

Article

A Detailed Reconstruction of the Roman Landscape and the Submerged Archaeological Structure at “Castel dell’Ovo islet” (Naples, Southern Italy)

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Abstract: In this paper, we present the results of a multidisciplinary study aimed to reconstruct the Roman coastal landscape between Pizzofalcone hill and *Megaritis* islet—the area of the ancient Parthenope, the first settlement along the Naples coast. This coastal sector was surveyed by a team of specialized divers (archaeologists and geomorphologists) and by using an Unmanned Surface Vessel (USV) equipped with acoustic and optical sensors. The indirect surveys provided a high-resolution dataset of morpho-acoustic and optical measurements, useful to obtain the geological, geomorphological and archaeological interpretations necessary to formulate hypotheses on the functionality of the complex submerged archaeological structure detected in the study area. In particular, the integration between the surveyed data, the high-resolution seafloor mapping and the previous knowledge deriving from the 1980s underwater research carried out by Centro Studi Subacquei, led us to interpret the submerged remains as a *vivarium* related to a 1st century BC Roman villa. Finally, by measuring the submersion of several channels and a well-preserved *crepido*, a relative sea level during the period of use at $-2.2 \text{ m} \pm 0.2 \text{ m}$ mean sea level (MSL) was deduced, in agreement with the previous geoarchaeological studies realized in the near coastal sectors.

Keywords: coastal landscape; submerged geoarchaeological site; relative sea level changes; archaeological sea level marker; Roman fish tank; *Neapolis*; unmanned surface vehicle (USV); morpho-acoustic and optical dataset

1. Introduction

The first Greek settlement along the coasts of the Naples Gulf (Southern Italy) was located on Pizzofalcone hill—the so-called “Parthenope” city (from the name of a mermaid believed visible on the fascinating *Megaritis* islet)—dates back to the 7th century BC. Only at the end of the 6th century BC, the city was re-located in the plain, at the foot of Pendino terrace and named *Neapolis* (“new city” in Greek). The study of the Late Holocene evolution of *Neapolis* coastal sector and its surroundings has made considerable progress in the last years thanks to the excavations of the new subway, offering the possibility to collect large amounts of stratigraphic and biosedimentological data. These studies have shed new light on the presence and configuration of the Greco–Roman harbor of *Neapolis*, as well as new data about the vertical ground movement that affected this area in the last millennia producing metric relative sea level changes [1–9].

The harbor was established in a sheltered bay (so-called Municipio plain in Figure 1), protected by the headland of Pizzofalcone ([10] and reference therein) from the sea storms mainly coming from the southern sectors. Traces of dredging dated between the 4th and 2nd centuries BC testify the intense activity of this harbor since its foundation [8]. Despite the huge sedimentary input due to the 79 AD Vesuvius eruption, the commercial basin remained active throughout the Roman period as testified by the construction of piers within the harbor basin in the 1st century AD. Only the sub-Plinian Vesuvius eruption in 472 AD and the subsequent increase of alluvial input related to strong on slope hydrogeological destabilization induced the final closure of the bay ([10] and reference therein). Finally, the harbor bay was buried by an anthropogenic infill in the early Middle Age, as testified by the Lafrery du Pérac map (1566), where the first phase of the modern harbor—with the construction of the Big and Small piers—is clearly visible. Nowadays, in this area, Municipio square is located.

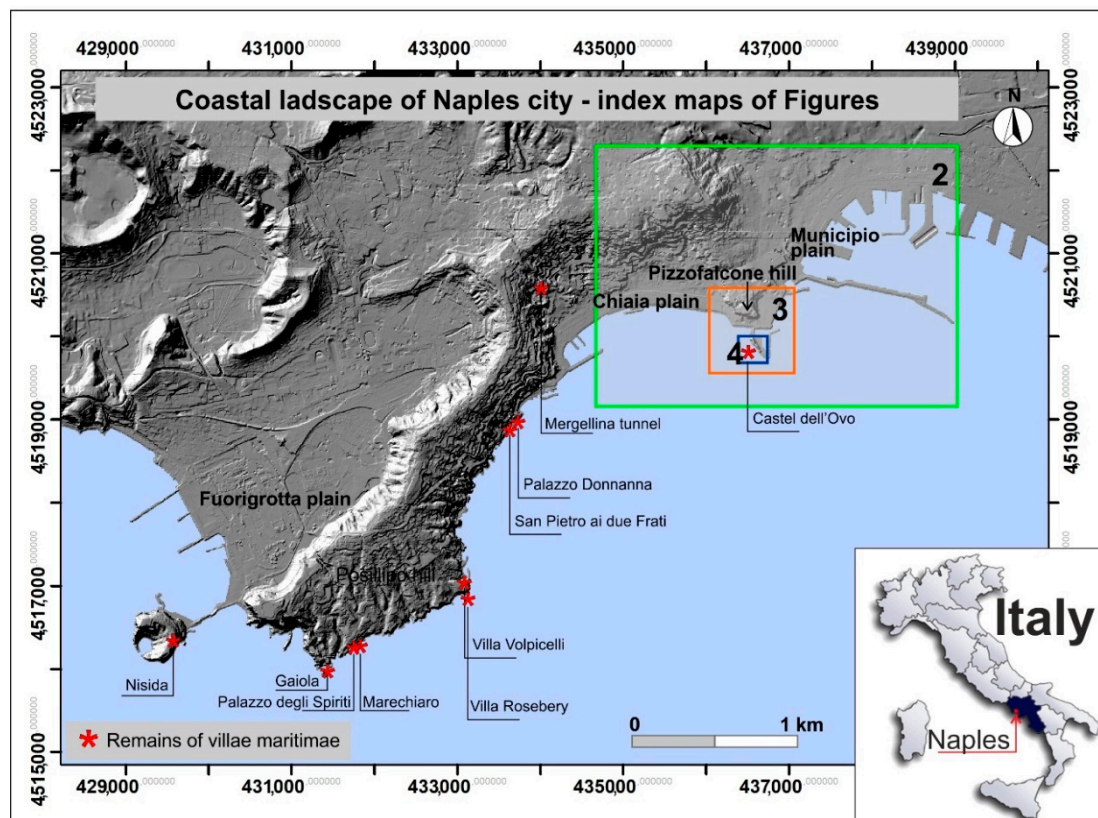


Figure 1. Location map of the *villae marittimae* described in Section 3 and index maps of the Figures contained in this text: (2) extent of Figure 2; (3) extent of Figures 3 and 6; (4) extent of Figures 7, 8, 10 and 11. The shaded relief was obtained from the digital terrain model (DTM), calculated by interpolating the 2013 LIDAR data provided by the Ministry of Environment.

As testified by several archaeological remains detected during the subway excavations, the urbanized area of *Neapolis* extended during the Imperial Age both on the hill of Pizzofalcone and in the adjacent plain of Chiaia (Figure 1 for locations) with the construction of maritime villas (Figure 1, see Section 3) and the *via per Crypta* that linked *Neapolis* to *Puteoli* [4]. In particular, the coastal plain of Chiaia appeared as a narrow plain with a prograding tendency, bordered inland by a palaeo-seacliff (active during the Protohistoric times) [4]. The natural evolution of this plain ended in 1780 when the beach zone was converted into an urban garden with a walkway (very popular in those years) by the will of Ferdinand IV of Bourbon.

Interpreting the historical sources, several authors hypothesize that Pizzofalcone hill was separated from the *Megaritis* islet (today known as Castel dell'Ovo, Figure 1, [11]) during Roman times [3,4]. Despite the fact that the history of Naples starts from this suggestive coastal sector, nowadays its

paleo-morphology, as well as the history of its use, is still little known today. During the 1980s, the Centro Studi Subacquei (Coordinator Armando Carola) undertook some underwater surveys (see Section 4) highlighting the presence of several remains ascribable to the Roman period.

Even if neither the remains of the Greek-Roman port of *Neapolis* nor the beach of Chiaia is still recognizable in the present coastal landscape of Naples, the state of knowledge on the landscape modifications and the relative sea level variations (see Section 2) in these sectors has improved considerably, thanks to the geoarchaeological studies carried out during the Line 5 subway excavations. Instead, no specific study has been carried out until today on the palaeo-morphology of the interposed promontory (Pizzofalcone hill and *Megaris* islet), which separates the two coastal plains.

Thanks to recent investigations carried out by the Department of Science and Technology of the Parthenope University of Naples during a PON (National Operational Program) project, it has been possible to define a new step in the knowledge of this area, in particular for the 1st century BC. Therefore, in this paper, we present the results of an interdisciplinary study aimed to reconstruct the Roman coastal landscape between Pizzofalcone hill and *Megaris* islet, and the function of the annexed submerged archaeological structures.

2. Geological and Geomorphological Setting

The “Castel dell’Ovo islet”—formerly called *Megaris* islet—is a sea stack related to the headland retreat of Pizzofalcone promontory (Figure 2). Both the promontory and the islet are mainly made of Castel dell’Ovo Tuff (OVO—78 ky BP, [12]), even if the SW sector of the OVO formation is covered by Neapolitan Yellow Tuff (NYT—15 ky BP, [13] through an erosional unconformity [12].

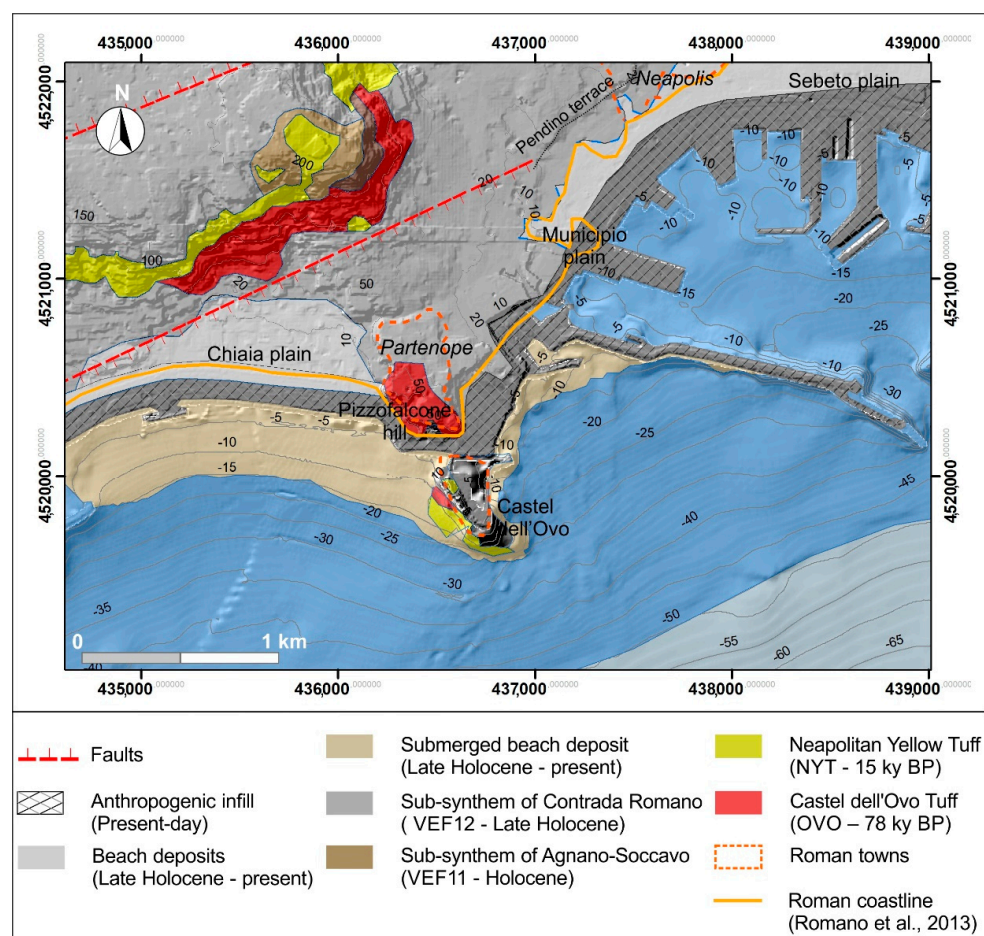


Figure 2. Geological map of the study area (Modified from [12]). The shaded relief was obtained from the DTM, calculated by interpolating the 2013 LIDAR data provided by the Ministry of Environment.

The headland of Pizzofalcone, with a maximum steepness and height respectively of 80% and 60 m above sea level (herein after asl), is bounded laterally by two plains strongly urbanized. The west side is occupied by Chiaia coastal plain, located at the base of a paleo-seacliff with a steepness of 80% and a maximum height of 174 m that runs for about 3 km. The seaward extension of the plain reaches 500 m. The dominant bedrock (as almost everywhere in Naples) is the NYT at least in the first tens of meters underground, covered by a sequence of pyroclastic deposits related to the Phlegrean Fields' more recent activity and referred to as Contrada Romano Sub-synthem (5–3.8 ky BP, [12], Figure 2).

The eastern sector of Pizzofalcone hill hosts the Municipio plain (position of the ancient Neapolis harbor), edged in the inner side from the Pendino terrace and strongly modified by the construction of the present Port of Naples. Additionally in this sector, the basal unit of the succession is represented by a deposit of the incoherent NYT facies, covered by a sedimentary infill about 15 m thick made of an alternation of sands, silty sands and silt [12]. This infill testifies the progressive infilling by silt of the bay that ended with the formation of a lagoon that persisted until the end of the V century AD [1,2,7].

The underwater sector of the study area is characterized by submerged beach deposits, except that at the footslope of Castel dell'Ovo islet where a wide submerged tufa platform outcrops at a depth of about 3–4 m-bsl (Figure 2, [12]).

The Late Holocene evolution of this coastal landscape was controlled by the interplay between endogenous, exogenous and anthropogenic factors. Nevertheless, a subsiding trend affected the coastal plains of Chiaia and Municipio in the last millennia, these areas were characterized by a prograding tendency mainly due to several phases of pyroclastic emplacement [1,4,5,10]. This tendency was interrupted only in the Middle Age by substantial anthropic interventions.

In particular, the relative sea level (RSL) oscillations in Chiaia and Municipio coastal plains, obtained by overlaying stratigraphic records and archaeological remains related to the ancient harbor, demonstrate a subsiding trend in both the two sectors (Table 1).

Table 1. Table of Greek-Roman relative sea level (RSL) from previous geoarchaeological studies

Location	Marker Type	RLS (m)	Age (Century BC/AD)	Reference
Municipio	Dredging of harbor basin	−3.85/−4.85	IV–III cen BC	[5]
Municipio	Dredging of harbor basin	−3.70/−4.70	III–II BC	[5]
Municipio	Shoreface	−2.60/−4.10	II cen BC	[5]
Municipio	Shoreface	−2.20/−3.70	I cen BC	[5]
Municipio	Shoreface	−1.85/−3.35	15 BC–15 AD	[5]
Municipio	Shoreface	−0.80/−2.30	II cen AD	[5]
Municipio	Biomarkers on pier	−2.60/−1.60	31 BC–IV AD	[10]
Chiaia	Shoreface	−1.85/−4.35	VI–III BC	[4]
Chiaia	Beachface	−3.30/−4.70	1st half I cen AD	[4]
Chiaia	Beachface	−2.40/−2.90	2nd half I cen AD	[4]
Chiaia	Beachface	−2.10/−3.00	2nd half III cen AD	[4]

3. Archaeological Setting

The human presence on the islet of Megaris can be probably related to the Greek settlement in the Bay of Naples, considering the proximity with the sites of the Palaiopolis, on the hill of Pizzofalcone-Monte Echia (VII century BC, [14]), and the mythological tradition possibly locating one of the Siren rocks in this part of the Neapolitan coast. Nevertheless, the archaeological evidence on the islet is not earlier than Roman times. The columns and the architectural remains reused in the present Castel dell'Ovo, as well as some small fragments of walls in *opus reticulatum* that were found, not in situ, during underwater surveys (see Section 4) carried out by the Centro Studi Subacquei (coordinator Armando Carola), are all dating back to the Roman era, when, according to the historical sources, a huge *villa maritima*, with impressive maritime structures, was built in that site [15].

As it is well known, since the end of the 2nd century BC the coasts of the Phlaegrean area, the entire Gulf of Naples and of the Gulf of Gaeta were quickly occupied by gigantic, luxury maritime

villas (see [16], for a general discussion on the subject). These estates, often taking advantage of natural promontories, bays and little islands, were the *otium* residences of some of the most representative men of the Roman Republican Age, whose names we know sometimes thanks to the epigraphic sources (marked lead pipes, honorary and funerary inscriptions), mostly thanks to the literary tradition [17]. As located not very far from Rome, embellished by the finest decorations of that time, provided with hot thermal waters, fishponds and private harbors, the Roman maritime villas reflected the power of their owners and their wealth. No wonder, therefore, that many of these complexes became a part of the Imperial properties, like in Baiae, Pausilypon, Capri or Sperlonga [18–21].

For the Neapolitan coast, a series of *villae maritimae* has been documented along the hill of Posillipo (Figure 1, [22]): in the Gaiola sector (late-republican villa of P. Vedius Pollio, later part of Imperial Pausilypon); in the nearby so-called Palazzo degli Spiriti [23–25]; in the bay of Marechiano/Marechiaro and along Capo Posillipo, in front of Villa Rosebery, among the so-called ruins of Pietra Salata.

The sequence of the villas (see Figure 1 for position) certainly continued also in the region between Capo Posillipo and Mergellina, where the Roman ruins reappear suddenly in the basement of more recent buildings, in Villa Volpicelli, San Pietro ai due Frati, Palazzo Donn'Anna, and a villa maritima was probably present also very close to the Ferrovia Cumana tunnel in Mergellina, but the suffocating presence of modern Naples considerably complicates our possibility of reconstructing the ancient coastline.

The promontory of Pizzofalcone and the close islet of *Megaritis* were certainly chosen for another of these villas. It is possible that a unique complex included the ruins still visible on the top of the hill of Monte Echia (with small surviving arches, and walls *in reticulatum*), in the modern via Santa Lucia and on a lower terrace directly on the sea, in the places now occupied by the Castel dell'Ovo (see Figure 1 for position), constituting the *pars maritima*.

A long historical tradition considered these ruins, that probably also incorporated some other walls reported underwater in the basin of Borgo Marinari (1566 Lafrery map), as the remains of the legendary villa of Licinius Lucullus. The *villae lucullianae* in Campania were widely reported in the ancient times as a classic example of the impressive possibilities and of the architectural effort typical of the *villae maritimae*. Like the famous Persian king *Xerxes*, *Lucullus*, *Serses togatus*, was able to cut the natural rock, to open sea-channels and to give a shape to landscape, complying with his wishes. Lush plantations of exotic species, cherry-trees, apricot-trees, imported from the East, together with wide artificial *piscinae* for the breeding of different fishes constitute only a part of the gigantic *Lucullianum*, a complex that could effectively be identified with the system Monte Echia/*Megaritis*, but also with the villa on the islet of *Nesis*/*Nisida* like we argued recently [26,27]. The identification of the owner, however, is an enticing, but not the fundamental question: around the 1st century BC *Megaritis* was certainly occupied by a magnificent *villa maritima*, owned by the wealthy *Lucullus* or by some other powerful member of the Roman senatorial aristocracy, that built his residence following the same principles.

4. Previous Underwater Research in the Study Area

In this section, the previous underwater research—carried out in a small part of our study area (Figure 3) between the 1980s and 1990s—are shortly described. These authors studied the submerged archaeological structures close to Castel dell'Ovo, nowadays, mostly covered by the modern breakwater built between 2013 and 2014.

In the 80s, the Centro Studi Subacquei (coordinator Armando Carola) carried out an underwater survey of the elongated archaeological structure parallel to Castel dell'Ovo laying at a water depth down to −6 m. As shown in Figure 4a,b, this structure reached −1 m of depth in its upper part, and was characterized by vertical walls sculptured in tuff and crossed by squared channels (with sides about 1 m wide). The researchers advanced the hypothesis that this structure was a remnant of a fish tank related to the Roman maritime villa built on the *Megaritis* islet (nowadays Castel dell'Ovo). Unfortunately, the structure was totally buried by the present-day breakwater. In the same sector but at a water depth down to −12 m, several walls in concrete were detected (Figure 4c), during the same

survey. These collapsed structures were crossed by small rounded holes (70×50 cm). Finally, at a depth range between -12 and -15 m, traces of collapsed walls in *opus reticulatum* and *opus incertum* were surveyed at a depth of -15 m (Figure 4d).

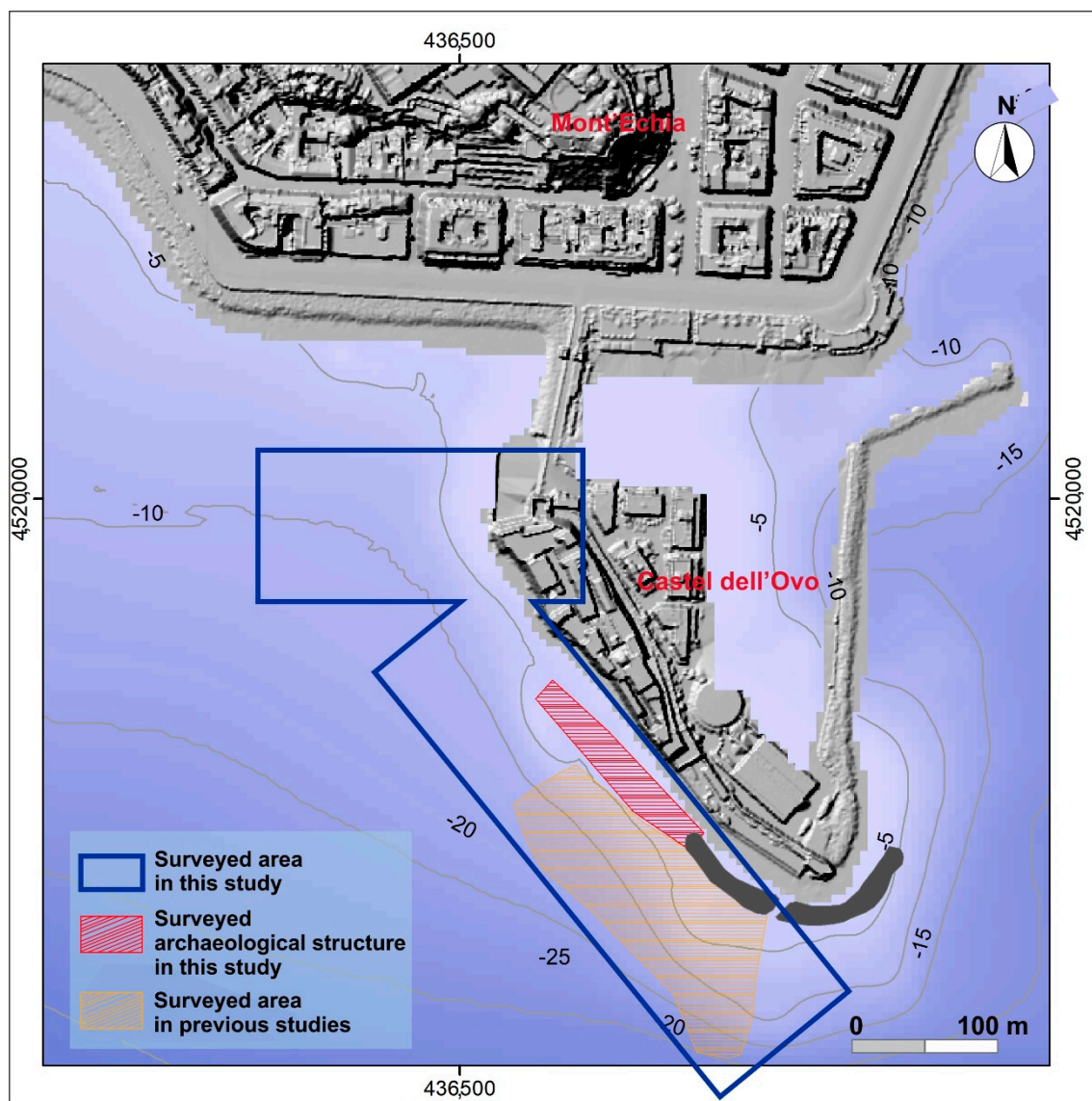


Figure 3. Location map of previous underwater surveys carried out by the Centro Studi Subacquei in the 1980s and [28].

During the 3rd International Symposium on Underground Quarries held in Naples, [28] surveyed the above described submerged structure nowadays buried by the breakwater (Figure 3), detecting four tunnels excavated in the tufa substrate, as below reported:

- Tunnel I is located in the southern part of the reef. It is formed like other tunnels by a single gently sloping corridor 6.5 m long and 1.6 m high. The depth of its roof is 1.4–2.6 m under the sea level.
- Tunnel II is located some 20 m north from Tunnel I only 1 m under the sea level. It consists of a single 4.5 m high and 1.9 m long rock bridge.
- Tunnel III is located only several meters north from Tunnel II. It is the longest one reaching almost 8 m of total length. It has a trapezoedric profile.
- Tunnel IV can be found in the separate rock of the structure almost 5 m under the sea level. It is several meters long with a small profile 60×80 cm.

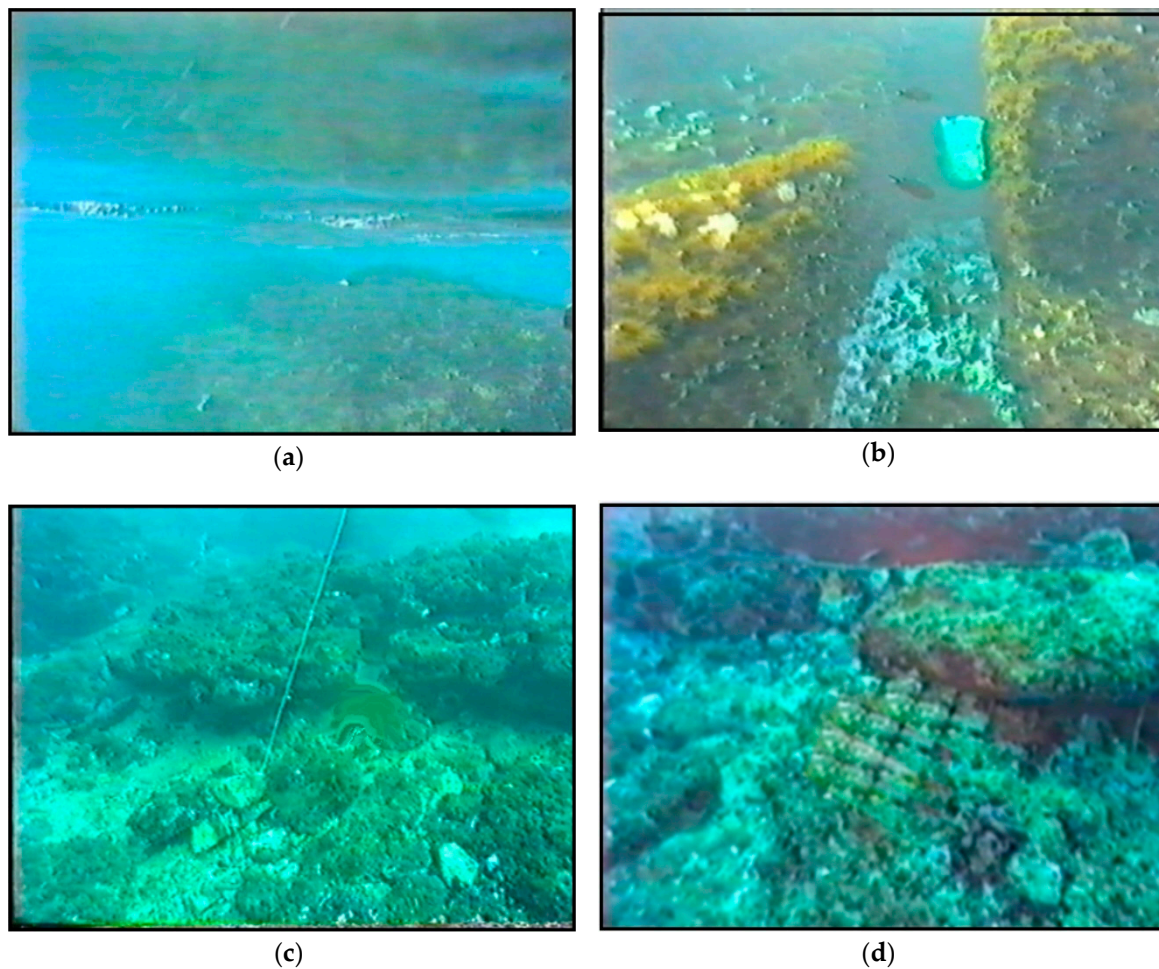


Figure 4. Underwater photos of the direct survey carried out by the Centro Studi Subacquei: (a) and (b) elongated archaeological structure parallel to Castel dell'Ovo; (c) walls in concrete crossed by small rounded holes; (d) remains of *opus reticulatum*.

They admitted that the semi-regular profile of the tunnels was of artificial origin, and supposed that the tunnels could represent the remains of the ancient Greek harbor of the Parthenope village.

Starting from this state of knowledge, we investigated a wider underwater area about of 87,000 m² in the western sector off Castel dell'Ovo (Figure 3), in order to characterize the seabed morphology and to detect all submerged archaeological structures visible until today.

5. Methods

The western marine sector of Castel dell'Ovo islet was surveyed by direct and indirect methods in order to reconstruct the natural and anthropic coastal landscape.

5.1. Direct and Indirect Surveys

The survey phases were divided into three steps:

- a direct survey with scuba divers, aimed at exploring the study area and identifying possible obstacles to the navigation;
- an indirect survey carried out by using acoustic and optical sensors installed on-board of an Unmanned Surface Vessel (USV);
- a direct survey, with scuba divers, on the targets of geological, geomorphological and archaeological interest, identified in the two previous phases.

The survey was carried out in a period in which the weather and sea conditions were stable, with a moderate wind from the north-east sector, and with an almost calm sea. The wind did not affect the navigation of the USV because the investigated area is located near the Castel dell'Ovo (see Figure 1).

The first phase involved a survey of the entire area of interest through a small boat of 5 m and the intervention of the scuba divers (geomorphologists and archaeologists), who identified the archaeological structures and verified the presence of underwater and/or surface obstacles (mainly fishing gear) dangerous for the navigation of the USV.

The second phase involved an indirect survey by using the MicroVeGA USV [29,30] belonging to the GEAC (Geologia degli Ambienti Costieri) research group of Parthenope University (Figure 5).

The marine drone used during the indirect surveys—designed exclusively for the geoarchaeological task—is the result of many years of experience in marine geophysical surveys applied to underwater archaeology [24,25,31–33].



(a)

Figure 5. *Cont.*



(b)



(c)

Figure 5. MicroVeGA Unmanned Surface Vessel (USV) during the navigation phases: (a) a turning; (b) a SE-NW navigation line; (c) a NW-SE navigation line.

During operations, the USV is launched from the pier of Borgo Marinaro. It operated with the support of a 5 m boat equipped with an outboard engine that carried a surveyor team.

The navigation made during the survey (Figure 6) was thus planned: three navigation lines in area A, three lines in area B, as well as a series of very dense lines in area C. During the surveys of area C, the drone—thanks to its small size and reduced draft—was able to navigate “above” the archaeological structure, continuing the data acquisition (mainly bathymetry and video) even in less than 1 m of depth.

This operational experience has led to the creation of a vehicle with a simple and robust structure but able to effectively carry out the necessary long working sessions at low speed typical of this kind of survey. The small dimensions (130 cm in length) and the presence of two brushless motors make it very manageable and suitable for use in coastal areas with shallow water even in the presence of outcropping obstacles.



Figure 6. Map of the navigation carried out during the indirect survey. The shaded relief in the figure has been calculated from the digital surface model (DSM, with a grid 1×1 m), provided by the Municipality of Naples.

The drone applies the multimodal mapping technique that involves using multiple onboard sensors for mapping, localization, and data collection. All data is broadcast in real time both to a base station and to all operators involved in the research (geophysicist, archaeologist, geomorphologist etc.).

The main task is the acquisition of data related to the morphology of the seabed, in order to realize three-dimensional landscape models, using geophysical (Single Beam Echo Sounder and Side Scan Sonar) and optical (underwater cameras for photogrammetry) instruments.

The MicroVeGA payload consists of:

- A 200 KHz digital echosounder
- A 450 KHz digital side scan sonar
- A high definition underwater photographic system.

The Single-Beam Echo Sounders (SBES) is an Ohmex with 200 KHz acquisition frequency and 60 m as maximum measured depth, therefore optimized for coastal bathymetric measurements.

The Side Scan Sonar (SSS) Tritech StarFish 450 C is a small instrument (0.378 m long), optimized for coastal waters (450 KHz CHIRP transmission). The slant range used during the survey is 50 m.

The instrument is embedded in the drone and has an offset of a few centimeters from the GPS. Under optimal conditions, the instrument is able to discriminate an object of 0.0254 m (1 inch). The side is used to acquire the morphology of both the target and the seabed [34].

The photographic system installed on-board of MicroVeGA consists of two Xiaomi YI Action cameras and a GoPro Hero 3.

The survey lasted approximately two hours during which—thanks to Multi-Modal Mapping technique—the USV acquired the following data:

- 1904 m of SSS sonographs;
- 3 h and five movies (geo-referenced) by means of the three high-resolution cameras;
- 4856 bathymetric points (georeferenced) by means of the SBES;

The third and last phase involved a series of direct diving on the targets previously identified, with scuba divers who made repeated measurements of the targets by using a graduated range pole and a tape measure. Moreover, during post-processing, thanks to specific software, more than 11,000 digital georeferenced images were extracted from the movies.

5.2. Post-Processing of Data

Geomorphological and geoarchaeological interpretations were obtained by elaborating in GIS the surveyed and bibliographic data, in order to reconstruct the coastal landscape during the Roman period.

The onshore digital terrain model (herein after DTM) of the study area was calculated by interpolating the LIDAR data provided by the Ministry of Environment (0–200 m mean sea level, herein after MSL) and with a Topo to Raster interpolator (1×1 m grid), in order to elaborate the geological map in Figure 1.

The three-dimensional present-day anthropic landscape of Megaris islet was obtained by elaborating the digital surface model (herein after DSM, with a spatial grid of 1×1 m) derived from the Lidar data provided by Napoli municipality (<http://sit.cittametropolitana.na.it/lidar.html>).

The bathymetric data were elaborated along with the SSS data in GIS environment, to reconstruct the morphology of the seabed and the archaeological structures detected in the study area [30].

The bathymetric data elaboration was structured in three steps. Primarily, the depths were referred to the vertical datum of mean sea level (MSL), correcting each measurement with respect to tidal height obtained from the tidal table of Naples provided by the Hydrographic Institute of the Navy. Secondly, the depth measurement was corrected with respect to the transducer submersion, measured by the acoustic system for the draught measuring [26]. Finally, the data were interpolated—by using a Topo to Raster interpolator—in order to obtain the detailed seabed bathymetry.

By analyzing the SSS data, two results were obtained:

- the detection and bordering of the archaeological remains
- the acoustic mapping of the seabed by discriminating the sandy bottom from the rocky one.

In the first instance, all sonographs were processed by using Chesapeake Sonar Web Pro 3.16 software, in order to create a GeoTIFF mosaic and obtain the sonar coverage of the whole area. This mosaic was elaborated in ArcGIS ArcScene obtaining a 3D view of the submerged acoustical landscape.

The analysis of the backscattering signal carried out in this research allowed the evaluation of the characteristics of the acoustic reflectors to be identified: archaeological remains, tufa bottom and sandy bottom. The trend of the backscattering signal along a horizontal line (sweep) was analyzed and graphed in a grey scale image, in order to obtain that the amplitude of the signal varies between 0 and 255.

6. Results

The interplay between direct and indirect surveys provided a high-resolution dataset of morpho-acoustic and optical measurements, useful to obtain both geological geomorphological interpretations useful to formulate hypotheses on the functionality of submerged archaeological structures.

6.1. Geomorphological Interpretations

As shown in the geological map (Figure 1), the sea bottom of the study area is characterized by the outcrops of the OVO formation in the NW sector and the NYT in the SE sector [12]. Morphologically, the underwater area can be divided in three sectors, by interpreting the results of the slope analysis on the high-resolution seafloor DTM (Figure 7).

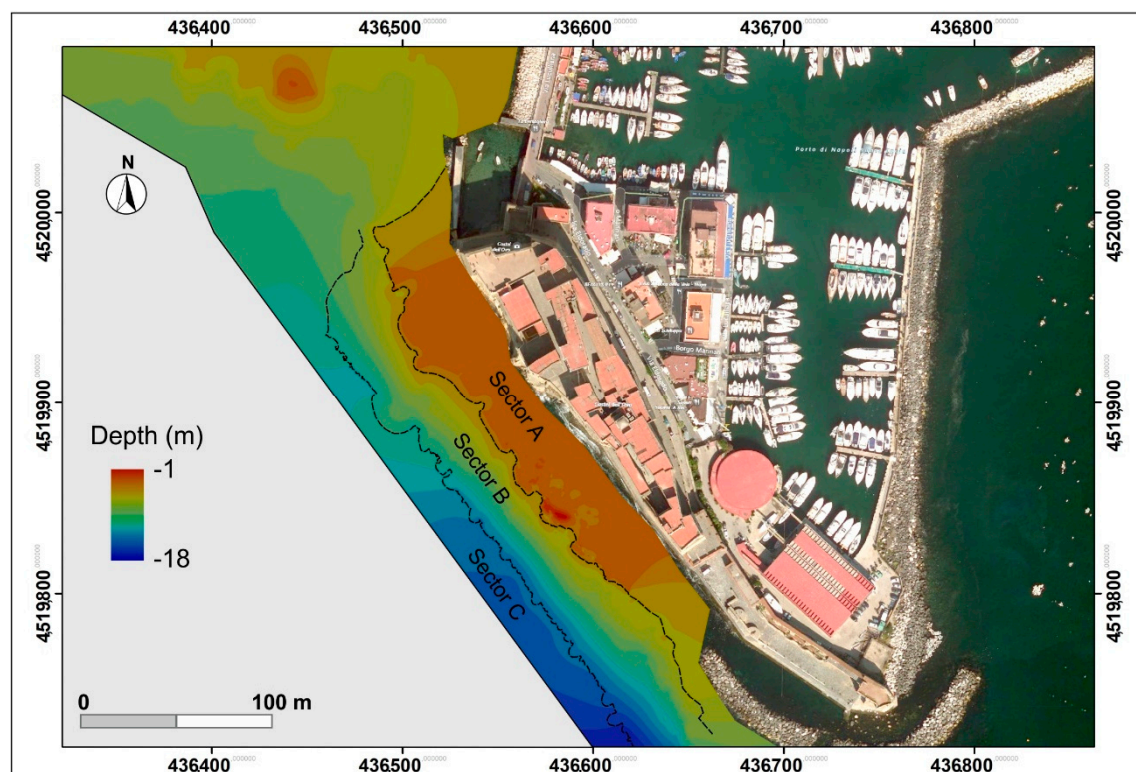


Figure 7. Bathymetric map of the study area.

A gentle sector (A—slope $<5\%$) with a bathymetric range between -2.8 and -3.2 m borders the *Megaritis* islet along the SW limit and extends 40–45 m seaward. On the outer margin of this submerged area, a complex structure sculpted in tuff emerges from the bottom up to -1 m of depth.

A steep slope sector (B—slope $>10\%$) that rapidly reaches -14 m mean sea level (herein after MSL), divides the previous sectors from the third sector gently sloping (sector C).

By overlaying the slope analysis with the underwater survey (see Section 4) carried out by the Centro Studi Subacquei, the remains of walls in *opus reticulatum* are located in the steeper slope sector. This result endorses the hypothesis that this remains slipped down to a depth of -12 m moving along the steep slope under the effects of the sea storms over time.

The analysis of the SSS data allowed a morphological characterization of the seafloor discriminating the archaeological targets from the natural landforms. By analyzing the backscattering signal, the seafloor sectors mainly characterized by outcropping tuff and the complex structure sculpted on it were precisely mapped (Figure 8).



Figure 8. Map of the SSS mosaic with geological interpretations.

In particular, the sectors A and B of Figure 7 were mainly characterized by a high reflective acoustic signature associated with a tufa surface (140 value in greyscale, Figure 9). Large areas of this tufa surface present erosive traces with an acoustic response between 45 and 60 in greyscale (Figure 9). In this area, the OVO and NYT facies outcrops.

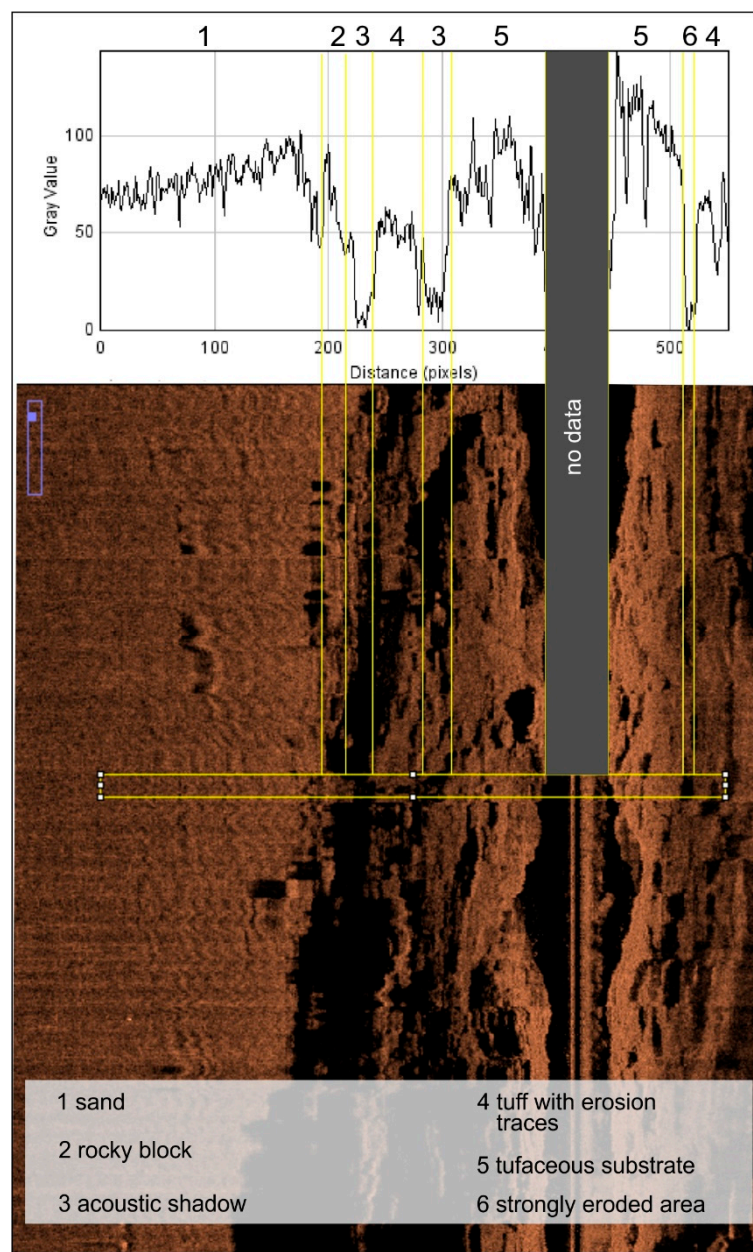


Figure 9. Backscattering signal analysis of a sweep passing through the tufaceous and sandy bottom with the amplitude of the acoustic signal (Y-axis) expressed in greyscale.

Instead, the sector C resulted mainly characterized by a low reflective response associated with a sediment coverage (95 value in greyscale, Figure 9).

By overlaying the slope calculation on the seafloor DTM (obtained by interpolating the bathymetric data) and the backscattering analysis of SSS data, the geological and geomorphological map of the underwater coastal sector here studied was obtained (Figure 10). Finally, the study area is mainly characterized by an abrasion platform in tuff laying at a depth between -3 and -4 m MSL, divided from a depositional surface by a scarp in tuff with a slope higher than 10%.

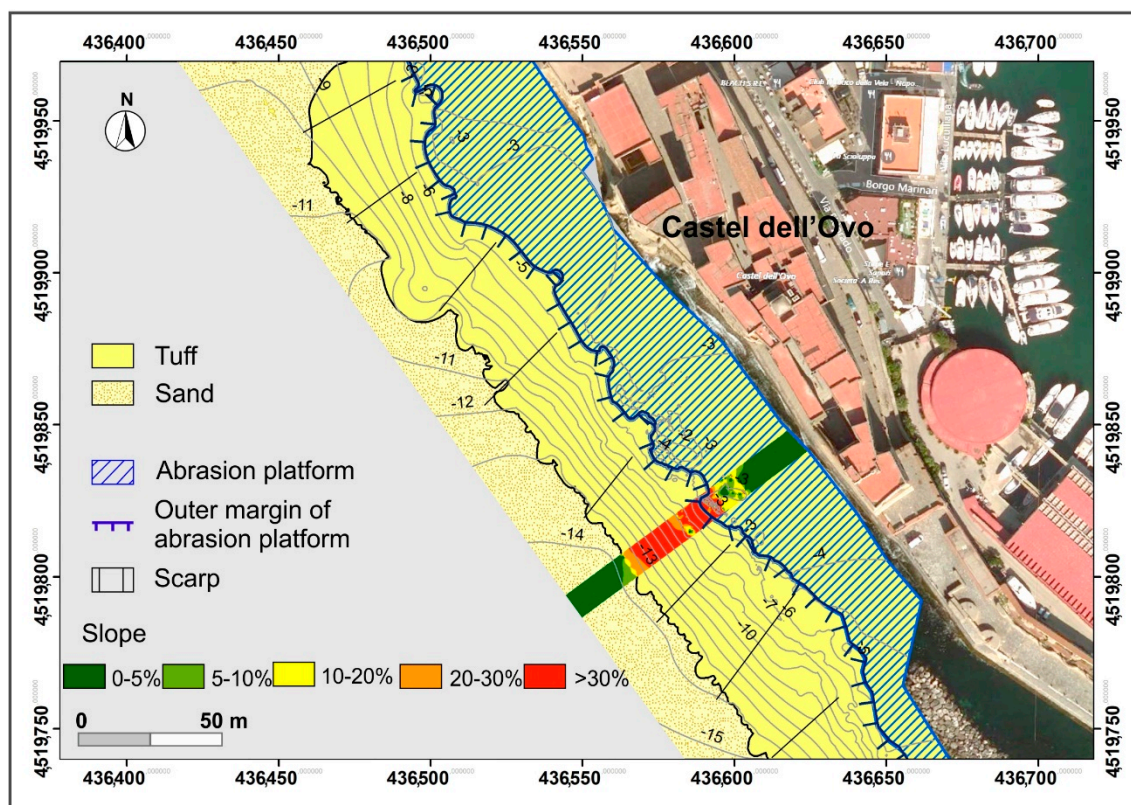


Figure 10. Geological and geomorphological map of the study area.

6.2. Geoarchaeological Interpretations

The MicroVeGA survey provided a georeferenced and synchronized dataset of optical and acoustic data. The overlap between the small-scale mapping of the morpho-acoustic elaborations and the large-scale photographic survey led to obtaining the archaeological interpretation of the complex structure sculpted in tuff extending along the outer margin of the sub-horizontal platform at -3.2 m. The measurement of acoustic shadow well identified on the NE side of the structure (Figure 11) allows evaluating the elevation of structure from the bottom that ranges between 1.5 and 2.5 m.

This structure has an NW-SE extension of 100 m (Figure 11) and is 1–3 m wide, but only the better-preserved part (58 m long) is visible from aerial photos. The top surface strongly eroded by the wave's action has a submersion ranging between -0.85 m and -1.9 m·MSL.

Three channels with a rather squared vault cross the structure in the NE-SW direction. The submersion of the channel tops ranges between -2.2 and -2.5 m·MSL (Table 2, Figures 12 and 13).

In the SSS mosaic, traces of two other channels with the collapsed vault were also identified.

The base of the three channel (Figures 12 and 13) slopes seaward ending on the outer border of the sub-horizontal tufaceous platform (Sector A in Figure 7) on which the structure was built. In addition, along their vertical sides, an alignment of holes with a diameter of 0.3 m was detected. These shapes probably represent the points where iron or wooden grating was inserted. Finally, on the top surfaces several traces of circular holes with a perimeter of 0.6 m were located (Figure 12c). The holes can be interpreted as the traces of the oaken stakes that supported the emerged structures resting on the tuff wall.

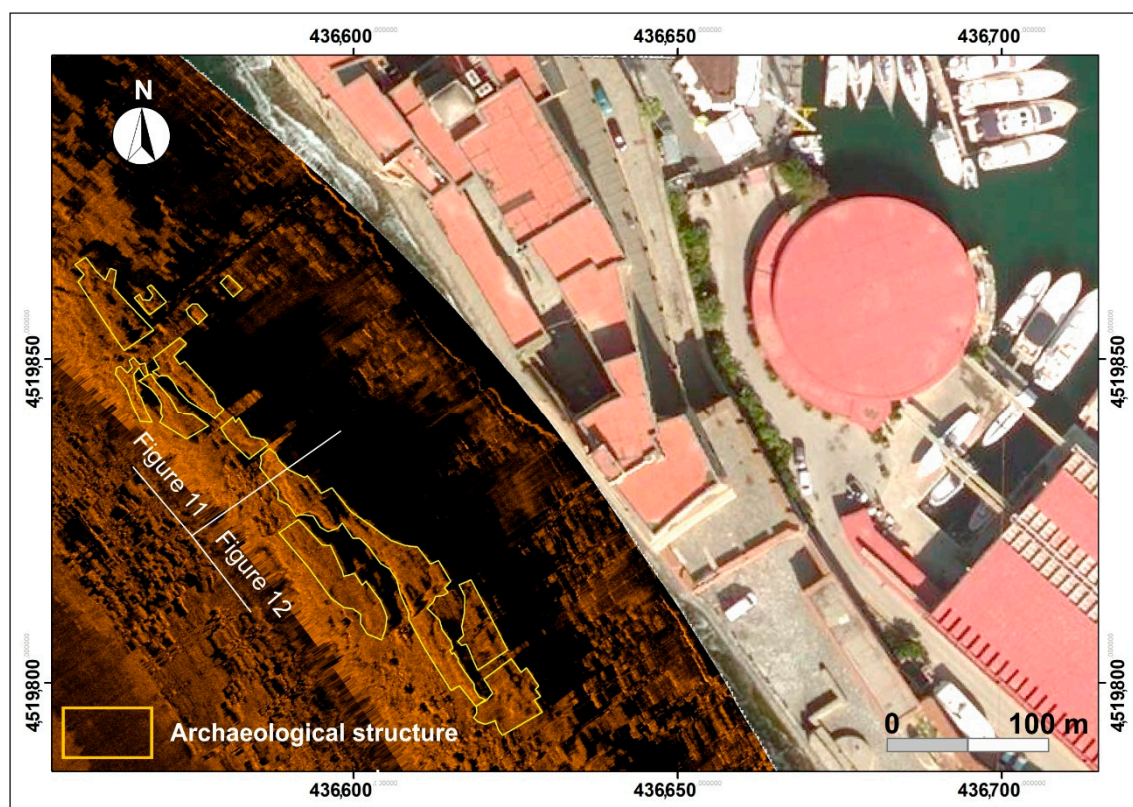
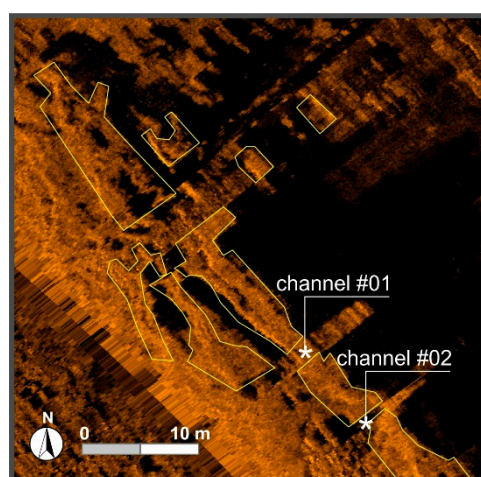


Figure 11. Map of the SSS mosaic archaeological interpretations.

Table 2. Channel dimensions from direct measurements.

Channel ID	Width (m)	Height (m)	Top Submersion (m)
#01	1.0	0.8	2.5
#02	0.8	1.3	2.2
#03	1.0	0.8	2.4



(a)



(b)

Figure 12. Cont.

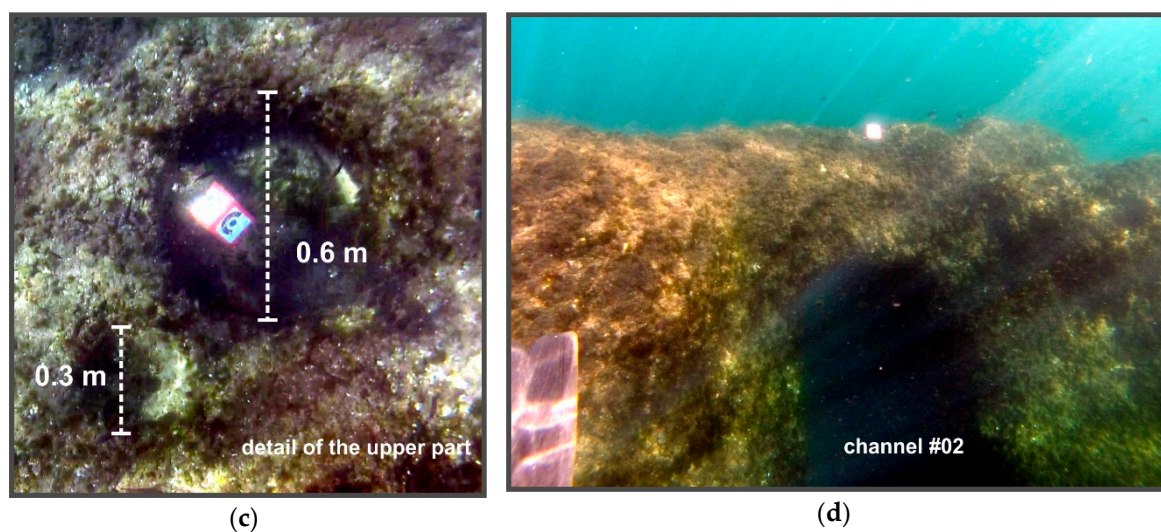


Figure 12. (a) NW zoomed sector of the map of the SSS mosaic; (b) underwater photo of channel #01; (c) underwater photo of circular holes located on the top of the archaeological structure; (d) underwater photo of channel #02.

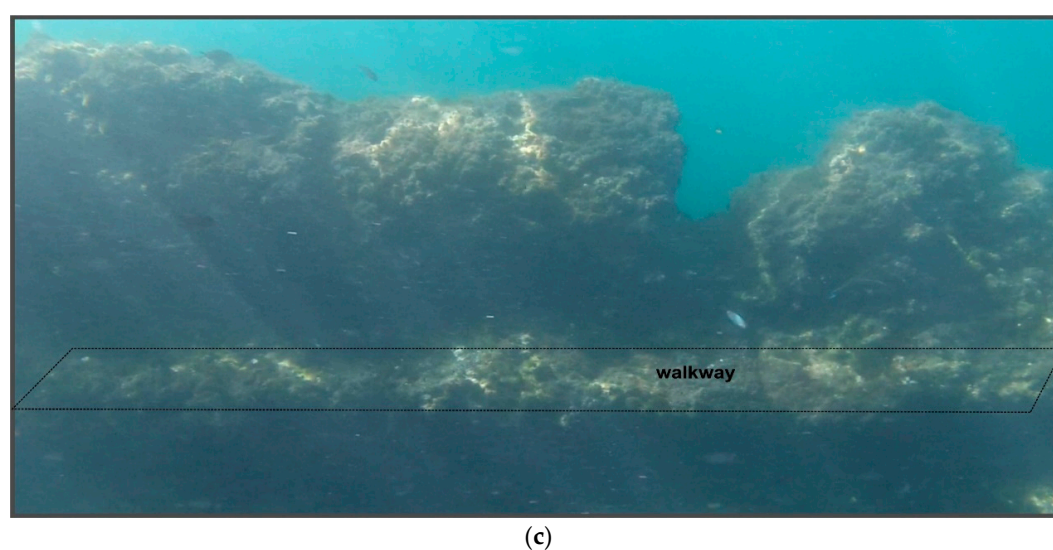
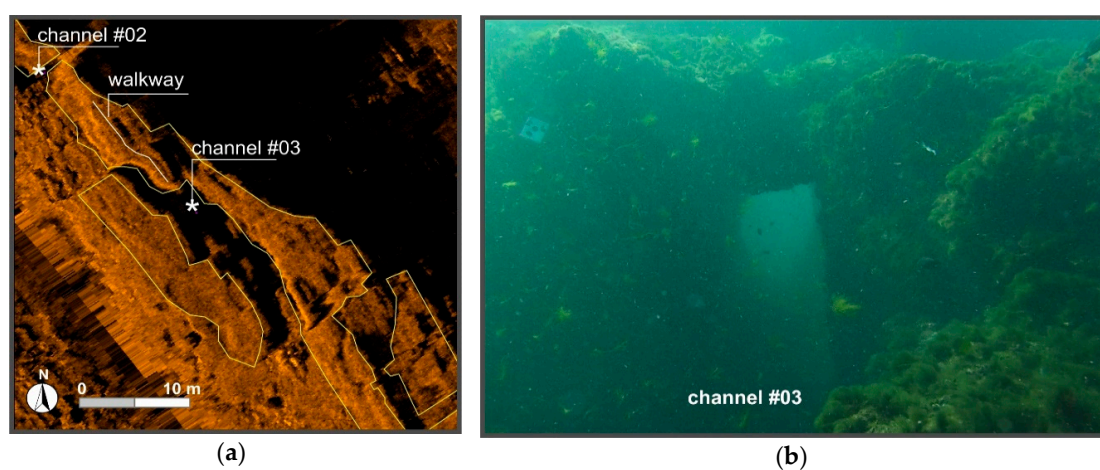


Figure 13. (a) SE zoomed sector of the map of the SSS mosaic; (b) underwater photo of channel #03; (c) underwater photo of the walkway between channel #02 and #03.

As shown in Figures 13–15, a well-preserved walkway extends between channels #02 and #03, about 0.45 m wide. Close to the third channel, the structure is divided into two parts in the length direction (NW-SE) from a deep channel that reaches 4.2 m in depth (Figure 13a).

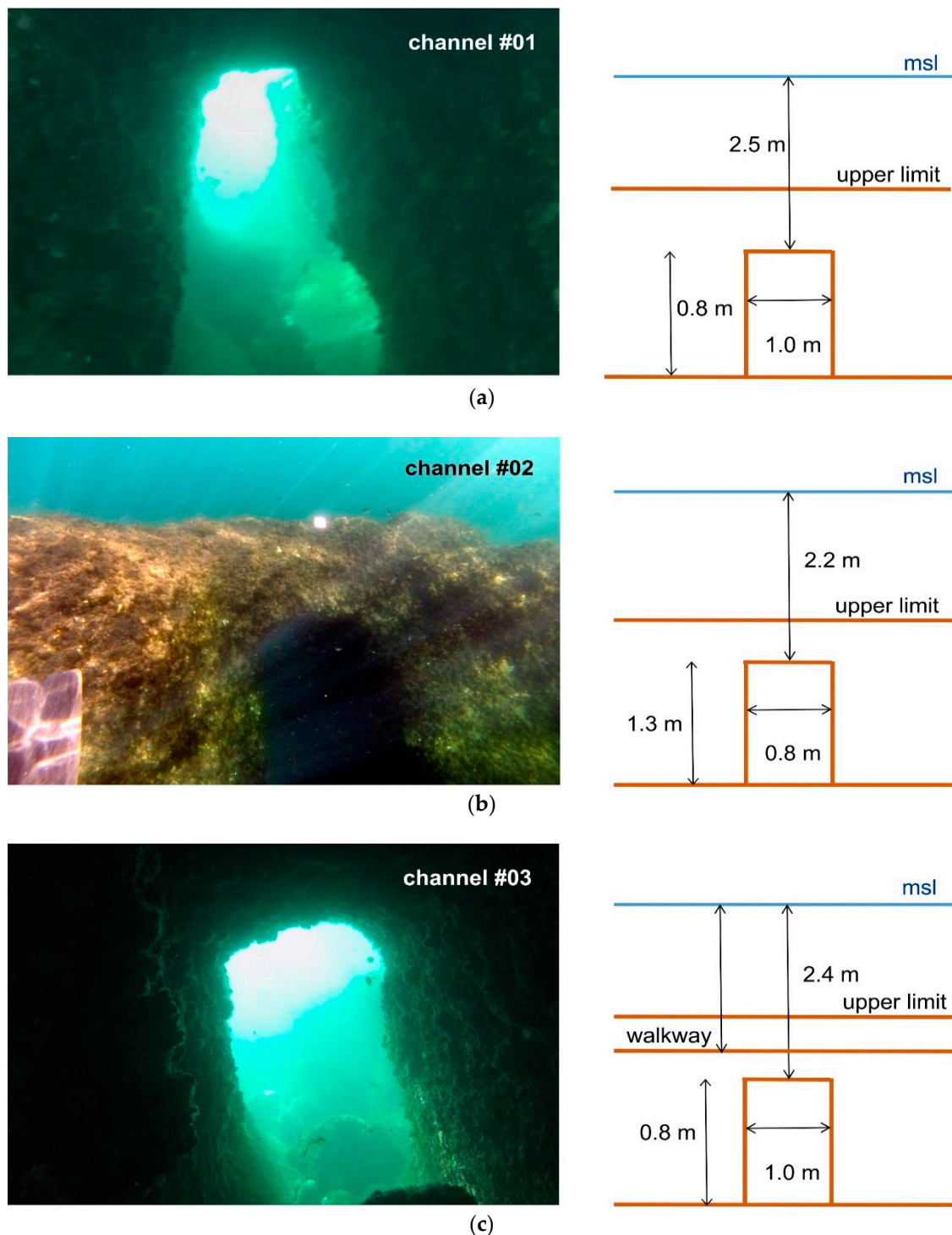


Figure 14. Measurements of the channel dimensions and submersion: (a) channel #01; (b) channel #02; (c) channel #03.

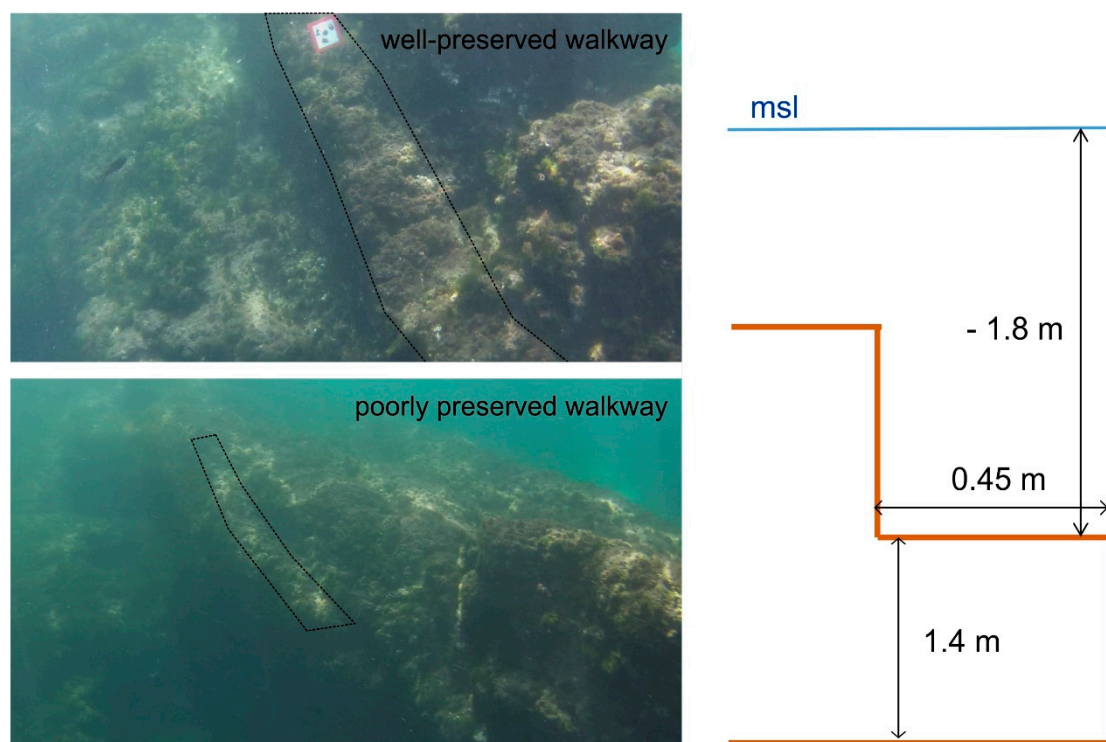


Figure 15. Measurements of the walkway.

The dimensions of each channel are described in Table 2 and in Figure 14.

7. Discussion

The main results of the integrated analysis of geological, geomorphological and archaeological data were combined with the high-resolution seafloor DTM in order to reconstruct the emerged-submerged landscape (Figure 16a) around *Megaritis* islet as well as to obtain the detailed three-dimensional reconstruction of the submerged archaeological structure (Figure 16a) studied here.

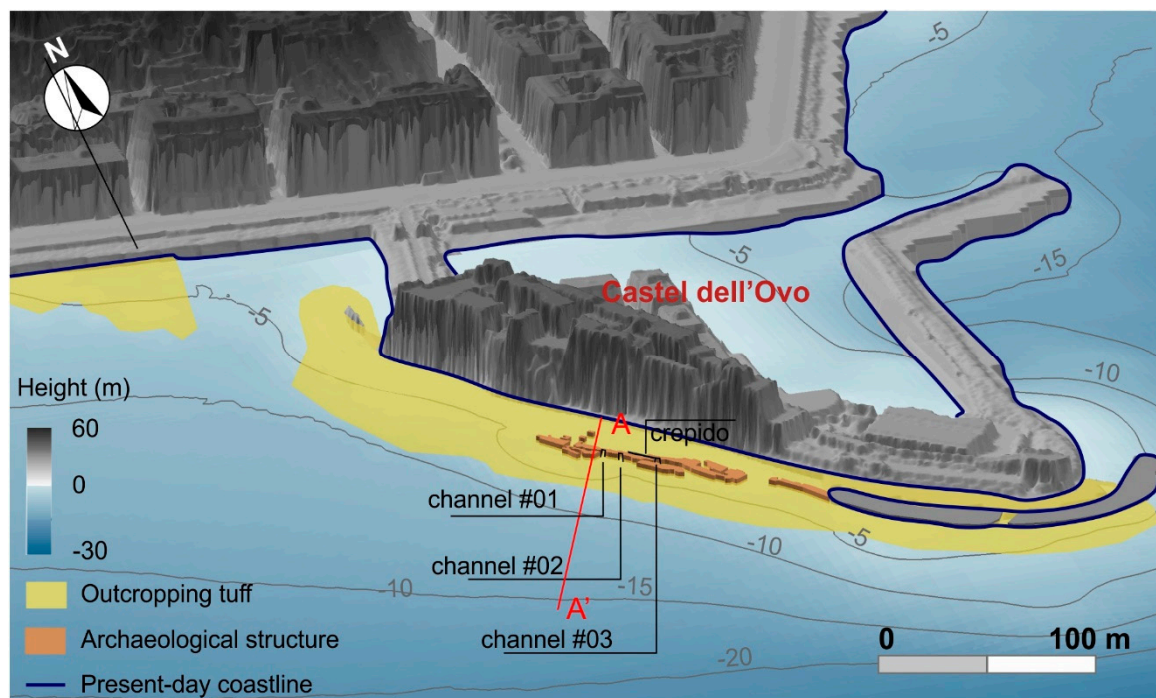
The morphometric analysis of the submerged archaeological structure—overlaid with the previous knowledge deriving from the other research—allowed to define the functionality of all elements detected and measured during the direct surveys, deducing the relationship between the archaeological structures and the ancient sea level (Figure 16b).

In particular, the submerged coast surrounding *Megaritis* islet in the western sector is characterized by a wide gently inclined tufaceous platform (about 100 m wide), on which a 100 m NW-SE elongated archaeological structure lies. About the genesis of this platform, we hypothesize that it is a former abrasion platform modelled in a second time by Romans. Indeed, part of the submerged archaeological structure is sculptured in tuff.

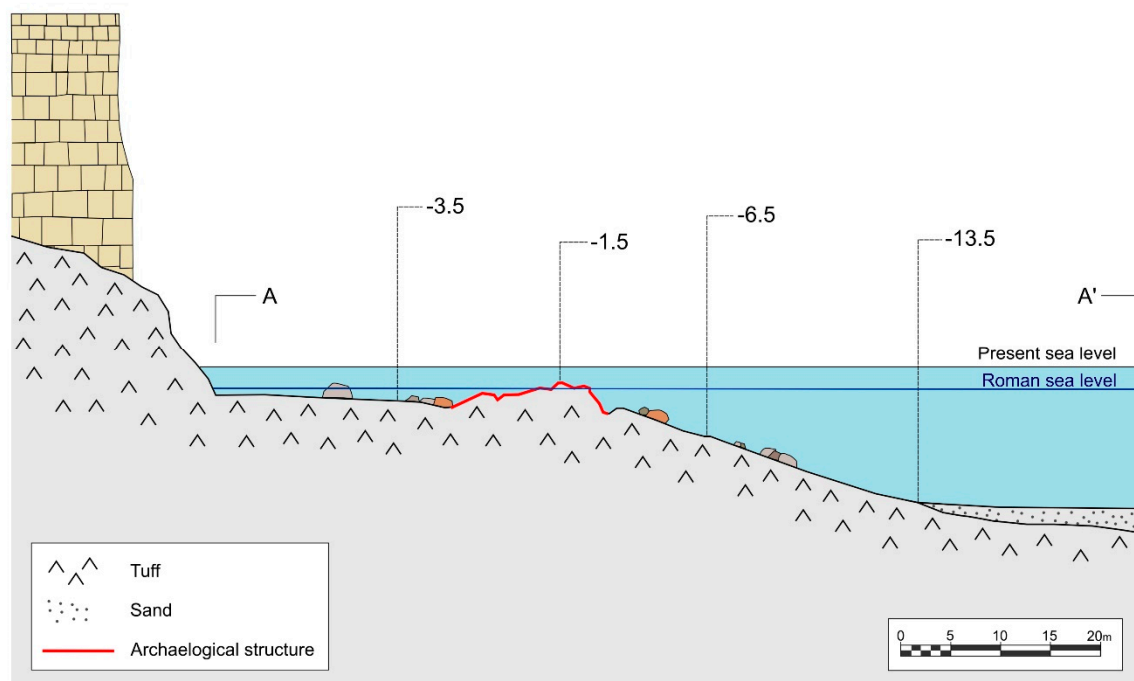
The resulting shape of the structure is very complex probably due to the erosive effects of the waves action in the last millennia (see Figure 16a). Nevertheless, it basically looks like an elongated perimeter wall crossed by three channels of square and regular shape, as described in Section 6.2.

The dimensions of the channels—too low to be crossed by a standing man—can be interpreted as the proof that this structure was built in an underwater environment and dug with canals to allow seawater to drain off (Figure 16a).

Another piece of evidence that these channels were used as drainage channels is the presence of several alignments of holes on the vertical sides that can be interpreted as points where iron or wooden grating was inserted.



(a)



(b)

Figure 16. 3D reconstruction of the (a) emerged submerged landscape and with archaeological structure studied here. The DSM in Figure (with a grid 1×1 m) was provided by the Municipality of Naples. (b) Onshore-offshore schematic profile crossing the main archaeological structure sculptured in tuff, for position see (a) of this figure.

We can hypothesize that this perimeter wall bordered an internal basin that could possibly be interpreted as a *vivarium*—a fish tank, as the remains of sluice gates, namely the channels here measured, testify. Another evidence is the walkway detected between the channels #02 and #03, very similar

to the *crepidines* that typically bordered the fish tanks, and that probably had the task of facilitating walking around to the workers.

Roman fishponds and fish tanks are nowadays represented by a very large number of examples in the Mediterranean Sea, with a concentration on the Tyrrhenian coasts of Italy, and especially in the Gulfs of Naples and of Gaeta, in the Regio I—Campania and Latium (for a detailed list, see [35,36]). All of these structures perfectly fit in the categories originally described by the ancient sources, especially Varro and Columella. On flat sandy coasts, fishponds are often realized with the building of walls directly on the shore and in the sea (*piscinae in litore constructae*); on rocky coasts, they are carved in the promontories, realizing artificial basins and caves, with a notable depth (*piscinae ex petra excisae*). Obviously, there are hybrid examples, always taking advantage of the landscape. Even if the variation of shapes and results can be notable, all Roman fishponds and fish tanks need to respect a series of building principles, again described by the ancient authors, in order to permit the surviving of fishes, taking a strong control of the water temperature, salinity and oxygenation parameters, above all.

The fish tank of *Megaritis* islet, even if in a very bad conservation state, due to the action of waves and to the long series of human activities in the area, could fit in the group of the *piscinae in petra excisae*. It is a very common type on the Neapolitan and Campanian coasts, and also on the Pontine islands, because of the abundance of tuff cliffs and platforms. The yellow tuff, especially, can be worked and carved very easily and offers the opportunity of a quick and not problematic construction as testified by the great number of artificial caves (not only fishponds but also quarries, *nymphaea* and private or public spaces). At the same time, the softness of the material often causes poor conservation over the course of centuries, especially in the structures that were originally conceived to be at the tidal limit. Year after year, the continuous action of waves and the sea level change erodes the ancient constructions, softens the angles and brings back the tuff to a natural shape, erasing the human intervention. The cave fish tank of Pausilypon, Misenum (Capo Miseno-Punta Terone), Pandateria (Ventotene), Pontia (Ponza, Grotte di Pilato) and the rock-cut fishponds of Torregaveta (villa maritima belonging to Servilius Vatia) can give us a good idea of how strong marine erosion on a tuff-cut ancient construction can be. There is no wonder if our best examples of rock-cut fishpond can be found where volcanic tuff is absent, substituted by limestone or sandstone coasts: Sant'Irene, in Calabria, Pietralacroce in the Hadriatic region of Marche [20] or El Campello [37] and Calpe [38], near Alicante in Spain.

The channels, for the circulation of water, and the *crepido* along a part of the perimeter, are, at this stage, the only archaeological evidence supporting the interpretation of the structure as a *vivarium*. According to this assumption, we can use this last functional element as a sea level marker, taking into account that it was built to always stay at a small elevation above the sea level in every tidal condition, and in particular, according to [39], 0.20 m above the high tide. Therefore, considering that the well-preserved *crepido* is positioned at -1.8 m MSL, we can suppose a relative sea level during the period of use at $-2.2 \text{ m} \pm 0.2 \text{ m}$ MSL. It is a meaningful datum because it allows us to date the fish tank to the 1st century BC: a chronological phase perfectly coinciding with the *reticulatum* walls found underwater, and with the archaeological and historical sources related with a big Late Republican maritime villa on the islet of *Megaritis*.

8. Concluding Remarks

By interpreting geological, geomorphological and archaeological data surveyed in the underwater sector of Castel dell'Ovo, a three dimensional model of anthropic interventions on the natural landscape were precisely reconstructed. The indirect survey provided an extensive high definition mapping and a morphometric analysis of natural and anthropic shapes. In addition, the direct surveys allowed detecting several traces that correlate the archaeological structure with a 1st century BC fish tank. Although, it cannot be excluded that this structure has been used with other functions over time.

However, certainly, the well-preserved *crepido* between the channels #02 and #03 led to suppose a relative sea level during this period at $-2.2 \text{ m} \pm 0.2 \text{ m}$ MSL. This deduction is in agreement with the previous geoarchaeological studies realized in the near sectors of Chiaia and Municipio coastal plains.

In particular, our results perfectly match with the lower limits of the RSL deduced by Liuzza (2014), by analyzing the *Lithodomus* holes on a Roman quay (1st century BC—5th century AD) between −2.5 and −1.6 m MSL (Figure 17).

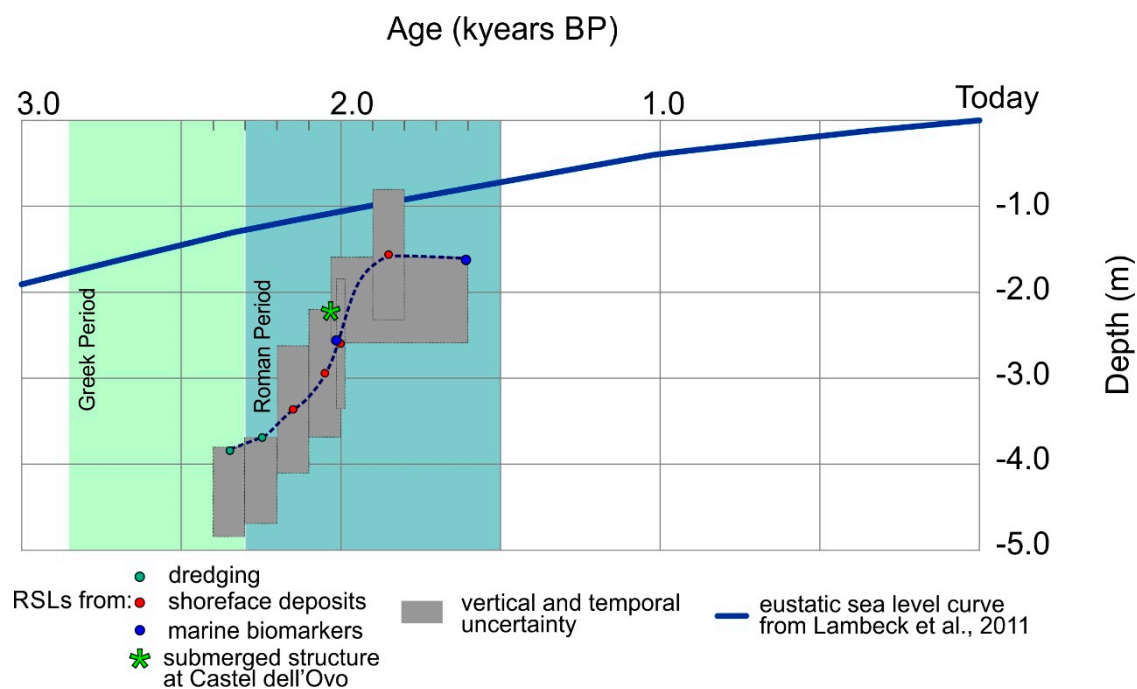


Figure 17. Chart of the relative sea level (RSL) variation in the near sector of Neapolis harbor and the RSL deduced by the fish tank related to the maritime villa at Castel dell'Ovo.

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