silty sands	Northern Ischia	–42 m	Bioclastic medium-grained sand with a silty matrix. Occurrence of bivalves, gastropods and bryozoan fragments.
B1794	Sands and gravelly sands	Ischia Bank	–27 m	Description lacking

Sample	Lithology	Location	Water depth	Description
B1796	Silty sands	Ischia Bank	−30 m	Coarse-grained sand with a silty matrix. Occurrence of small bivalves and live worms. Small lithic fragments.
B1798	Sandy silts	Ischia Bank	−74 m	Clay with a dark green sandy fraction. Occurrence of bivalves, rhizomes of *Posidonia oceanica*, gastropods and echinoids. Volcanic lithics, small pumice and remains of coal. Yellow superficial veil, slightly oxidized.
B1800	Sands and gravelly sands	Ischia Channel	−34 m	Sands with a silty matrix, overlying coarse-grained bioclastic sands. Fragments of bivalves, small lamellibranch, red algae, small gastropods, rhizomes of *Posidonia oceanica*, branched bryozoans.
B1802	Sands and gravelly sands	Ischia Bank	−24 m	Coarse-grained sand with a silty matrix. Occurrence of shell fragments, small regular echinoids and scarce lithics.
B1804	Sands and gravelly sands	Vivara (Procida)	−18 m	Bioclastic medium-coarse-grained sand in a scarce muddy matrix. Occurrence of *Posidonia oceanica* and lamellibranchs.
B1806	Silty sands	Ischia Channel	−63 m	Compact mud with medium-fine-grained sandy fraction, consisting of bioclasts, small pumiceous clasts and lithics. Very residual of *Posidonia oceanica* in the first subfloor with masses of rhizomes.
B1808	Silty sands	Ischia	−70 m	Gravelly mud ("Détritique Cotier"). Occurrence of lamellibranchs, red algae, single corals and pumiceous clasts.
B1810	Silty sands	Ischia harbor-Casamicciola	−99 m	Gravelly mud ("Détritique Cotier"). The gravelly fraction is composed of pumice and tuff fragments.
B1815	Sands	Forio-Casamicciola	−38 m	Sands with a silty-muddy matrix. The sandy fraction consists of lithoclasts and bioclasts. Living organisms (small crabs and lamellibranchs). Occurrence of tuff pebbles.
B1816bis	Sandy silts	Forio Bank	−159 m	Superficial veil saturated with water, towards the bottom mud. Occurrence of a bioclastic component composed of shells of marine organisms.
B1818	Sands and gravelly sands	Western Ischia offshore (Citara)	−36 m	Coarse-to-middle grained litho-bioclastic sand with a scarce muddy matrix.
B1820	Sandy silts	Maronti	−96 m	Mud with rare sedentary polychaetes.
B1084	Sands	Northern Ischia (Punta Cornacchia promontory)	−30 m	Bioclastic medium-grained sand with a silty matrix. Occurrence of bivalves and fragments of lamellibranch shells.
B1088	Silts	Northern Ischia	−73.2 m	Bioclastic coarse-grained sand on a silty matrix. Color 5y4/2. Occurrence of small bivalves, fragments of calcareous algae and branched bryozoans.

Sample	Lithology	Location	Water depth	Description
B1092	Silts	Northern Ischia – Punta Caruso promontory	–133 m	Superficial veil composed of oxidized silt of about 1 cm in thickness. Proceeding downwards plastic clay. Color 5y4/2.
B1095	Silty sands	South-western Ischia – Punta Imperatore Promontory	–71 m	Centimetric pebbles in a sandy matrix composed of fine-grained sand. Occurrence of lamellibranch and pectinidae valves.
B1097	Silty sands	South-western Ischia – Citara beach	–40 m	Volcanic rocky substratum with superficial algal incrustations colonized by red algae.
B1100	Sandy silts	South-western Ischia –Citara beach	–100 m	Fine-grained sand. Occurrence of fragments of calcareous algae and reworked *Posidonia oceanica* flakes. Occurrence of surface veil, about ½ cm thick, oxidized, silty.
B1102	Silts	Northern Ischia – Monte Vico promontory	–136 m	Towards the base clay. Color 5y4/1. Superficial veil composed of silty mud. Color 5y 4/3.
B1104	Sandy silts	South-western Ischia – Chianare di Spadera	–109 m	Fine-grained sand with a silty matrix. Occurrence of *Posidonia oceanica* flakes.
B1106	Sands and gravelly sands	South-western Ischia – Punta del Chiarito promontory	–40 m	Medium-coarse-grained volcanic sand. Occurrence of red algae, gastropods and lamellibranch fragments.
B1107	Sandy silts	South-western Ischia – Punta del Chiarito promontory	–168 m	Slightly sandy silt. Color 5y4/2. Reworked *Posidonia oceanica*.
B1796	Silty sands	Ischia Bank	Not recorded in the navigation data	Coarse-grained sand with a silty matrix. Occurrence of small bivalves and live worms. Small lithic fragments
B1798	Sandy silts	Ischia Bank	–74 m	Clay with a dark green sandy fraction. Occurrence of bivalves, rhizomes of *Posidonia oceanica*, gastropods and echinoids. Volcanic lithics, small pumice and remains of coal. Yellow superficial veil, slightly oxidized.
B1800	Sands and gravelly sands	Ischia Channel	–34 m	Sands with a silty matrix, overlying coarse-grained bioclastic sands. Fragments of bivalves, small lamellibranch, red algae, small gastropods, rhizomes of *Posidonia oceanica*, branched bryozoans.
B1802	Sands and gravelly sands	Ischia Bank	–24 m	Coarse-grained sand with a silty matrix. Occurrence of shell fragments, small regular echinoids and scarce lithics.

Sample	Lithology	Location	Water depth	Description
B1804	Sands and gravelly sands	Vivara (Procida)	–18 m	Bioclastic medium-coarse-grained sand in a scarce muddy matrix. Occurrence of *Posidonia oceanica* and lamellibranchs.
B1806	Silty sands	Ischia Channel	–63 m	Compact mud with medium-fine-grained sandy fraction, consisting of bioclasts, small pumiceous clasts and lithics. Very residual of *Posidonia oceanica* in the first subfloor with masses of rhizomes.
B1808	Silty sands	Ischia	–67 m	Gravelly mud ("Détritique Cotier"). Occurrence of lamellibranchs, red algae, single corals and pumiceous clasts.
B1810	Silty sands	Ischia harbor-Casamicciola	–99 m	Gravelly mud ("Détritique Cotier"). The gravelly fraction is composed of pumice and tuff fragments.
B1815	Sands	Forio-Casamicciola	–38 m	Sands with a silty-muddy matrix. The sandy fraction consists of lithoclasts and bioclasts. Living organisms (small crabs and lamellibranchs). Occurrence of tuff pebbles.
B1097	Silty sands	South-western Ischia – Citara beach	–40 m	Volcanic rocky substratum with superficial algal incrustations colonized by red algae.
B1110	Silty sands	North-western Ischia – Monte Vico promontory	–53 m	Coarse-grained bioclastic sands. Occurrence of bryozoans, bivalves and calcareous algae fragments. Occurrence of rocky fragments of centimeter dimensions.
B1112	Sands	Northern Ischia - Casamicciola	–32 m	Rocky substratum. Occurrence of volcanic blocks, immersed in a matrix composed of medium-coarse-grained bioclastic sands. Occurrence of branched bryozoans, lamellibranch valves and calcareous algae fragments.
B1795	Sands and gravelly sands	Ischia Bank	–30 m	Medium-coarse-grained sand with shell fragments overlain by *Posidonia oceanica* meadow. Occurrence of a poor fine-grained sandy matrix.
B1797	Sands and gravelly sands	Parasitic vent of the Ischia Bank	–37 m	Bioclastic sand in a silty matrix. Occurrence of glass fragments, branched bryozoans and red algae.
B1801	Sands	Ischia Channel	–39 m	Bioclastic sands, medium-coarse-grained. Occurrence of red algae and branched bryozoans.
B1803	Sands and gravelly sands	Ischia Channel	–16 m	*Posidonia oceanica* on a coarse-grained sandy bottom, with red algae. Occurrence of shell fragments in the sandy part.
B1805	Sands and gravelly sands	Ischia harbor	–24 m	Living *Posidonia oceanica* on a dark sandy ground with a muddy matrix. Occurrence of lamellibranch valves, fragments of lamellibranchs, live rhodoliths, bryozoans and echinoids.

Sample	Lithology	Location	Water depth	Description
B1807	Sandy silts	Ischia Channel	−53 m	Silt with fine-grained sands. Occurrence of reworked *Posidonia oceanica* and lamellibranchs. Oxidized surface veil.
B1809	Muddy sands	Ischia harbor	−51 m	Slightly oxidized superficial silty-sandy veil. Below bioclastic sands in abundant muddy matrix with living worms and fragments of mollusks.
B1813	Sands and gravelly sands	Casamicciola	−55 m	Slightly oxidized superficial silty-sandy veil. Below bioclastic sands in an abundant muddy matrix with living worms and fragments of mollusks.
B1816	Sandy silts	Forio Bank Base of the volcanic edifice	−191 m	Oxidized mud with gastropods.
B1817	Sandy silts	Western Ischia offshore (Citara)	−179 m	Compact oxidized surface mud with rare sub-rounded pumice.
B1819	Sandy silts	Cava Grado	−88 m	Mud with fine-grained sand. Downwards the sediment is full of valves of large lamellibranchs, colonized by single corals. Rare tufaceous pebbles, many polychaetes.
B1821	Sands	Cava Grado	−41 m	Medium-grained lithoclastic sand with a poor muddy matrix. Presence of glass, slag, tufaceous granules; worms and fragments of gastropods and lamellibranchs.

Table 1.
List of sea bottom samples and their lithology based on grain-size analysis. Location, water depths and description of sea bottom samples are indicated.

Marine geological survey on a scale of 1: 10.000 has allowed to map the Late Quaternary depositional sequence, which includes the TST-HST deposits (slope deposits) and the HST deposits (submerged beach deposits; inner and outer shelf deposits, either bioclastic or epiclastic in origin). This sequence covers significant accumulations of debris avalanche/debris flow deposits, which are located both in the northern offshore of Ischia between Lacco Ameno and Casamicciola and in the western offshore of Ischia, between the promontories of Punta del Soccorso and Punta Imperatore. These debris are composed of heterometric blocks and accumulations of blocks and lavas immersed in a coarse-to-fine grained matrix. Furthermore, significant outcrops of undifferentiated volcanic substratum have been recognized, whose precise attribution in the volcanic deposits of Ischia is problematic, due to the lacking of direct sampling.

The Section 40 at a 1:10.000 scale, located in the northern offshore of Ischia (promontory of Punta La Scrofa; **Figure 3**) has shown textures that include sands, pelitic sands and sandy pelites. The Late Quaternary marine deposits unconformably overlie the deposits of the northern debris avalanche and the undifferentiated volcanic substratum. Here the rhodolith deposits are represented by bioclastic detrital sands, the elements of which are composed of fragments of calcareous algae, bryozoans, mollusks and echinoids. These bioclastic sands, from a few decimeters to a few centimeters thick, cover pelitic drapes. The inner shelf deposits

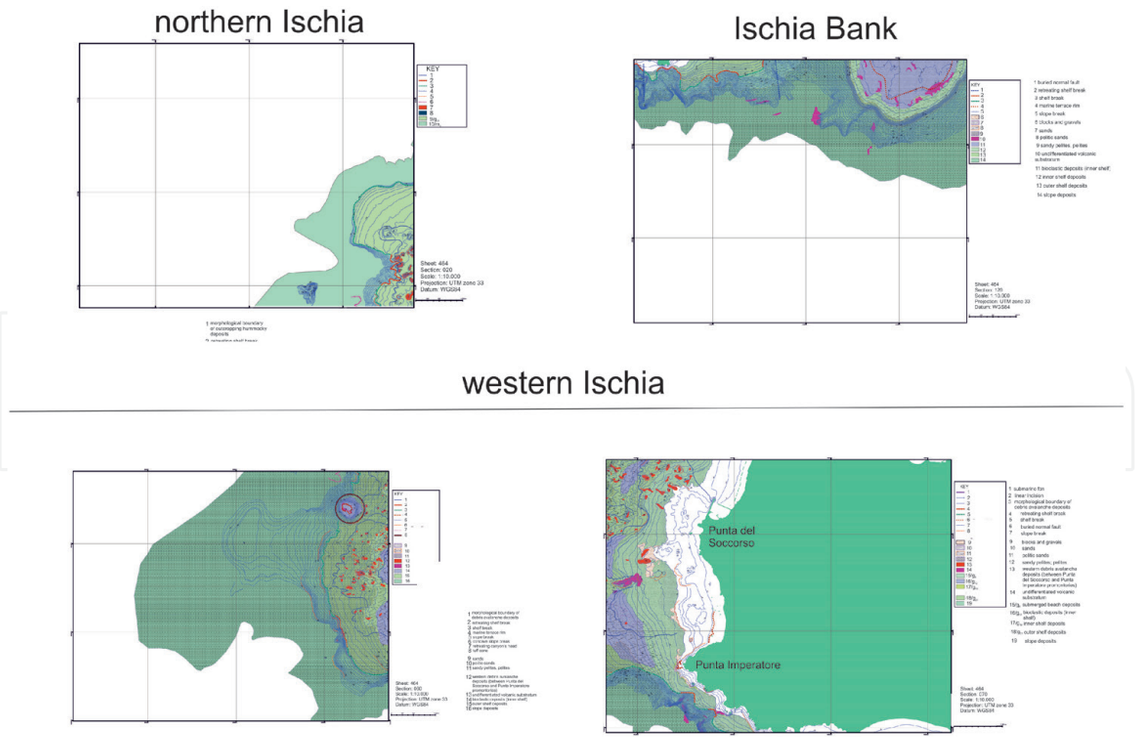

Figure 3.
Sketch frame of some cartographic sections of the Ischia marine geological survey (scale 1:10.000).

are composed of medium-coarse-grained sands and fine-grained pelitic sands. The outer shelf deposits are characterized by pelites with variable fractions of medium-fine-grained sands.

The Section 60 at the 1: 10.000 scale is located in the western offshore of Ischia, outside the promontory of Punta del Soccorso (**Figure 3**), and sands, pelitic sands, sandy and pelitic muds have been mapped. The Late Quaternary marine deposits unconformably overlie the deposits of the western debris avalanche and the undifferentiated volcanic substratum. The Forio Bank has been mapped as a tuff cone, the top of which is found at a water depth of −38 m. At the top of the tuff cone of the Forio Bank rhodolith deposits have been found, represented by bioclastic sands in a scarce pelitic matrix. Furthermore, the outer shelf deposits are composed of pelites with variable fractions of medium-fine-grained sands, with volcaniclasts, bioclasts and rhizomes of *Posidonia oceanica*.

The Section 70 at the 1:10.000 scale is located in the western offshore of Ischia between the promontories of Punta del Soccorso and Punta Imperatore (**Figure 3**). A large area of the sea bottom between the two promontories is characterized by the outcropping deposits of the western debris avalanche of Ischia. The submerged beach deposits are composed of well-sorted sands and pebbles, made up of volcanic lithic elements, from rounded to sub-rounded, with a scarce pelitic matrix and subordinately by bioclasts. The rhodolith deposits crop out on the Forio Bank and are composed of coarse-grained bioclastic sands and bioclastic gravels, similar to those ones found on the Ischia Bank. The inner shelf deposits are characterized by medium-coarse-grained sands and fine-grained pelitic sands. The outer shelf deposits are composed of pelites with variable fractions of medium-fine-grained sands, with volcaniclasts and bioclasts and subordinately, with rhizomes of *Posidonia oceanica*. Finally, the slope deposits are formed by pelites and sandy pelites.

In the Ischia offshore the inner shelf deposits, Holocene in age, are composed of four lithologic associations. The first lithologic association is characterized by

heterometric blocks and pebbles, which come from the recent and current rearrangement of the adjacent deposits of debris avalanche/debris flow and crop out within depressed or protected areas.

The second lithologic association consists of medium-coarse-grained lithoclastic sands, sometimes pebbly, with scattered heterometric clasts and blocks, of pyroclastic composition (pumice, lithic and scoria) and lava, from rounded to subrounded, often immersed in a scarce sandy matrix, medium-fine-grained. Locally, a bioclastic component is present.

The third lithologic association is characterized by bio-lithoclastic sands, from medium-fine-grained to fine-grained, immersed in a scarce pelitic matrix, which include heterometric pebbles, from centimetric to pluri-centimetric, of lava and/or pyroclastic composition. The main components are represented by volcaniclasts (pumice, lithic and scoria) and bioclasts, mainly composed of fragments of mollusks. This association extensively crops out in large sectors of the proximal inner shelf and indicates a low-energy sedimentation on flat sea bottoms.

The fourth lithologic association, ranging in age between the Late Pleistocene and the Early Holocene, includes the palimpsest deposits, composed of gravels and sandy gravels with a prevalent pyroclastic composition, from rounded to subrounded, immersed in a scarce sandy matrix, from medium-fine-grained to fine-grained. In the offshore of Ischia this lithologic association is found in scattered outcrops in southern Ischia (La Guardiola), at water depths ranging between −12 m and −15 m and in western Ischia (Forio), at water depths of −30 m, where these deposits are associated with ancient shorelines.

3.2 Sedimentological data

Sedimentological analyses were performed with the aim of showing the main compositional and textural characters of sediments sampled at the sea bottom in Ischia. The sediment fractions recognized at the sea bottom based on particle size analyses include gravel sands, sands, silty sands, muddy sands, sandy silts and silts. Multibeam, Sidescan sonar and seismic data, together with samples, were acquired during the realization of sheet n. 464 “Ischia Island” of the new geological map of Italy [13].

Some textural classes have been identified on the basis of the integrated interpretation of geophysical and geological data. The recognized textures have provided additional information on the lithofacies associations, in order to identify the differences in the depositional elements that have been mapped. Moreover, ternary plots have been constructed for a better evaluation of different grain size (**Figure 4**), considering as variables respectively clay-sand-silt and gravel-sand-silt. The samples have been plotted in ternary diagrams subdividing them with respect to the oceanographic cruises GMS02_01 (diagrams in the upper part of **Figure 4**) and GMS06_03 (diagrams in the lower part of **Figure 4**).

In particular, the ternary diagram located in the upper left corner of **Figure 4** has considered as variables: clay, sand and silt. This plot has shown that the main lithologies are the clayey silts and the sandy silts (**Figure 4**). The ternary diagram located in the upper right corner of **Figure 4** has considered as variables: gravel, sand and silt. This plot has shown that the main lithologies are represented by silty sands and gravelly sands.

Moreover, the ternary diagram located in the lower left corner of **Figure 4** has considered as variables: clay, sand and silt. This plot has highlighted that the main lithologies are represented by sands and silty sands (**Figure 4**). The ternary diagram located in the lower right corner of **Figure 4** has considered as variables: gravel,

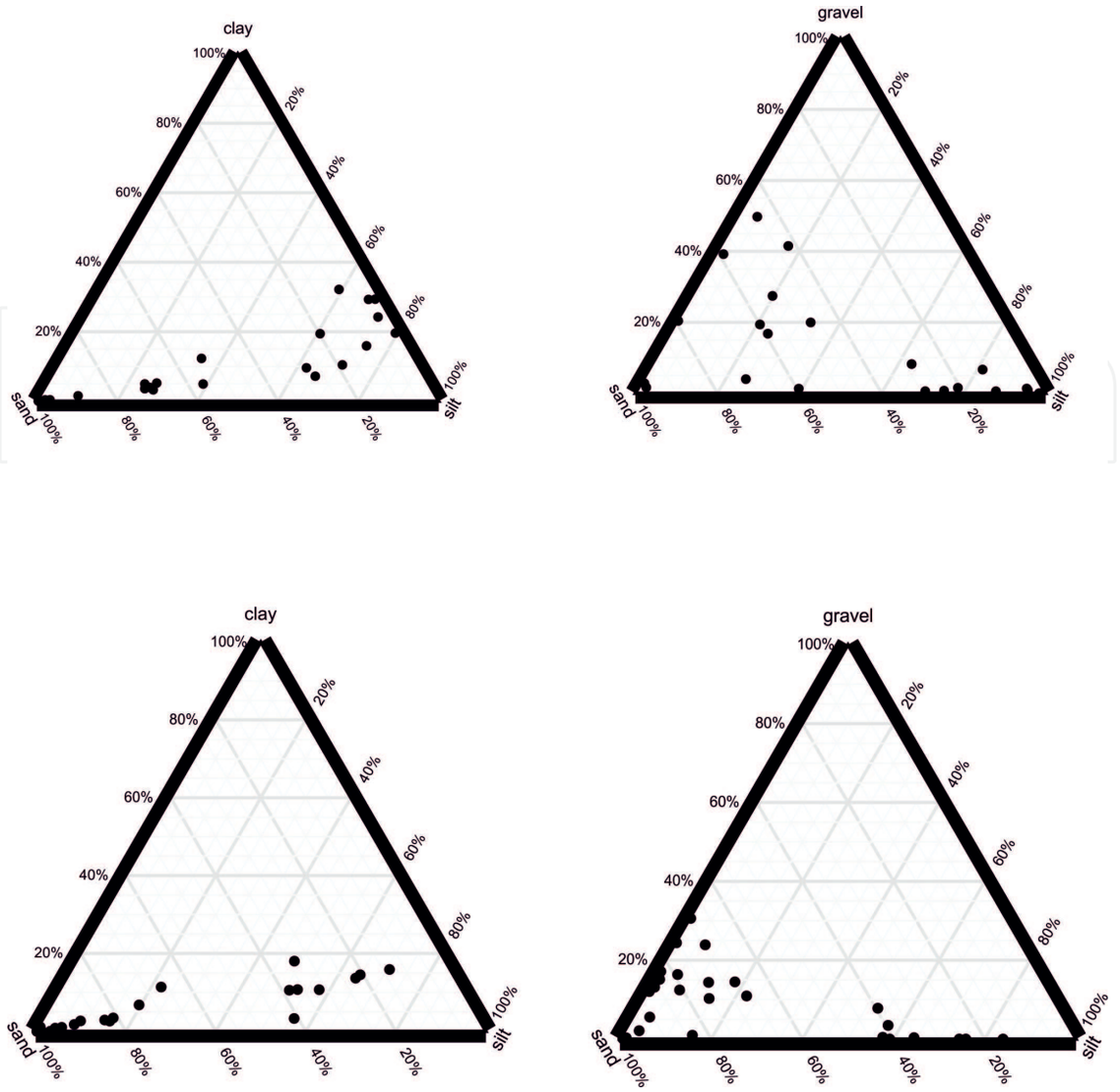

Figure 4.
Ternary plots of the processed sea-bottom samples.

sand and silt. This plot has highlighted that the main lithologies are represented by sands and gravelly sands and subordinately, by sandy silts (**Figure 4**).

3.3 Rhodolith deposits

On the Ischia Bank, a large volcanic edifice located in the south-eastern offshore of Ischia, an extensive meadow in *Posidonia oceanica* covers dark brown heterometric bioclastic sands (sample B1794; **Figure 5**) interpreted as rhodolith deposits due to the presence of living coralline algae. The sands cover a pebbly deposit consisting mainly of shells of mollusks, with fragments of echinoids, widespread on the *Posidonia oceanica* meadow. A low percentage of mud fraction occurs in these deposits.

The rhodolith deposits were also found on the parasitic vent, genetically connected to the main volcanic edifice of the Ischia Bank (sample B1797; **Figure 5**). Here bioclastic sands with glassy fragments, bryozoans and coralline algae have been found in a muddy lithoclastic matrix with a volcanic component. Rhodolith deposits were also found in sample B1799, located on the same adventitious cone, in which these deposits are associated with mollusk shells, small gastropods and scarce bryozoans (**Figure 5**).

Figure 5.
Sea bottom samples showing the occurrence of bioclastic deposits in the Ischia offshore.

Rhodolith deposits were also found in the Ischia Channel, a morphological threshold located between the islands of Ischia and Procida, where they were sampled by sample B1800. Here the rhodolith deposits are covered by an extensive meadow in *Posidonia oceanica*. Coralline algae are associated with fragments of mollusks, small gastropods, rhizomes of *Posidonia oceanica* and branched bryozoans, as well as with small slags and volcanic glass (**Figure 5**).

Rhodolith deposits were also found in the offshore of Casamicciola (Ischia north; sample B1813; **Figure 5**). Here these deposits grade laterally to sandy and muddy sediments and to the debris avalanche deposits present in Casamicciola.

In the western offshore of Ischia, rhodolith deposits are present at the top of the volcanic edifice of the Forio Bank, where they are characterized by coarse-grained sands and bioclastic pebbles in a scarce pelitic matrix. These deposits are completely analogous to those found on the Ischia Bank, given that the fundamental genetic analogy between the two volcanic edifices.

3.4 Seismic stratigraphy

The sampling data on rhodolith deposits have allowed to review previous interpretations of seismic lines in the offshore of Ischia [15]. At Ischia, the occurrence of isolated volcanic bodies, which include intrusions, domes and volcanic chimneys, was particularly complex to apply seismic and sequence stratigraphy in the interpretation of seismic data [37–39]. Volcanic bodies, which include lava flows, volcanic domes and volcanic intrusions, cannot be investigated by reflection

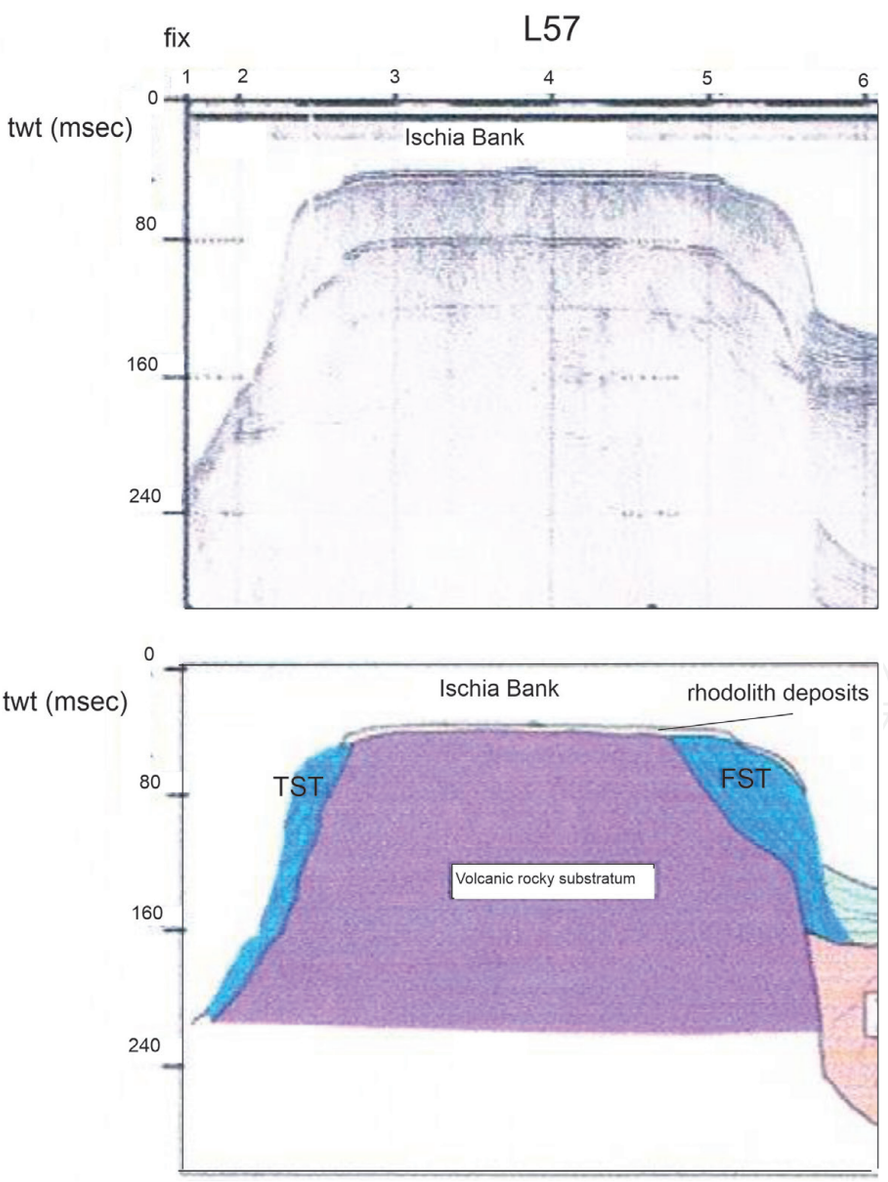

Figure 6.
Detail of the seismic profile L57 (Ischia Bank), showing the seismic unit cropping out at the sea bottom, including the rhodolith deposits occurring at the top of the volcanic edifice.

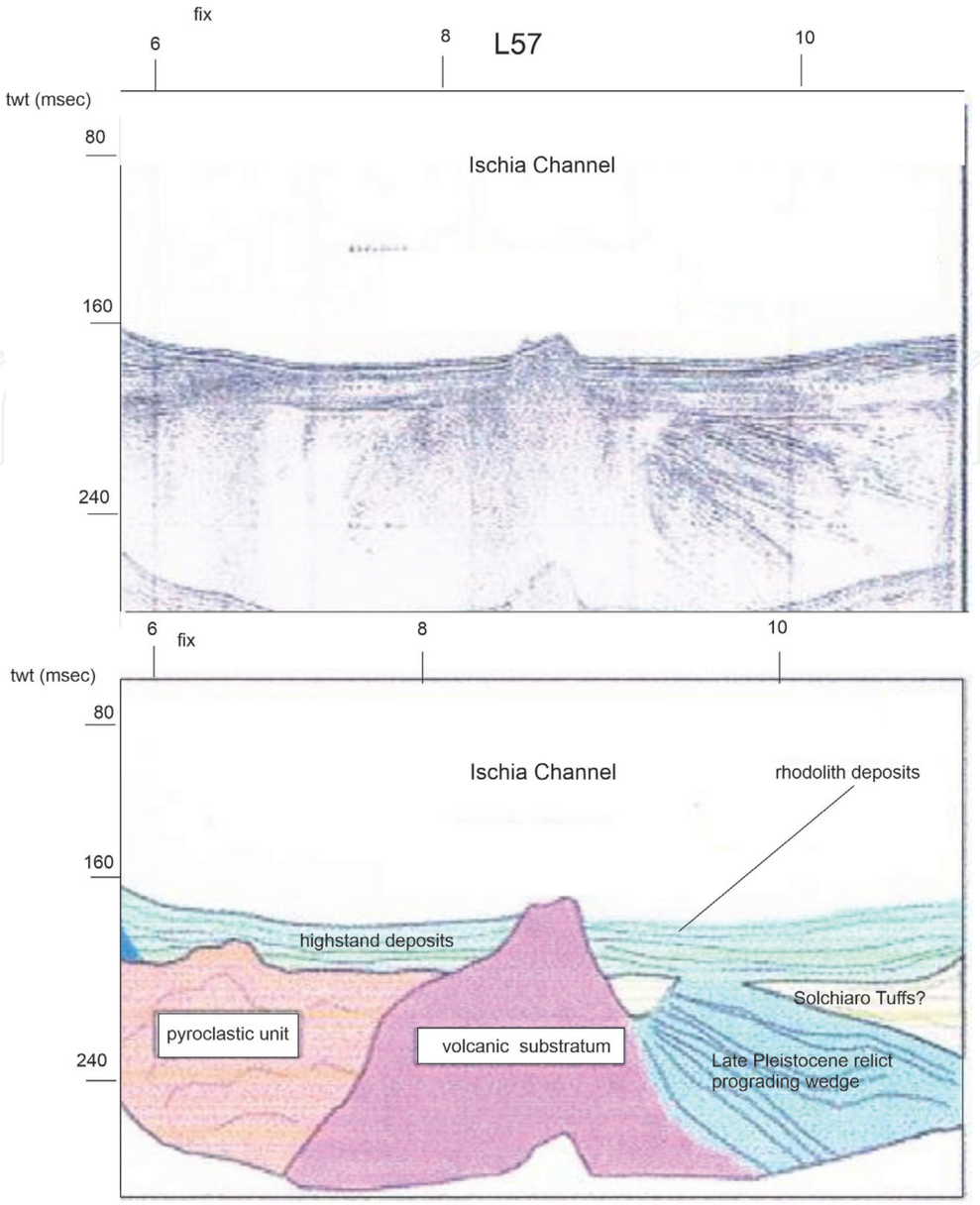

Figure 7.
Detail of the seismic profile L57 (Ischia Channel), showing the highstand deposits, Holocenic in age, within which the rhodolith deposits are inter-layered.

seismic data, except for their external geometry, since they are mainly acoustically-transparent. On the contrary, the seismic facies of pyroclastic edifices and buried pyroclastic deposits can be identified, thanks to the inner stratification of the pyroclastic deposits.

On the Ischia Bank, the rhodolith deposits are probably included within an extensive wedge-shaped unit located at the top of the volcanic edifice, which unconformably overlies the volcanic rocky substratum, which characterizes the bank (**Figure 6**). This unit crops out at the sea bottom and can be interpreted as a unit consisting of bioclastic and partially rhodolith deposits. The volcanic rocky substratum, which characterizes the main morpho-structure of the Ischia Bank, is characterized by an acoustically-transparent seismic facies, corresponding with lavas and pyroclastites (**Figure 6**). On the south-western and north-eastern slopes of the bank there are thick sedimentary wedges, which, accordingly to the geometries observed on the seismic line, are respectively interpreted as trangressive deposits (retrogradational) on the south-western slope and as forced regression

wedges (progradational) on the northeastern escarpment (**Figure 6**). These deposits are not coeval, since the forced regression deposits are older than the transgressive deposits, which on the south-western slope of the bank have not been preserved.

In the Ischia Channel the rhodalgal facies are probably inter-stratified in the highstand deposits, which unconformably overlie the volcanic unit of the Ischia Channel. This unit was identified on the north-eastern section of the L57 seismic line, which runs from the Ischia Bank to the continental platform of Procida, crossing, in the Ischia Channel, the relict volcanic edifice of "Il Pertuso" (**Figure 7**). The volcanic unit of the Ischia Channel has been correlated with pyroclastites and lavas genetically connected with the relict volcanic edifices of the Ischia Channel.

In the Casamicciola offshore, the rhodolith deposits are represented by convex bodies, acoustically transparent, rooted in the top part of the seismic units interpreted as debris avalanches deposits (**Figure 8**). The acoustic facies and the rounded external appearance make them similar to algal bioconstructions.

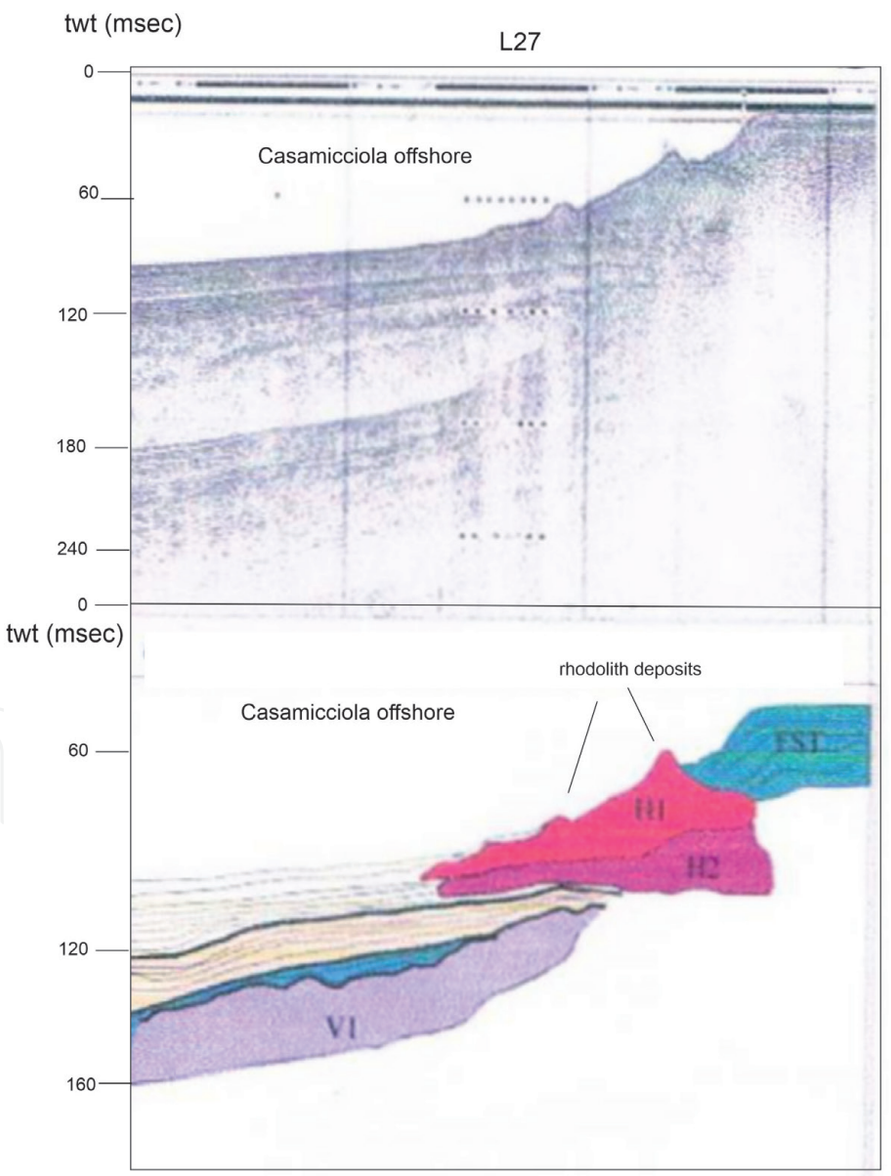

Figure 8.
Detail of the seismic profile L27 (Casamicciola offshore), showing the debris avalanche deposits (H1 and H2), within which the rhodolith deposits are inter-layered, appearing as mounds, representing algal bioconstructions.

4. Discussion

The bioclastic deposits of Ischia are here discussed and compared with similar deposits that are found in adjacent marine areas, with particular reference to the rhodolith layers. They represent detrital facies deriving mainly from in situ rearrangement processes of organogenic material on rocky sea bottoms. These deposits are composed of medium-coarse-grained sands and bioclastic gravels in a scarce pelitic matrix and crop out at the sea bottom in a portion of the inner shelf located at water depths between −20 m and −50 m, characterized by a prevalent carbonate sedimentation. Other significant outcrops are found on the morphological thresholds (Ischia Channel) and at the top of relict volcanic edifices, both in Ischia (Ischia and Forio Banks) and in Procida (La Catena, Il Pertuso and Vivara ants). Below water depths of −30 m the bioclastic deposits are rhodolith, characterized by gravels and lithoclastic sands, the biological component of which is made up of fragments of shells of mollusks (gastropods and lamellibranchs), echinoids and corals. Rhodolith deposits are often found near the *Posidonia oceanica* meadows and/or in protected areas near the rocky outcrops.

In particular, the Ischia Bank represents an excellent natural laboratory for the study of rhodolith deposits. On the Ischia Bank, below the *Posidonia oceanica* meadow, both bioclastic sands immersed in a muddy matrix and volcaniclastic gravels were sampled. The type of bioclastic sedimentation present in this area is characteristic, since the most of the carbonate shells, which come from the overlying meadow, settle at the net limit between the meadow and the sea bottom, where sands and bioclastic gravels crop out. Both the mollusk shells and the volcaniclastic fragments, where the contribution of the silty and sandy fractions is lower than 20%, were colonized by some species of red algae, while in the marine areas with a low gradient a maërl facies was deposited.

The sedimentological results obtained on the rhodolith layers are in agreement with the previous data on rhodolith deposits in the Mediterranean area [40], with particular reference to the southern Tyrrhenian Sea [5, 40], and to the Gulf of Naples [18, 19, 29–31]. In the Mediterranean area the rhodoliths were found in the eastern and western sub-basins at water depths of −30 m to −75 m, but also extend to water depths greater than −75 m [40, 41]. Rhodolith layers were reported in the most of the coastal sections of the Mediterranean, while they are missing along the coasts of the eastern Adriatic sea, Egypt, Syria, Lebanon and the Black Sea [40, 41]. Rindi et al. [41] that in the Mediterranean sea these deposits have shown a high spatial and bathymetric extension, also if the biocostructions of coralline algae virtually occur in all seas. Moreover, these authors have addressed specific research issues in future works, including more detailed paleontological studies, a more accurate taxonomic reassessment, and the extension of the studies on the effects of the climate change and acidification on a wider set of species.

Bracchi & Basso [5] have discussed the occurrence of calcareous algae on the Tyrrhenian continental shelf (Pontine Islands), finding two different carbonate facies, namely the coralline algae facies and the carbonate matrix facies. These authors have highlighted that the Pontine Islands represent a mobile sea bottom of the littoral zone, accordingly with the classification proposed by Peres & Picard [11]. The corresponding biocenosis has been called “Détritique Cotier” and is typically composed of a mixture of sands, gravels and muds. Furthermore, a moderate variability of sedimentary facies, in particular of sands dominated by biogenic carbonates, has been suggested in this area [33]. In this area of the Tyrrhenian Sea, coralline algae represent the most important control factor in the production of carbonate sediments and are typically found in a depth range between −40 m to −70 m. These

water depths are consistent with the depths of the rhodolith deposits found in the Ischia offshore and discussed in this work.

In the marine area of the Nisida inlet and Posillipo offshore (Nisida Bank; Cavallara saddle), previously reported by Walther [18] as an area of massive discovery of rhodolith deposits on the rocky outcrops and on the surrounding sea bottom, pyroclastic gravels are frequently mixed with rhodolith deposits characterized by living red algae. The rhodalgal facies is mainly composed of dead, fallen or transported thalli from submerged rocky outcrops, which are colonized in a variable way. In addition, the biogenic fraction is composed of sandy skeletal assemblages, forming variable types of deposits, which have undergone an intense mechanical degradation.

Various types of rhodalgal facies have been found in the Miseno Bank area (Gulf of Pozzuoli). In correspondence with the rocky outcrops, live thalli were found, difficult to sample. On the surrounding sea bottom, characterized by gravels and bioclastic sands, palimpsest deposits were sampled, formed by bioclastic sands. In particular, the presence of a palimpsest drapes, consisting of fragments of algal thalli and invertebrate shells has been reported.

On the Ischia Bank, whose top is found at water depths between −28 m and −30 m, there is a living *Posidonia oceanica* meadow, extending down to −40 m of water depth. In correspondence with the channellised areas, where the *Posidonia oceanica* meadow is lacking, there are extensive fields of sandy ripples. Rhodolith deposits were found below the *Posidonia oceanica* meadow, characterized by living coralline algae (*Phymatolithon calcareum*, *Lithotamnion corallioides*, *Lithotamnion minervae*, *Lythophyllum racemes*) [29]. The rhodolith layers are well developed, covering a gravelly sea bottom, formed by mollusk shells.

The geological and sedimentological data have shown that around the Ischia island the rhodolith deposits have been controlled by different geomorphological and hydrological settings, which have influenced the variable structure of the coralline algae. Among these control factors, the most important one is represented by the topography of the seafloor, deeply influencing the stratigraphic architecture of the rhodolith deposits. Based on the studied data these deposits mainly occur next to the relict volcanic edifices, to the morphological thresholds and to the rough morphologies occurring at the sea bottom corresponding with the outcrops of debris avalanche deposits [42].

In the Ischia offshore the best developed rhodalgal carbonate factory has been found on the outermost bank (Ischia Bank), lacking of the fine-grained fraction and subjected to an intense action of the currents at the head of the adjacent tributary channel, where a part of the biogenic sands are locally transported towards the head of the Magnaghi canyon. Palimpsest deposits or partially remobilized deposits have been found on some other banks (Miseno and Nisida - La Cavallara), where the fine-grained fraction or the geomorphological characteristics have prevented the formation of an active carbonate production by red algae. The Forio Bank, located in the western offshore of Ischia, has shown rhodolith deposits similar to those ones found on the Ischia Bank, but to a smaller scale, having more limited dimensions with respect to the Ischia Bank, as suggested by Multibeam bathymetric data.

In the northern sector of Ischia (Casamicciola) the seismic data have suggested that the rhodolith deposits and, as a general rule, the bioclastic deposits have rounded-shaped morphologies, corresponding with algal bioconstructions and are rooted within the seismic units of debris avalanches. Further data on these deposits in the northern sector of Ischia have been highlighted by Babbini et al. [30] and Gambi et al. [31]. These authors have reported the occurrence of a maërl facies in

the north-western sector of Ischia and in particular, in the offshore of Forio and in the San Francesco area on the basis of samples carried out at water depths between −50 m and −80 m. The microscopic characterization of these deposits has shown the occurrence of well-pigmented thalli and of variable morphologies (crusty, lumpy, mammellate, arborescent). The maërl facies looks like an accumulation of whole thalli of calcareous algae or fragments of calcareous algae, which often accumulate within the concavities of the rocky substratum. Furthermore, the ROV images collected in the Forio area (western offshore of Ischia) have shown the occurrence of important algal accumulations within the concavities of the ripple marks, occurring on the sandy bottoms [30]. Assemblages of very well diversified benthic organisms are associated with this facies [31], typical of the "Détritique Cotier" and "Détritique Du Large" biocenosis.

Moreover the obtained results have been compared with the distribution and characterization of rhodolith beds off the Campania region [43]. In the Gulf of Naples these authors have studied and described four selected sites, represented by Capri, Punta Campanella, Secchitiello, and Ischia. In particular, regarding Ischia, the authors have correlated their results with the data previously obtained by Babbini et al. [30] and Gambi et al. [31], which have singled out the occurrence of three morpho-types of rhodoliths, with a prevalence of unattached branches of *Phymatolithon calcareum* and *Lithothamnion corallioides*. In addition, Rendina et al. [43] have underlined a high percentage of dead thalli of red algae, accompanying the alive rhodoliths, suggesting that this percentage has been controlled by a high fraction of fine-grained sediments, triggering the burial of the rhodolith deposits.

The importance of the geomorphological and topographic control factors in controlling the stratigraphic architecture of the rhodolith deposits has been recently highlighted for extra-Mediterranean examples (Udo Island, Korea) [44], suggesting that the distribution of the rhodolith deposits is strongly affected by both the topography of the sea bottom and related physical energy and by different types of surface sediments. In particular, these authors have suggested that a bedrock exposed area is covered by alive rhodoliths (water depths up to – 10 m), where a rough topography of the sea bottom has prevented for a continuous growth of rhodoliths. An active growth area of alive rhodoliths and a sand dune area with dead rhodoliths have been suggested at water depths ranging between – 10 m and – 15 m. While the first area provides stable conditions for the growth of the rhodoliths, the second one represents an adverse environment for the development of rhodoliths. The seagrass covered area with alive rhodoliths develops at water depths greater than – 15 m, where various sizes of rhodoliths have been found.

5. Concluding remarks

The Ischia Bank is characterized by an active carbonate factory dominated by coralline algae, which have colonized an area where suitable environmental conditions have been established for the deposition of native and living rhodalgal deposits. The rhodalgal deposits are locally abundant and are mostly deposited in situ with a centimeter thickness.

Although in the Ischia offshore the investigated deposits were found in a similar bathymetric range, these deposits have shown how in different geomorphological and hydrological environment the coralline algae facies have different structures. Moreover, the topography of the sea bottom has controlled the stratigraphic architecture of these deposits (relict volcanic edifices, morphological tresholds, rough topographies controlled by the development of debris avalanche deposits).

Although qualitatively, the correlation between the sampling data and the interpretation of seismic profiles, previously interpreted and reviewed here, has suggested that the rhodolith deposits are inter-stratified within large seismic units, cropping out at the sea bottom or sub-surficial. In particular, on the Ischia Bank these deposits are inter-layered in a wedge-shaped unit located at the top of the volcanic bank. This unit unconformably overlies the acoustic rocky substratum, representing the main stratigraphic bulk of the bank. Although not documented by the seismic profiles, but only through sea bottom samples, the rhodolith deposits were also found at the top of the parasitic vent, genetically connected to the main building of the Ischia Bank volcanic edifice.

In the Ischia Channel the rhodolith deposits are presumably inter-layered with the highstand deposits, represented by a thick seismic unit partly cropping out at the sea bottom. This unit overlies volcanic seismic units of a probable pyroclastic nature, which are deposited within depressed palaeo-morphologies and which are probably correlated with the yellow tuffs of Solchiaro, cropping out onshore in Procida.

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