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Underwater Paleotopographic and Geoarchaeological Investigations at Le Castella (Crotone, Italy): New Data on the Late Holocene Coastline Changes and the Presence of Two Disappeared Islets

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Abstract: A submerged elevation located off the coast of Le Castella, a small village on the Ionian Coast of Calabria (Italy) populated for thousands of years that features notable archaeological remains from the Great Greece (*Magna Graecia*) and the Middle Ages, was investigated through in-depth, multidisciplinary, geoarchaeological research. This submarine elevation, once aligned with the marine terrace MIS 3 of Le Castella and still completely emerged between 10 and 8 ka years ago, slowly sank due to erosion and local tectonic-structural subsidence and was also favoured by a submerged normal fault that cuts the terrace in two. The dismantling and sinking of this part of the marine terrace has significantly changed the Late Holocene shorelines, with notable consequences on a topographic and archaeological level. In fact, one of the consequences of the sinking of this ancient promontory was the disappearance of two small islands that were reported to be right in front of Le Castella by numerous historical and cartographic sources. In the last decades, there has been a scientific debate over the existence of these islets, but no convincing evidence has been found about their actual presence up until now. This research, funded by the Marine Protected Area "Capo Rizzuto", was conducted by means of underwater archaeological and geological surveys, geophysical seabed mapping systems, and both direct and instrumental optical surveys made with an Autonomous Surface Vehicle. The outcomes allow us to confirm the presence of these two partially emerged rock bodies up to half a millennium ago. In addition, the presence of anthropogenic extrabasinal materials in a marine area corresponding to one of the highest points of the submerged elevation allows us to define the exact position of one of the two islets. These archaeological findings have been subject, for the first time ever, to a thorough topographical and architectural analysis, then compared with other near and very similar submerged structures. On the basis of these comparisons, the findings should be attributed to the Byzantine Age or, at most, to the Middle Ages. In-depth archival research on portolan charts and navigation maps, in many cases unpublished and dating from the Middle Ages to the early 18th century, supports the results of our marine investigations from a historical point of view.

Keywords: marine geology; maritime and underwater archaeology; coastal geoarchaeology; Late Holocene; coastline erosion; marine geophysical investigations; coastline change; underwater acoustics; underwater 3D surveying; Calabria; Ionian Sea; Marine Protected Area of Capo Rizzuto

1. Introduction

Among the local population of Le Castella, a village in the province of Crotone along the Ionian coast of Calabria, in the Marine Protected Area of "Capo Rizzuto" (Southern Italy), there is a deep-rooted traditional account about some fortified islets located off the actual coast. However, today, there is no emerged trace of the islets in question [1]. The presence of archaeological sites swallowed up by the sea in front of the fortress is confirmed by accounts from the locals. They point out that "at just one kilometre or little more from Le Castella, on calm sea days, there are some remains and traces of masonry buildings nearby a shoal, which could prove that the submerged formation was an island rather than a reef" ([1] p. 60), [2–5]. All this has even contributed to the spreading of the idea that the toponym "Le Castella", already mentioned in this plural form since the Middle Ages, should refer to "the presence, in an unspecified age, of several fortified islands". This theory would be based, in fact, on the "localisation of vast underwater shoals, on shallow waters, with very evident traces of masonry works, approximately half a mile SSW of today's village" ([2] p. 89), [4].

In 1994, following a report made by a diver, the Archaeological Superintendency of Calabria, along with some archaeologists from Cooperativa Aquarius, carried out a brief exploration in the stretch of sea in front of Le Castella at a depth of approximately 7 m. The results were limited to assessing the presence of "a rubble-work made up of whitish rocks [. . .] with a sinuous shape [. . .] broken up into groups of boulders, either contiguous or shortly isolated among each other. . . which did not show any traces of lime or mortar between the rocks" ([6] pp. 12,13), [5,7,8]. Based on this submerged evidence, some scholars, while studying the subsidence in the area of Crotone, have developed the hypothesis that the site in question could coincide with an islet swallowed up by the waves [8–12]. Since then, there have been no significant advances in research. The actual extrabasinal nature of such evidence has never been clarified, nor have surveys aimed at defining its topography from a historical-archaeological perspective been conducted.

While a number of works published in the last twenty years demonstrated the scientific importance—in geological terms—of the inshore and offshore area of Le Castella (see chapter Geological Setting), its archaeological importance is notable as well. In fact, the islet was attended in the Neolithic era [5,13], occupied in the Bronze Age [14–16] and hosted a monumental archaeological site during the 4th century BC, with a *phrourion* (fortress) which controlled the southern sector of the *polis* of *Kroton* [5,17]. In Roman times, the site of Le Castella hosted a *statio* along the Ionian coastal road that connected Taranto with Reggio Calabria [18]. The waystation was known as *Castra Hannibalis* [5,16] due to the encampments that the Carthaginian leader set up there between 205 and 203 BC. (Liv. XXVIII, 46, 16). In Le Castella—still populated in the Byzantine era and fortified as early as the 12th century—Andrea Carafa built a castle at the beginning of the 16th century, which still proudly stands on the small island [2,4,19,20] (Figure 1).

Figure 1. The fortress of Le Castella as seen by a drone (from *Sail in History—Magna Grecia Cruise*, 2019, MAGNA Project brochure; photo by F. Mauri).

This work is the result of well-structured interdisciplinary research involving geologists, archaeologists, biologists, engineers, and technicians specialising in marine geophysical systems. It aims to present the preliminary results of a number of underwater geo-archaeological explorations. With the data obtained from these investigations, duly cross-referenced with the historical-literary documentation, it has been possible to propose an initial paleotopographic contextualisation of the coastal and marine area of Le Castella in the Late Holocene age, with particular attention to the *vexata quaestio* concerning the alleged existence and disappearance of two small islands not far from the coast.

2. Geological Setting

Complex geological processes have shaped the sedimentary infill of the Crotone basin (Figure 2a), a segment of the Ionian forearc basin within the Calabrian accretionary wedge [21–23], over time. It formed within the broader framework of the rollback-subduction mechanism and the south-eastward migration of the Calabrian arc [24–26], coinciding with the opening of the Tyrrhenian Sea from the Serravallian/Tortonian stages onwards. The geological history of this basin, as evidenced by several works [22,23,27], reveals a dynamic interplay of extensional to transtensional tectonic forces, periodically punctuated by compressional to transpressional phases [28–30]. The tectonic-stratigraphic sequences within the basin reflect these changing stress regimes and deformation patterns exerted on the sedimentary fill.

The Crotone basin is geologically limited by two left-lateral shear zones, named the Rossano-San Nicola (RSSZ) and Petilia-Sosti (PSSZ) shear zones (Figure 2b). It shows a fascinating geological sequence, beginning with Pliocene marine clays, as documented by Roda [31], and overlain by Pleistocene marine limestone formations [32]. These limestone deposits give rise to a series of at least five marine terraces, as identified by Palmentola et al. [33]. The formation of these terraces is linked to the fluctuating eustatic sea levels during the Late Pleistocene interglacial and glacial phases. Subsequently, the tectonic activity within the Calabrian-Peloritan arc uplifted these terraces [29,34–36]. The limestones are constituted by a rich array of shallow-water temperate biogenic carbonates, bioclastic limestone, and fossil algal reefs (=Coralligenous), complemented by the occurrence of fossil rhodolith beds [37–40], which are still witnessed in rhodolite beds with live thalli surveyed as part of the Regional Marine Strategy Centre (CRSM) of the Regional Agency for Environmental Protection (ARPA Calabria) "Marine Strategy" activities (Operational Plan of Activities 2022–2024). Recently, Minelli et al. [41] also described a gravitational sliding of the basin toward the SE that probably started in the Pliocene and is caused by the presence of a deeper Messinian evaporitic layer. The effect of the sliding is indeed complex. Velocities towards the E vary in the order of 4–5 mm/yr for the area between the mouth of the River Neto and Capo Colonna and part of the Tacina River valley only. In all other areas, there is an uneven distribution of values of horizontal displacement (generally less than 1–2 mm/yr), both positive (toward the E) and negative (toward the W) [41]. The vertical movements are complex and have a rather irregular pattern.

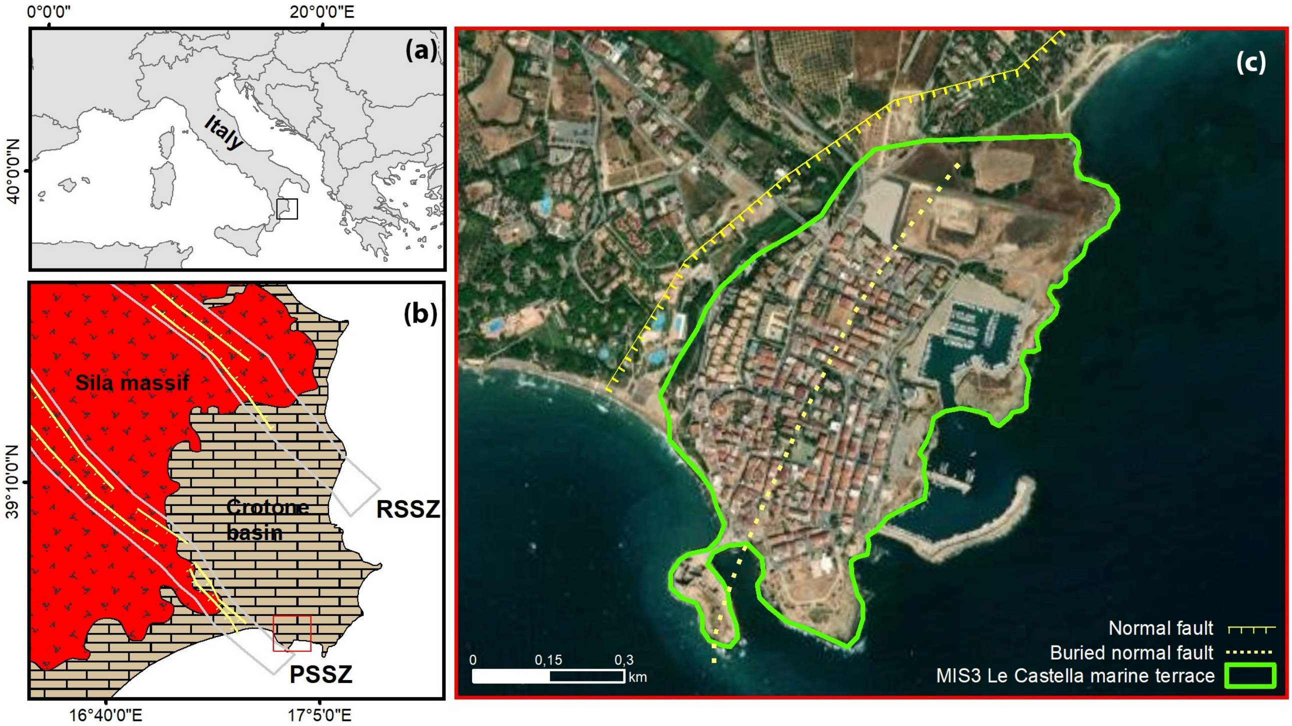

Figure 2. The Geographical and geological setting of the studied area. (**a**) A simplified geographical setting with the indication of the studied area indicated with the black box. (**b**) A simplified geological map of the study area, with the indication of the Sila Massif, mainly composed of Paleozoic intrusive and low- to high-metamorphic rocks and the sedimentary Crotone Basin. The position of the two main left-lateral shear zones (the Rossano-San Nicola as RSSZ and the Petilia Sosti as PSSZ) affecting this area and limiting the Crotone basin is also reported. The red box indicates the study site. (**c**) The study site with the indication of the Marine Isotope Stage 3 marine terrace (green line), the proximal margin marked by a normal fault, and the inferred buried normal fault (dotted yellow line).

In Le Castella village, the terrains correspond to the marine terrace formed during the Marine Isotope Stage 3, dated between 40 and 60 thousand years ago [42,43] (Figure 2c). Its internal margin corresponds to a normal fault (Figure 2c). Its origin derives from a rapid marine transgression, and it is the youngest and least extensive [44,45]. Lithologically, it is formed by bioclastic shoreface calcarenites. Next to the Aragonese castle, as in other areas along the Le Castella coast, marine terrace deposits are dominated by fossil Coralligenous bioconstructions, locally with abundant colonies of *Cladocora caespitosa* [40], topped by calcarenite. The complex stratigraphic architecture of these terraced deposits is represented by the presence of a seaward-oriented stratification, about 10 m high, generated during the marine regression phase [44,45]. The prograding body of this terrace, represented by a small promontory called "Punta Cannone", is made up of a sedimentary spit directed towards

ESE and formed by bioclastic sands, with an evident clinoform conformation [44,45]), possibly related also to the inferred buried normal fault (Figure 2c).

Geophysical surveys carried out in the area immediately surrounding the castle revealed the presence of a calcarenitic slab with an extension up to 8 m below the sea level [16]. The presence of this formation, which lies like a kind of "raft" into the clayey substrate, can justify the absence of significant structural damage to the castle [16].

In addition, several studies conducted by Ispra (2002–2004) and the Regional Marine Strategy Centre (CRSM) of the Regional Agency for Environmental Protection (ARPA Calabria) (2015–2024) as part of activities conducted under the Marine Strategy Directive have repeatedly shown the actual presence of marine phanerogams, both *Posidonia oceanica* and *Cymodocea nodosa*, within this calcarenitic slab. The former grows on the outcropping part of the calcarenite slab and occupies almost uninterruptedly the entire southern and deeper area, whereas in the shallower part, closer to the village and the castle, it is possible to find its "patch" presence on the rocky blocks, along with encrusting red algae. Among the calcarenite blocks, the Pliocene Cutro clay locally crops out. Elsewhere, a coarse biogenic sediment is observed on the seafloor.

3. Materials and Methods

To reconstruct the geo-morphological evolution and the underwater paleotopography of Le Castella, in the Marine Protected Area of "Capo Rizzuto", the investigations included the following activities:

(a) Wide-ranging research in historical-archival sources;
(b) Geophysical surveys with Multibeam Echosounder (MBES) and Sub-bottom Profiler (SBP);
(c) Direct underwater geological and archaeological surveys;
(d) Macroscopic examination of a number of stone elements for identification of the sourcing area;
(e) Photogrammetric optical surveys using Autonomous Surface Vehicles and 3D underwater surveys.

3.1. Historical-Archival Research

A complex scrutiny of historical and archival sources has been conducted to evaluate testimonies that support and confirm the data collected through geological and archaeological surveys. The sources include both literary works from the Greco-Roman age and a series of portolan charts and nautical charts dating from the 12th to the beginning of the 18th century.

3.2. MBES Surveys

To reconstruct the geomorphology and the nature of the seabed, we surveyed the area with a high-resolution Multi-Beam Echosounders (type SONIC, model 2020, produced by R2 Sonic—Austin, TX, USA) mounted on the head of a pole, dropped on one side of the vessel (Cantieri Catarsi Calafuria model 98). The high-accuracy Position and Orientation System used (IMU+GNSS) is the Trimble Applanix POS MV (produced by Applanix, Richmond Hill, ON, Canada). The backscatter was acquired by snippets technology.

3.3. SBP Surveys

To reconstruct the Holocene sediment stratigraphy in terms of thickness and geometry, we surveyed the area by using a high-resolution Sub-Bottom Profiler specific for operating in shallow waters (<100 m) (INNOMAR SES 2000 SBP, produced by Innomar Technologie, Rostock Germany) on board the Calafuria boat (owned by ARPA Calabria). The SBP tracks were acquired both parallel and perpendicular to the coastline (Figures 3 and 4).

Figure 3. The boat ARPACAL (Regional Agency for Environmental Protection—Calabria) used to carry out the SBP surveys. The arrow indicates the instrument's "pole" arrangement on the side. Some curious dolphins participate in the survey activities (photo by F. Mauri).

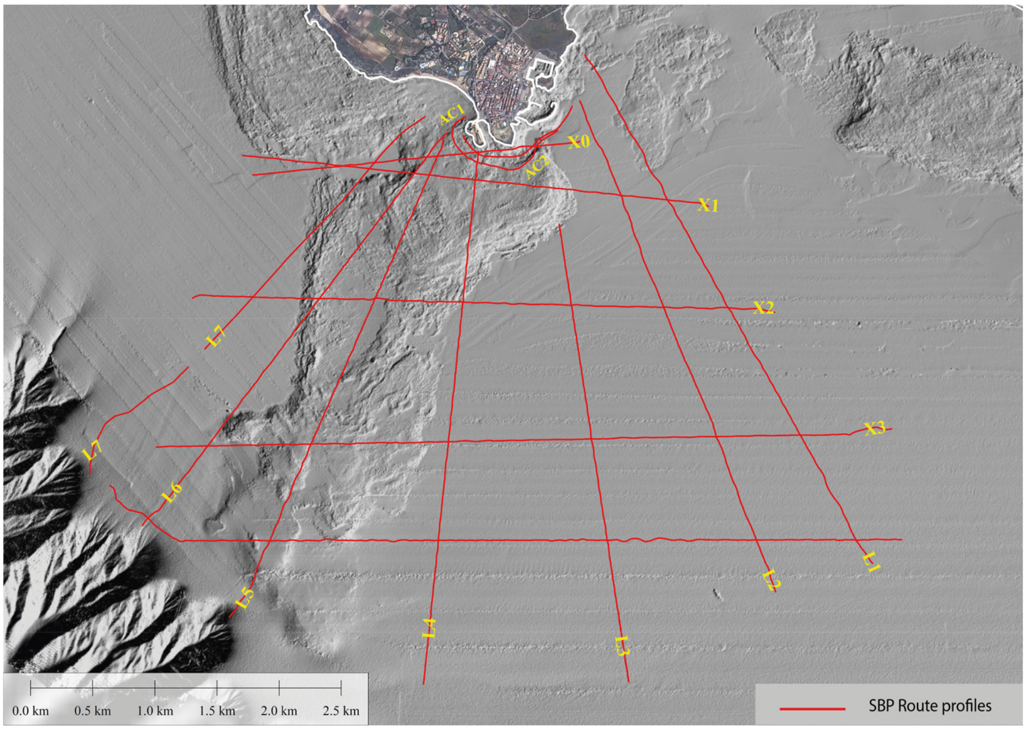

Figure 4. The SBP Route profiles viewed on a DTM (Digital Terrain Model) MBES and LiDAR by ISPRA derived from LiDAR scanning on an aerial platform acquired by the PON-MAMPIRA (Monitoring of Marine Protected Areas Affected by Environmental Crimes) project integrated with ISPRA MBES (Multibeam Echo Sounder) surveys.

3.4. Underwater Surveys

The marine area in front of the fortress in Le Castella was the subject of direct underwater surveys conducted in two separate campaigns in August and September 2022. Specifically, the marine sector included two sample areas. The first, smaller sector (A), is located close to the Aragonese fortress, not far from the entrance of the small port. The second, larger sector (B), is located approximately 500 m away from the S-W end of the Aragonese manor (Figure 5).

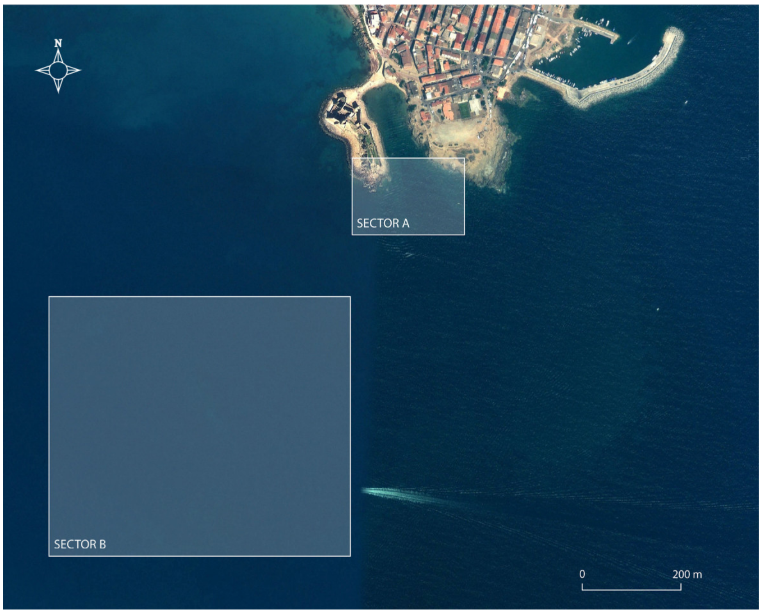

Figure 5. Locations of underwater surveys.

The vertices of these areas were demarcated with marker buoys, and the surveys were conducted by dividing the area into parallel transects. The operators, sometimes using underwater scooters, explored the entire area, orienting themselves on the seabed with a compass. The absolute positioning of the evidence identified during the surveys was conducted with a floating artificial atoll on which a GPS AtlasLinkTM GNSS Smart Antenna was installed, from which a leaded line was moved in synchrony by surface and underwater operators (Figures 6 and 7).

Figure 6. Artificial atoll with GPS Atlaslink^{TM} GNSS Smart Antenna.

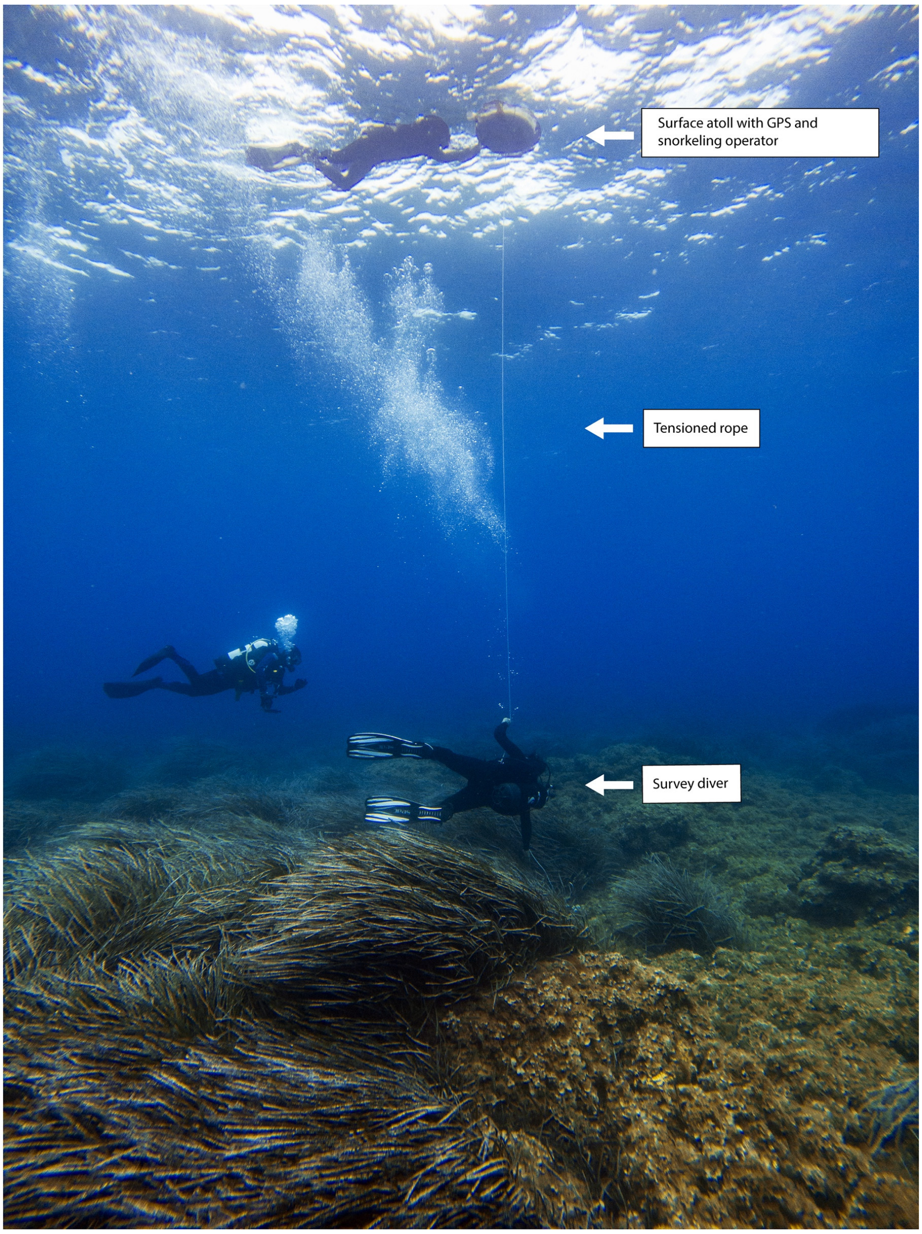

Figure 7. The scuba divers and surface operators while conducting a GPS positioning.

3.5. Geological Examination of Stone Elements

Some stones were carefully examined during scuba diving to be selected for further laboratory analyses and petrographic identification at the University of Milano-Bicocca.

3.6. Optical Survey

A detailed survey of a vast underwater area, combined with the elusive nature of archaeological evidence, presents complex technical and operational challenges. Although multibeam bathymetry offers detailed data, it lacks the resolution necessary to capture specific topographic features of the seafloor, which are critical for archaeological investigations. To address this limitation, an orthomosaic of the seabed was generated from thousands of images captured with an Autonomous Surface Vehicle (ASV) named DEVSS (DEvelopment Vehicles for Scientific Survey). This approach enabled the rapid documentation of the site during the preliminary stage of the archaeological campaign (Figure 8).

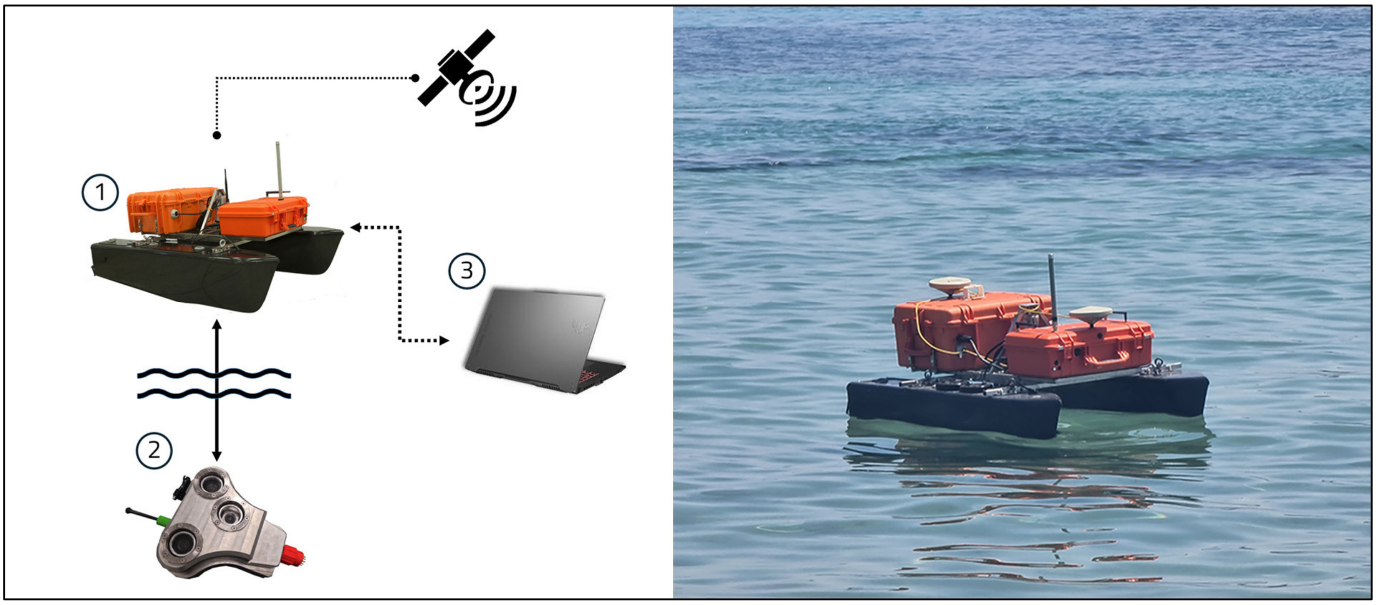

Figure 8. Autonomous Surface Vehicle (ASV) named DEVSS.

DEVSS is a highly adaptable and robust ASV developed by the University of Calabria for scientific investigations in challenging aquatic environments. Measuring 1.15 m by 1.50 m and propelled by two 3.3 kW hydrojet engines, which together provide a thrust of approximately 25 N, the vehicle is capable of reaching cruising speeds of up to 5 knots. Its carbon fibre hull is reinforced with Kevlar and allows the ASV to navigate efficiently in strong sea currents and under demanding environmental conditions.

DEVSS is designed with a modular architecture comprising two key components: the Navigation Unit and the Sensor Unit. The Navigation Unit includes a PixHawk 4 board, which integrates a GNSS receiver, IMU, digital compass, and barometer, ensuring precise and stable navigation. The Sensor Unit is housed in a watertight case that supports a variety of sensor integrations, such as optical cameras, multibeam echosounders, side-scan sonar, multi-parametric probes, and USBL systems, allowing the vehicle to be adapted to different survey tasks.

For this archaeological survey campaign, the ASV was equipped with a photogrammetric system comprising a high-resolution mono camera (21 megapixels) for image acquisition. This camera collects high-resolution data used for offline 3D reconstruction of the seafloor environment. Additionally, a stereo camera system is used for real-time 3D scene reconstruction via a Simultaneous Localization and Mapping (SLAM) algorithm. The stereo camera operates at approximately 15 frames per second (a typical frame rate for commercial off-the-shelf cameras) but produces lower-resolution 3D reconstructions compared to the mono camera, which is optimised for high-fidelity post-processing.

The mono camera was set to automatic white balance mode, which was appropriate given the shallow depth (~5–6 m) of the site and the favourable water clarity that ensured minimal image distortion. Positioned in a downward-facing configuration beneath the vehicle, the camera acquired the images while the ASV followed overlapping survey paths, with a forward overlap of 70–80% and a side overlap of 50%. Real-time mission parameters, including navigation adjustments, were calculated by the onboard software to ensure optimal coverage of the survey area, which measured approximately 7762 square meters.

Following the survey, the dataset was processed to generate an orthomosaic of the surveyed area using a Structure-from-Motion (SfM) methodology. To streamline the processing workflow, GNSS coordinates from the ASV's navigation logs were embedded in the image metadata (EXIF) using a custom Python script, with synchronisation achieved through timestamp matching. Using the pre-aligned camera positions, the commercial software Agisoft Metashape Pro (v. 1.8.2) successfully aligned a dataset of 4200 images, producing an orthomosaic with a ground resolution of 10 mm per pixel.

Within the broader survey area, two sample zones were identified for more detailed investigations. These areas, measuring approximately 25 × 25 m and 39 × 21 m, respectively, were surveyed using 3D optical methods performed by divers. High-resolution data was captured in each area, with a focus on generating accurate 3D reconstructions through photogrammetry.

For image acquisition, divers used a Sony A7II mirrorless camera equipped with a 36 × 24 mm CMOS sensor with a resolution of 6000 × 4000 pixels (24 megapixels). The camera was paired with a Sony Zeiss 16–35 mm f/4 lens set at a focal length of 16 mm, providing the necessary wide-angle field of view for capturing the extensive underwater environment. The camera was housed in an Easydive underwater housing, and a spherical 125 mm diameter port was used to correct diffraction. Given the low depth of the site, no artificial lighting was necessary. The photogrammetric acquisition was carried out following standard aerial survey principles. The camera was positioned primarily in a nadir orientation (downward-looking) but also captured oblique angles to ensure coverage of sub-horizontal features. The camera network was planned to achieve a Ground Sample Distance (GSD) of 0.075 cm/pixel at a depth of 2 m. Given the level of detail required, all images were captured in RAW format, allowing for post-processing adjustments. Image enhancement techniques were applied to correct white balance, mitigate caustic effects, and optimise contrast and sharpness. The Structure-from-Motion (SfM) reconstruction was performed using the commercial software Agisoft Metashape Pro. A local metric coordinate system was established based on a network of Ground Control Points (GCPs) that were defined using a preliminary low-resolution model. A total of 30 GCPs were positioned, and their Euclidean coordinates were determined through a Direct Survey Method algorithm using in situ measurements. A non-linear optimisation process was applied to enhance the accuracy of the 3D model, adjusting both camera poses and internal orientation parameters to minimise error at the GCP locations. Finally, the 3D models of the two areas were generated through a meshing and texturing process. A dataset consisting of approximately 2800 images was processed for the 3D reconstruction, resulting in a dense point cloud of 18,503,704 points and a mesh comprising 4,272,000 polygons for the first area. For the second area, the process yielded a dense point cloud of 114,668,118 points and a mesh with 8,650,000 polygons. These detailed reconstructions provide highly accurate representations of the surveyed areas, essential for further archaeological analysis.

4. Results

4.1. The Islets off the Coast of the Crotone Peninsula According to Historical Sources

4.1.1. A Disappeared Archipelago in Ancient Literary Sources

Two literary sources—one from the Hellenistic age and the other from the early Imperial age—recall the existence of islets, nowadays disappeared, on the Ionian Coast of the Crotone peninsula. It should be noted that none of these ancient geological formations could be located with certainty; however, these data are useful to demonstrate how the coast of central-eastern Calabria, at least in the Late Holocene age, underwent heavy geomorphological changes that affected the coastal perimeter and the adjacent submerged area.

The first of the two pieces of evidence is contained in the Περίπλους τῆς θαλάσσης (*The Circumnavigation of the Inhabited Word*) by Pseudo-Scylax. This is a geographical work that Marcian of Heraclea erroneously attributed to Scylax of Caryanda, the great admiral and traveller to whom Darius I, King of Persia, entrusted the exploration of the banks of the Indus (Herod., IV, 44, 1-2). Today, there is some consensus on the fact that Περίπλους should be attributed to an anonymous compiler from Athens or from the wider Attica region, who composed it between 338 and 335 BC. [46,47]. This is a work of descriptive geography [48], which outlines the coasts of the Mediterranean with its cities, main ports, promontories, rivers, islands, and local populations. The excerpt in question can be found at the end of paragraph 13, in which Pseudo-Scylax describes the coast of today's Ionian

Calabria, from South to North, listing a series of *poleis hellenides* (Ps.-Scyl., 13, 5): "And I return again onto the mainland, from where I turned away. For past Rhegion the cities are as follows: Lokroi, Kaulonia, Kroton; Lakinion, a sanctuary of Hera; and Kalypso's Island, in which Odysseus dwelt beside Kalypso; and the river Krathis, and Sybaris and Thouria, a city. These are the Hellenes in Leukania" ([46] p. 13).

Pseudo-Scylax was not the only one to mention a νῆσος Καλυψοῦς (island of Calypso). In the first century AD, in *Natural History*, Pliny the Elder places—in the same stretch of sea—an entire archipelago made up of five islands. The excerpt in question can be found in a section of Book III, which contains the geographical description of Italy (*NH*, III, 38–138) and, more specifically, of the stretch of coast that corresponds to a sector of today's Ionian Calabria, once named *Magna Graecia* (III, 95-96: "*Magna Graecia appellata*) and known as the "*Frons Italiae*" [49]. Within this stretch of coast, when describing the Gulf of Squillace from South to North (*sinus Scylacius*), Pliny mentions Cape Lacinium and then the five islands (Plin., NH, III, 96): ". . .and the promontory of Lacinium, off the coast of which ten miles out lies the Island of the Son of Zeus and another called Calypso's Island, which is thought to be Homer's island of Ogygia, and also Tyris, Eranusa, and Meloessa". Pliny's information is extremely detailed, even for toponyms, and this has led critics to consider his work—despite the inherent limitations of a very ancient geographic description—reliable on a topographical level [50]. As Pliny himself points out, the information about the Ionian Coast of Bruttium came from Agrippa and Varro [51]. However, it is plausible that the information regarding the islands came from M. Terentius Varro. He was not only the author of lost works of a maritime nature (*Ephemeris navalis*; *De Litoralibus*) from which Pliny may have obtained the description, but he also had a deep knowledge of the stretch of sea in question, as in 67 BC, he was as a legate of Pompey and commander of naval operations against pirates on the coasts of the Ionian Sea, between Sicily and Delos (Varr., *De re rustica*, II *praef*. 6; Floro, I, 41, 10; App., *Mith*. 95) [52,53].

After examining these two sources, two brief remarks should be made. The first is that both sources mention the island of Calypso. This clearly shows that the two authors had a common source of information, which needs to be sought in Pythagorean circles, both in Athens (as in the case of Pseudo-Scylax) and Magna Graecia. This conclusion could be drawn from an excerpt by Iamblichus who in *De vita Pythagorica* recalls how Pythagoras, while speaking to Krotonian women in the temple of Hera at Lacinium (Iambl., *V. Pyth.*, 54), leveraged a tradition that was very popular in Kroton (περὶ τὴς χώριον τῶν Κροτωνιατῶν), i.e., the loyalty of Odysseus who renounced the immortality promised to him by Calypso (Iambl., *V. Pyth.*, 57) ([54] p. 157), ([47] p. 186). The theme of the nymph Calypso and the moral implications deriving from the exemplary conduct of Odysseus was so popular in Kroton that we cannot ever rule out a local myth that identified Ogygia with some small island that emerged along its coast ([50] p. 253).

The second remark regards the valuable information that can be obtained from nesonyms. Those of the Crotonian archipelago depict, on a geographical and historical level, a very ancient phase that dates back to the earliest maritime explorations of the peninsular coasts of South Italy by audacious Greek and Levantine navigators. This explains the name of "Tyris", of probably Phoenician origin, and the toponymic suffixes -ουσσα, which survived the Latin transformation in Pliny's work but are still clearly recognisable in the names "Eranusa" and "Meloessa". These suffixed toponyms dating back to the first millennium, scattered along the Mediterranean coasts colonised by the Greeks, are mostly referring to islands. Some scholars have found "Homeric echoes" as they are mirrored only in epic epithets, with a scarce presence in spoken language or classical prose. For this very reason, they have been variously connected with Rhodian, Chalcidian, Euboean or Phocaean navigations ([55] pp. 70–72 with bibliography and *status quaestionis*).

Even in the mention of the island of Calypso a very ancient paleotopographic trace of the pre-colonial age is recognisable. In fact, it has been observed ([56] p. 23) that, at the time when the Ionian Coast of Calabria appeared to the Euboean sailors as the westernmost point explored up to that time, they placed the remote island of Ogygia there, which, in the Greek imagination, represented a frontier location. As the Greeks traced new routes, the Homeric sites (including the location of the island of the nymph Calypso) moved progressively towards the West ([56] pp. 23,51,86). A final element to consider is the name of the island of *Dioscoron,* mentioned by Pliny. It is certainly no coincidence that in the Greek tradition, and in particular in an excerpt by Diodorus (XIII, 3, 4), the Athenian fleet heading for Sicily in 415 BC, after having passed the sanctuary of Hera at Lacinium and before reaching Scylletium, rounded a promontory called Διοσκουρίας. Beyond the identification of this promontory (for which Capo Rizzuto has been proposed, for example ([57] p. 944); ([58] p. 65); ([59] p. 158); ([60] pp. 63,64), it is of undoubted interest that this toponym indicates a coastal settlement in the area of Crotone that plausibly hosted a sanctuary dedicated to the twins, Castor and Pollux, who were known for being protectors of sailors ([50] pp. 249–251). Once again, this demonstrates the credibility of Pliny, who could have recalled an island, or in any case, a rock body emerging from the waters, located near a promontory dedicated to the memory of the Διόσκουροι.

4.1.2. The Islets of Le Castella in the Portolan Charts

For our investigation, we selected and examined a series of portolan charts, mostly handwritten and often unpublished, dating from the late Middle Ages to the beginning of the 18th century, in which there are explicit mentions of the site of Le Castella. As is known, these navigation guides for sailors are a precious historical, toponymic, and geographical source for reconstructing coastal landscapes of the past [61,62]. We can divide them into three groups according to the provided information:

(a) The portolan charts that mention Le Castella only as a coastal site with limited and scant information, e.g., the distances from some important sites on the Ionian route (usually Capo Colonna and Squillace). Among these include *Lo Compasso de Navegare,* written in the 13th century ([63] p. 24) and the *Porttolano di Grazia Pauli di chartte XXXII* written in the 14th century (Cod. ms. Palatino n. 468 of the Biblioteca Nazionale di Firenze ([64] f. 7v): "E da Scilaci al chappo di Chastella à miglia LX per grecho di ver levantte. E da la Chastella al chapo de le Cholonne à miglia X intra grecho e tramontana".

(b) The portolan charts that do not mention the islets but describe some very dangerous shoals at half a mile or a mile off Le Castella. Among the numerous documents that fall into this category, we shall limit ourselves to a few examples: the handwritten *Portolano* from the second half of the 16th century kept in the Vatican Apostolic Library (ms. Barb. lat. 5063), the *Portolano della maggior parte dè luoghi da stantiar navi et galee in tutto il Mare Mediterraneo* by Bartolomeo Crescenzio from the early 17th century [65], the *Agrigentinus* kept in the Biblioteca Lucchesiana of Girgenti from the first half of the 17th century [66], and the *Portolano di tutte le parti e luoghi da stanziare navi e galere per tutto il Mare Mediterraneo* by Zaccaria Rispolo dated between 1625 and 1675 (ms. 1364, Biblioteca de Catalunya): "A miglia quindici vi sono li Castelli dell'Occhiali, dove vi sono molte secche pericolosi et sono mezzo miglio à mare et si può sorgere con Nave et Galere, la traversia è mezzo giorno, e libici" (c. 42v).

(c) The portolan charts in which one or two islets off the coast of Le Castella are explicitly mentioned. Some of these documents deserve particular attention.

The first attestation is contained in the *"Liber de existencia riveriarum et formas maris nostri Mediterraneani"*, one of the oldest portolan charts known, written in Pisa between 1160 and 1200 AD. While describing the coast from Crotone towards the South, the portolan chart shows an island NE of Tacina: "A littuna usque ad Crotonim ml. xxx [. . .]. Inde ad Tacina. lv., habens in aquilone insulam [. . .]" ([67] p. 157). From about a century later is the manuscript portolan chart dated to the late 14th century, held at the University of Minnesota Libraries: "[. . .] de sopra lo cavo de Castelle son 2 ysole [. . .]" (Minnesota Libraries, James Ford Bell Library, Bell Call #1300 Po, 38v). The *Portolano Parma-Magliabecchi* of the first half of the 15th century contains a short mention of a small island in the Gulf of Squillace: "Da stillo a cauo del golfo desquilaci 50 miglia quarta di greco ver tramontana et insul cauo e una isoletta picola passa di fuori" ([68] p. 309). By contrast, the *Portolano dei naviganti*, probably authored by Alvise da Cà da Mosto and printed by Bernardino Rizo in Venice in 1490 [69], mentions two islands located one mile in front of Le Castella: "Chastele e cita e soura le castelle a mio uno sono di ixolete et intorno vi sono molto aspreo e simelmente alo statio dela cita chusi da leuante chome da ponente la cita e quaxi ixolata et a mal statio" ([68] p. 491). Among the 16th century portolan charts, the *Kitab-iBahriyye* (*Book of the Sea* or *of Navigation*) by Piri Reis is important to mention. The book was written for Suleiman I in two versions, dated 1521 and 1526, respectively. It is a cartographic work with a descriptive text that describes in detail the coasts and islands of the Mediterranean. Among the most renowned manuscripts, we should mention Suleymaniye—Aya Sofya 2612 [70] and Marsili 3609, belonging to the "Biblioteca Universitaria di Bologna" [71]. About Le Castella, Piri Reis notes: "[...] in a (sort of) peninsula, there is another promontory; inside this promontory there is a village which they call *Qastàlò*. On either side of the village there are two inlets. These are good mooring points for small boats. At one mile, in front, there are two small islands. The space between those two small islands and the stronghold is passable by boats (although) the sides of the two islets are dotted with rocks" ([72] p. 108). The manuscript *Vaticanus Ottobonianus graecus* 150, dating back to the end of the 16th century, also mentions two rocky bodies emerging off the coast of Le Castella: "καὶ ἀλάργου ἀπὸ τὸ Καστέλι μίλλια 2 ἤγουν μίλλια δύο εἰς τὸ πὲλαγος ἔχει δύο σκόγια" [73] (p. 330). In the 17th century, there were other mentions of the islets in portolan charts, and a few of them should be recalled. In the *Tratado de cosmografía y navegación, con un derrotero de las costas e islas del Mediterráneo y del Adriático*—a manuscript dated 1651 and kept in the Biblioteca National de España (Ms. 9025)—there is a mention of "uno escollos" located near Le Castella (El Castillo) and, more precisely, "Levante del largo de Tierra Una milla" (c. 89^{v}). In the handwritten *Portulano,* kept at the Biblioteca Nazionale di Firenze (ms. Magliabecchiano XIII, 77), dated 1665, it is stated that "Castella è una città et lontano un m(iglio) ha 2 isole intorno alle quali non vi è troppo netto, et il fondo è cattivo (c. 50^{v}). It is worth remembering that the same indications contained in the Magliabecchiano of Florence are also present in the manuscript Italien 2115 (56^{v}), kept in the Bibliothèque Nationale de France, titled *Portolano ove si contiene tutto il costaggio di terra ferma* (Figure 9). In another handwritten *Portolano* from the 17th century, kept at the Biblioteca Regionale della Sardegna, it is stated that "sopra dette Castelle un miglio sono due isolotti intorno à quali vi è brutto e similmente appresso terra e non vi è stanza" (coll. "Armadio libri rari". Cat. arch. supp. orig. 0105000428). Finally, Sebastiano Gorgoglione mentions "two small islands at one mile from the land" of Le Castella in his *Portulano del Mare Mediterraneo,* printed in Naples in 1705 ([74] p. 28).

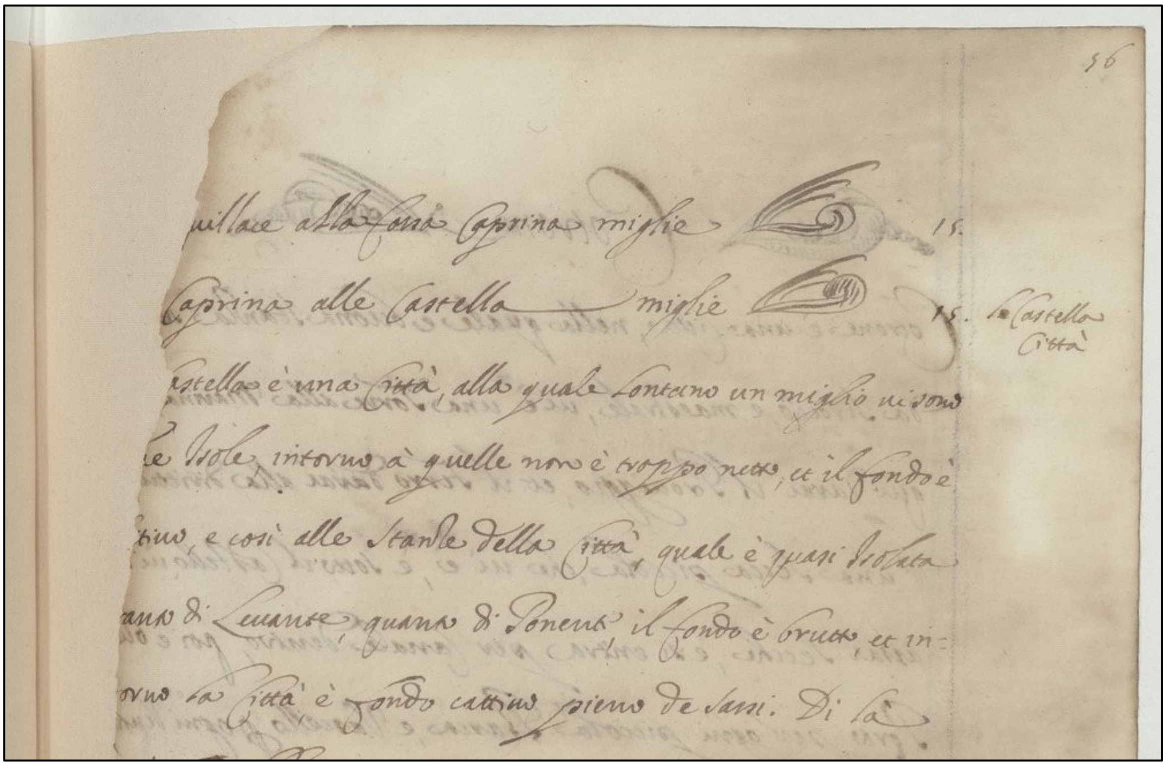

Figure 9. A portion of folio 56^{v} belonging to the Italian Manuscript 2115 (17th century) preserved in the National Library of France, Manuscripts Department: "[Da Squ]illace alla fossa Carpina miglie 15. [Da] Caprina alle Castella miglie 15. Castella è una Città, alla quale lontano un miglio vi sono [d]ue Isole, intorno à quelle non è troppo netto, et il fondo è [. . .]itino, e così alle Stanze della Città, quale è quasi Isolata [. . .] anti di Levante, quanto di Ponenti, il fondo è brutto, et [int]orno la Città, è fondo cattivo pieno de sassi". Source https://gallica.bnf.fr—https://gallica.bnf.fr/ark:/12148/btv1b55002492h (accessed on 20 October 2024).

4.1.3. The Islets of Le Castella in Medieval and Modern Age Nautical Charts

There are numerous navigation charts that depict one or more islets along the southern coasts of the Crotone Peninsula, starting from the early 12th century. Although these are the earliest cartographic representations, with evident topographic limitations due to an excess of approximation and schematisation in coastal profiles, their value as a historical-geographical and toponymic document is widely acknowledged. These "Charts", made of parchment, were useful for navigation and for setting routes, included in the ship's equipment together with portolan charts and compasses. They were the result of direct nautical observations in which the main elements of the coastlines were recorded and used by helmsmen for orientation [75–77].

The earliest representations of rocks emerging from the waters of Le Castella were made by Petrus Vesconte from Genoa, a cartographer to whom the first dated navigation charts are currently attributed. Vesconte, already in the editions of 1311 (Archivio di Stato di Firenze, ASFir, N1), 1313 (Bibliothèque Nationale de France, GE DD-687), and 1321 (Zentralbibliothek Zürich, ms. R.P.4; British Library, ms. 27376; Bibliothèque Municipale de Lyon, ms. 175), places three dots in correspondence with the toponym *Castele* to indicate emerging rock bodies. Moreover, Vesconte drew the islets that appear on the chart dated 1321 and attached them to the *Secreta fidelium crucis* by Marino Sanudo, kept at the Vatican Apostolic Library (Vat. lat. 2972, 110r). An islet located near Le Castella (not indicated) can be found on the anonymous chart made in Genoa between 1325 and 1350, kept in Paris at the Bibliothèque Nationale de France (Latin 4850). This library also houses the navigation chart by Angelino Dulcer, authored in Majorca in 1339, in which an island painted in red appears in front of *Castelli* (BNF, département Cartes et plans, GE B-696).

Another island is visible near Le Castella in a parchment chart made by an anonymous author and dated between 1320 and 1350, kept at the Library of Congress in Washington (P6 Vault: Vellum 3, Ristow-Scelton 3), in the "Carta della Biblioteca Palatina" in Parma authored in Venice by Francesco Pizigano in December 1367 (ms. Palat. n. 1612), and in the ms. Italien 1704 depicting the Mediterranean, the Black Sea, and Western Europe kept at the "Bibliothèque Nationale de France". Even in the works of Guglielmo Soleri, kept in Paris (Bibliothèque Nationale de France, GE B-1131, RES) and Florence (Archivio di Stato, CN 3), dated 1380 and 1385, respectively, one island is associated with the toponym *Castelle*. The islets become two in the anonymous chart kept at the Archivio di Stato of Lucca and dated after the first quarter of the 14th century (Fondo stampe n. 1193). In the Yale University Beinecke Library, there is a chart made in Savona in 1403 by Francischus Becharius of Genoa. The map shows a red crescent-shaped island in front of the toponym *Castelle* (Art Storage 1980.158). In Paris, at the Bibliothèque Nationale de France, there is an exquisite navigation chart drawn in Venice and attributed to Albertino de Virga, which dates back to 1409 and features an island painted in the bay near *Casteli* (CPL GE D-7900, RES). Among the various Atlases made in Venice and attributed to Giacomo de Giroldi, now scattered in several libraries in Europe, a mention is deserved to those kept at the British Library, dated between 1425 and 1450 (Add. 18665) (Figure 10A, that of 1422 kept at the Bibliothèque Nationale de France (GE C-5088—RES) and those of the Vatican Apostolic Library (ms. Vat. Lat. 9015 of 1452 and ms. Rossi 676 of the second quarter of the 15th century) in which two small islets are drawn in the gulf of Squillace, near Le Castella.

A large island painted in red and a series of dots, perhaps indicating semi-submerged reefs, appear in front of *Castelle* in the navigation chart made in 1435 and kept at the Biblioteca Palatina di Parma (II. 21. 1613), attributed to Battista Beccari. The illustrations of the Atlas made in Venice in 1448 and kept at the Österreichische Nationalbibliothek (Cod.410*) shall be attributed to Nicolò Nicolai. The chart features two small islands painted in red in the stretch of sea in front of *Castelle* and at the mouth of the Tacina. As for the documents of the second half of the 14th century, the Carta del Mediterraneo Centrale, made in Venice by an anonymous author and kept in the Topkapi Palace Museum Manuscript Library (Ms. Deissmann 47), features an island in front of *Chastelle* indicated with a sort of cross.

Moreover, in the well-known navigation chart by Grazioso Benincasa of 1461, kept at the Archivio di Stato of Florence (CN 9), there is a crescent-shaped island drawn in front of *Castelle*. In the Carte di Petrus Roselli, dated to the 1460s and kept in Modena (Biblioteca Estense Universitaria, CGA5.B), London (Egerton MS. 2712), Paris (CPL GE C-15118, RES; GE C-5090, RES; GE C-5096, RES), New Haven (Beinecke Library, A.S. 49cea 1425), and Nuremberg (Germanisches Nationalmuseum, ms. La 4017, R041), we can see a large, red-coloured island in front of *Castelle*, with a series of emerging reefs contouring the bay in a SW direction (Figure 10B). A similar topographic characterisation can be found in the chart by Salvatore de Pilestrina, kept in the Biblioteca Teresiana di Mantova and dated between 1476 and 1500 (Ms. 1032), as well as in the numerous maps made between 1514 and 1538 and attributed to Baptista Agnesius—the prolific Genoese geographer who worked mostly in Venice—of which we recall, as an example, those kept at the Herzog August Library in Wolfenbuttel (Cod. Guelph. 100 Aug. 2°), of the British Library (Royal 14 CV), of Dresden (Saxon State and University Library, Mscr. Dresd. F 140b) (Figure 10C), and finally, that of Philadelphia (University of Pennsylvania Library, Schoenberg Institute, LJS MS 28).

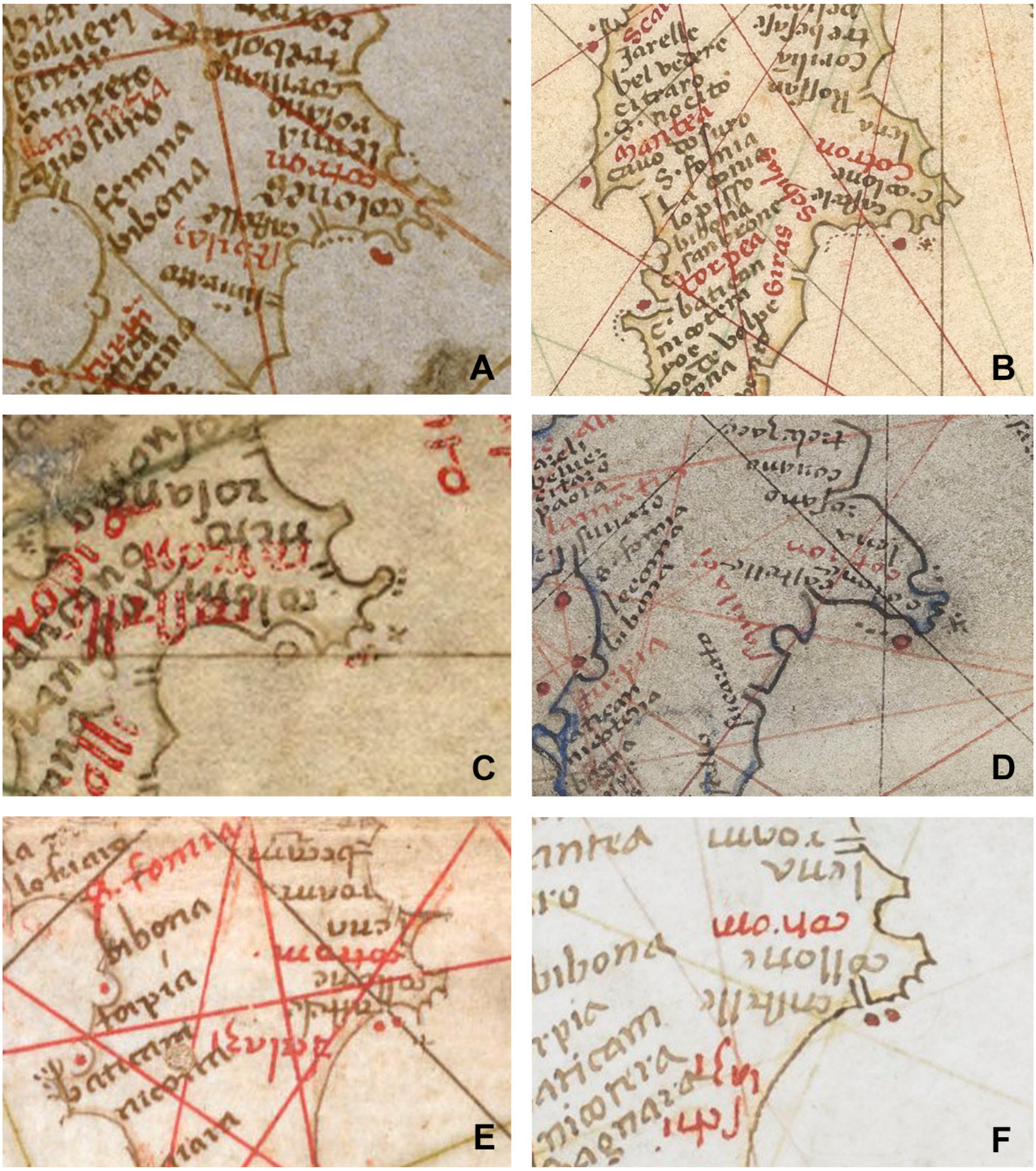

Figure 10. Some excerpts from the navigation charts: (**A**) Giacomo de Giroldi, Chart of the central Mediterranean and the Adriatic Sea, 1425–1450 (British Library, Add. 18665); (**B**) Petrus Roselli, Chart of the Mediterranean and the Black Sea, 1450–1500 (https://gallica.bnf.fr/accueil/en/content/accueil-en?mode=desktop accessed on 24 October 2024 Nationale de France, Département Cartes et Plans CPL GE C-15118); (**C**) Battista Agnese, Chart of the central Mediterranean and Adriatic Sea, c. 1536 (Saxon State and University Library Dresden, Mscr. Dresd. F 140b, PDM 1.0); (**D**) Vesconte Maggiolo, Chart of the central and western Mediterranean, 1511 (John Carter Brown Library, 3-SIZE Codex Z); (**E**) Petrus Russus, Chart of the Mediterranean, Black Sea, and western Europe, 1516 (https://gallica.bnf.fr/accueil/en/content/accueil-en?mode=desktop accessed on 24 October 2024 Nationale de France, Département Cartes et Plans, CPL GE B-1425; and (**F**) Zuan from Naples, Chart of the central and eastern Mediterranean and Black Sea, before 1489 (Cornaro Atlas, Egerton MS 73, British Library).

Among the numerous navigation charts dating from the late 15th century to the last first half of the 16th century that show one or two islets off the coast of Le Castella, we can also recall the one dated to 1505 and attributed to Judah Abenzara, kept in New Haven (Beinecke Rare Book and Manuscript Library, Art Storage 30cea 1505), the one from 1511 by Vesconte Maggiolo in Providence (John Carter Brown Library, 3-SIZE Codex Z 2) (Figure 10D), the one by Petrus Russus (ca. 1516) in Paris (Bibliothèque Nationale de France, CPL GE B-1425, RES) (Figure 10E), the one by Alonso de Santa Cruz (1541–1545) at the National Library of Spain (MSS.MICRO/12638), the one by Zuan from Naples belonging to the Cornaro Atlas of the British Library (Egerton MS 73) (Figure 10F), the one by Anonymous in the Archivio di Stato of Turin (J. b. II.11) 1529, and the one from 1537, kept in Venice by the Cretan Giorgio Sideri (Biblioteca Nazionale Marciana, Ms. It. IV 61 = 5323).

We have already mentioned the Ottoman work by Piri Reis, the *Kitab-iBahriyye*, in relation to the text of the portolan chart. However, the cartographic apparatus should be mentioned as well, as it shows two islets right in front of the fortress of Le Castella. In the ms. Marsili 3609, these have unequal dimensions and contours and are marked with different colours, including blue and red. Their perimeter is also surrounded by a dotted line to indicate rocky shallows ([71] p. 77). In the ms. Süleymaniye—Aya Sofya 2612, the two islands, coloured in red, have equal dimensions, and also, in this case, they are surrounded by a dotted line ([70] p. 1034). This variability is also found in other editions like ms. Supplément turc 956, kept at the Bibliothèque Nationale de France, and the later edition is at the Baltimore Walters Art Museum (Figure 11).

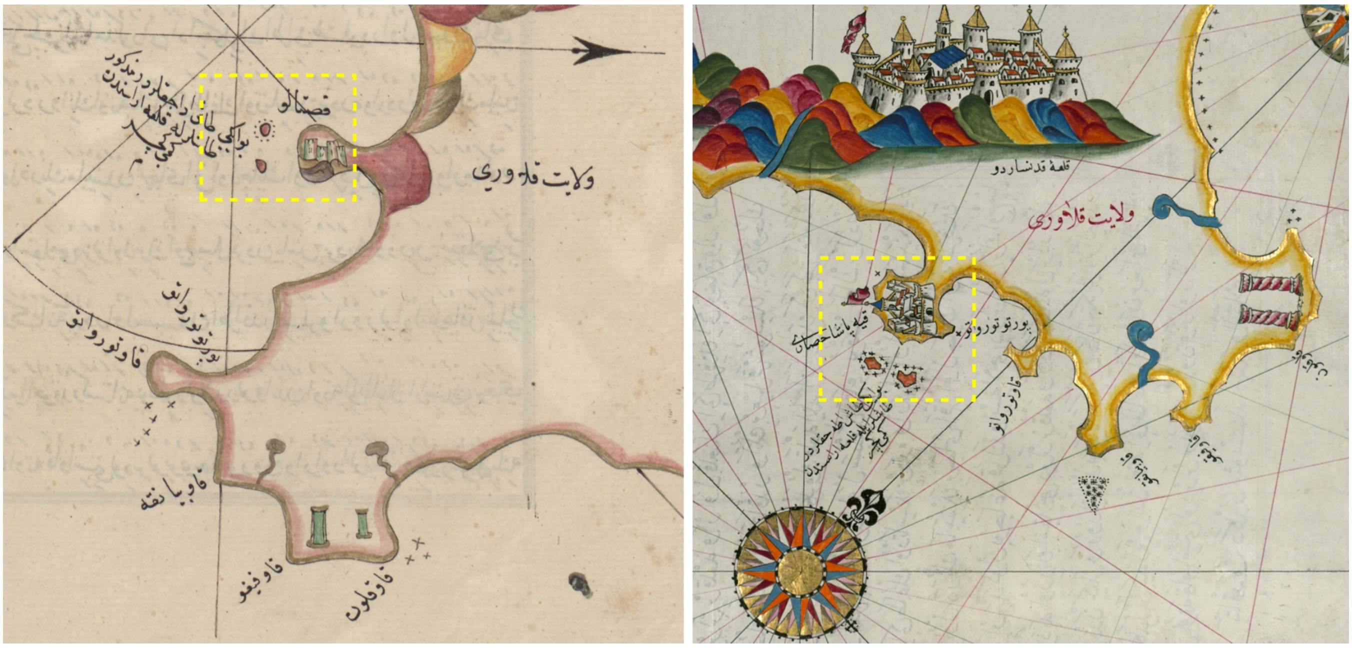

Figure 11. Piri Re'is' *Kitab-iBahriyye*: excerpts depicting the stretch of the coast between Capo Colonna and Le Castella. On the **left**: https://gallica.bnf.fr/accueil/en/content/accueil-en?mode=desktop accessed on 24 October 2024 Nationale de France, Département des Manuscrits. Supplément turc 956, 244v; on the **right**: Table 212b of ms. Baltimore Walters Art Museum 658.

The islets are depicted in the navigation charts by Sebastião Lopes at the National Maritime Museum in Greenwich (G230:1/12, approx. 1555) and that by Diogo Homen of 1561, kept at the British Library (Add. MS 5415-A). Two islets coloured in red with reefs depicted as dark dots are represented in the Parisian navigation chart dated 1558 and attributed to Niccolò Zeno (Bibliothèque Nationale de France, GEEE-5610, RES), while a large island surrounded by a dotted line to indicate shallows can be seen in a chart by Jacopo Scotto, dated around 1590 and kept in Washington (Library of Congress, G1782.M4P5 S3 1590, Vellum 11).

During the first half of the 17th century, depictions of Le Castella with one or two islands became increasingly rare. A large island contoured by a series of rocks in front of the coast of *C. Castelli* is present in dozens of navigation charts attributed to Joan Oliva, among which, for example, those kept at the Bibliothèque Nationale de France (Sgy 1705 Rés), the Huntington Library (HM 40), and the Library of Congress in Washington (G1059.O4 1590, Vellum 8). An island surrounded by a chain of rocks was included by two other Olivas, namely Francesco and Francesco II. The former created the first chart dated 1614 and kept at the Austrian National Library (Cod. 360), while the latter, working in Marseilles between 1650 and 1662, made the charts kept at the State Archives of Luzern Canton (PLA 65-5), the National Maritime Museum of Greenwich (P/10), the Biblioteca Nazionale of Naples (Ms. XV.AA.9, 2a), and the Bibliothèque Nationale de France (GE DD 2009, RES). Francesco Oliva II, in Marseille, also made the charts kept in Greenwich (P/11), in New York at the Hispanic Society of America (K17), and in Paris at the Bibliothèque Nationale de France (CPL GE DD-6657, RES), presumably dated between 1650 and 1670, in which in front of *Castelli* there is no longer an island, but only a large area of shallows rendered with a dotted line. Only one island appears in a chart dating back to the first quarter of the 17th century, made by Nicolaos Vourdopolos in Paris (Bibliothèque Nationale de France, Supplément grec 1094), while in the charts made in Livorno by Giovanni Battista Cavallini and kept the National Library of Finland (no. 2607, of 1640), as well as the ones kept at the "Biblioteca Nazionale" of Naples (Ms. XII.D.71,4, of 1635-1640), at the National Maritime Museum in Greenwich (G230:1/3, of 1656), at the Bibliothèque Nationale de France (CPL GE DD-2019 del 1639) (Figure 12) and at the Library of Congress in Washington (G5672.M4P5 1640.C3, Vellum 24 of 1640), the typical illustration by Oliva comes back, with an island surrounded by shallows and emerging rocks indicated with a dotted line in front of *Castelli*.

Figure 12. Giovanni Battista Cavallini, Chart of the Mediterranean and Black Sea, 1639 (gallica.bnf.fr /Bibliothèque Nationale de France, Département Cartes et Plans, CPL GE DD-2019 RES.

4.2. Geological Data

The MBES investigation produced 72 vessel tracks for a total travelled length of 95 km. The obtained DTM profile has a maximum resolution of 0.1 m $\times$ 0.1 m and covers an area of 1.78 square kilometres. The obtained DTM (Figure 13) shows the occurrence of a large rocky platform with an extension of about 1 km^2, characterised by an almost flat-parallel linear trend and an average depth of about 9 m. There are three major structural reliefs at depths < 9 m, with the highest point located at 4 m.

In the innermost portion of the western shoal, in correspondence with the shallower areas, there are numerous rocky megablocks (up to 17 m per side) and sharp edges. To the SW of the platform, there are blocks with an increasingly amorphous and irregular appearance. Near the northern shoal, the blocks lying on the bottom are more scattered and have little geometric contiguity, with maximum dimensions of about 6–8 m. The presence of a small ridge with a length of about 200 m and an average depth of about −7 m at the north-western extremes of the data field should also be noted.

The backscatter analysis revealed the general pattern of the *Posidonia oceanica* coverage in this area, showing sparse patches mixed with rocky outcrops, with a tendency to gradually become more homogeneous towards the south. The extension is smaller than the other two structural surveys, while there is a greater cover of *Posidonia. oceanica* with probable patches of *Cymodocea nodosa*.

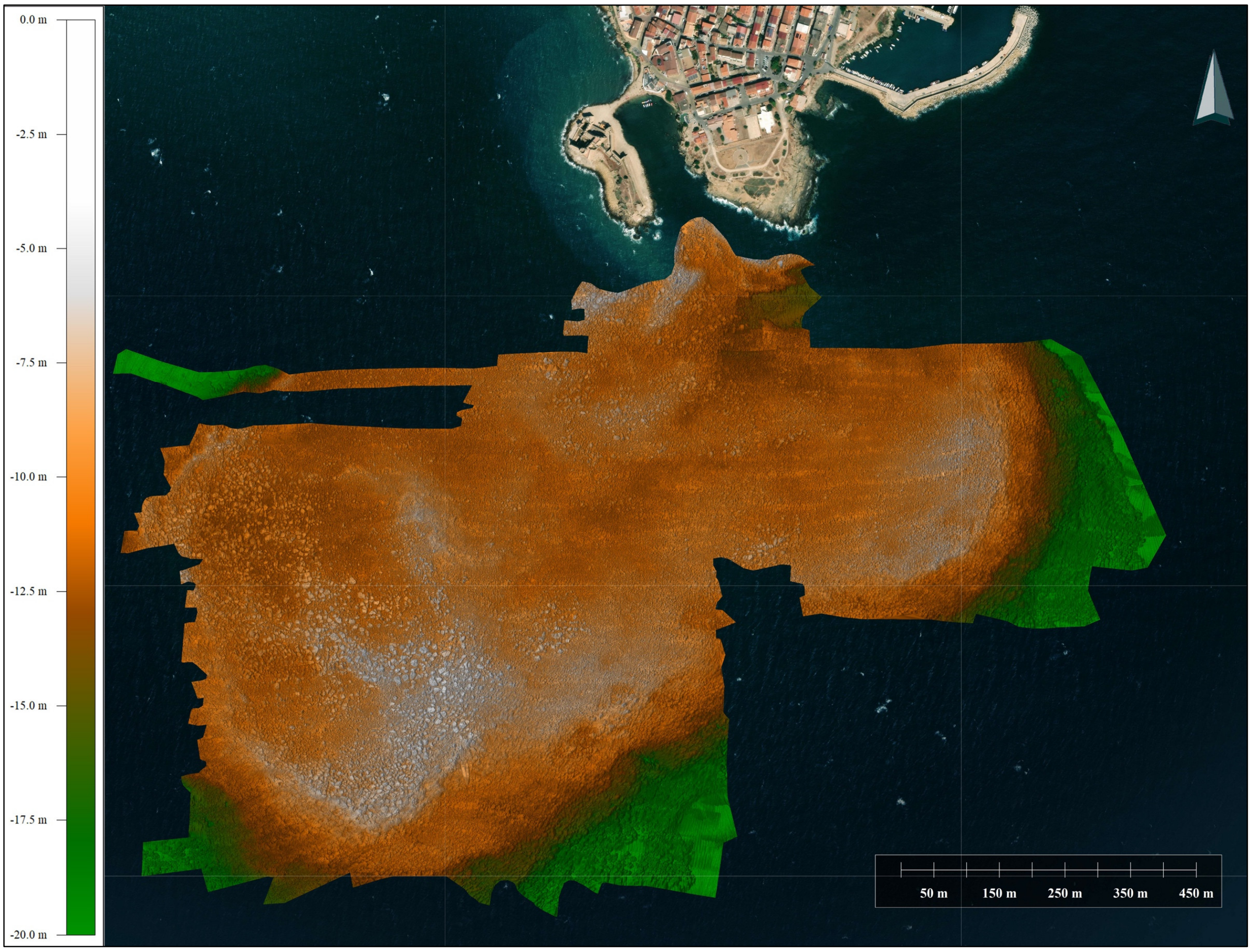

Figure 13. The DTM (Digital Terrain Model) from the MBES conducted by CSRM, ARPA Calabria (elab. by F. Mauri).

The SBP survey covered over 50 km of tracks in the sea in front of the Aragonese castle of Le Castella, down to a depth of 100 m. SBP profiles were created both parallel (n = 5) and radial (n = 7) to the coast, plus two around the castle, covering an area from 3 m down to more than 90 m wd at the edge of the continental shelf, in order to assess the presence, geometry and thickness of the Holocene sedimentary deposits (Figures 3 and 13).

The SBP profiles parallel to the coast showed the occurrence of rocky blocks as the seaward continuation of the rocky promontory of Le Castella, starting from 8 m wd, down to 30 m wd (Figure 14a). These blocks formed an asymmetric, WE-oriented saddle structure with an irregular profile (Figure 13). The western limit of the saddle has a gentle inclination, while its eastern boundary can be located in correspondence with a sudden deepening of the seabed that goes from 10 to 25 m within about 100 m (Figure 14a). No significant sedimentary deposits are observed on the top of the saddle. Offshore, in areas deeper than about 30 m, the rocky blocks disappear and the thickness of the sedimentary cover increases. All radial SBP profiles show constant seabed deepening, from about 8 m down to 90 m. The occurrence of rocky blocks between 8 and 30 m in depth is confirmed (Figure 14b), as well as the presence of the saddle as a flat-topped structure at 8/9 m wd (Figure 14b). From the saddle, the seabed deepens with a first marked step down to 20 m wd and a gentler inclination toward the open sea down to 30/40 m. Below this depth, all the profiles show layered sediments on a poorly defined rocky or very coarse substrate. The layered sediment thickness ranges between about 12 m at around 45/55 m and 17 m at the shelf edge.

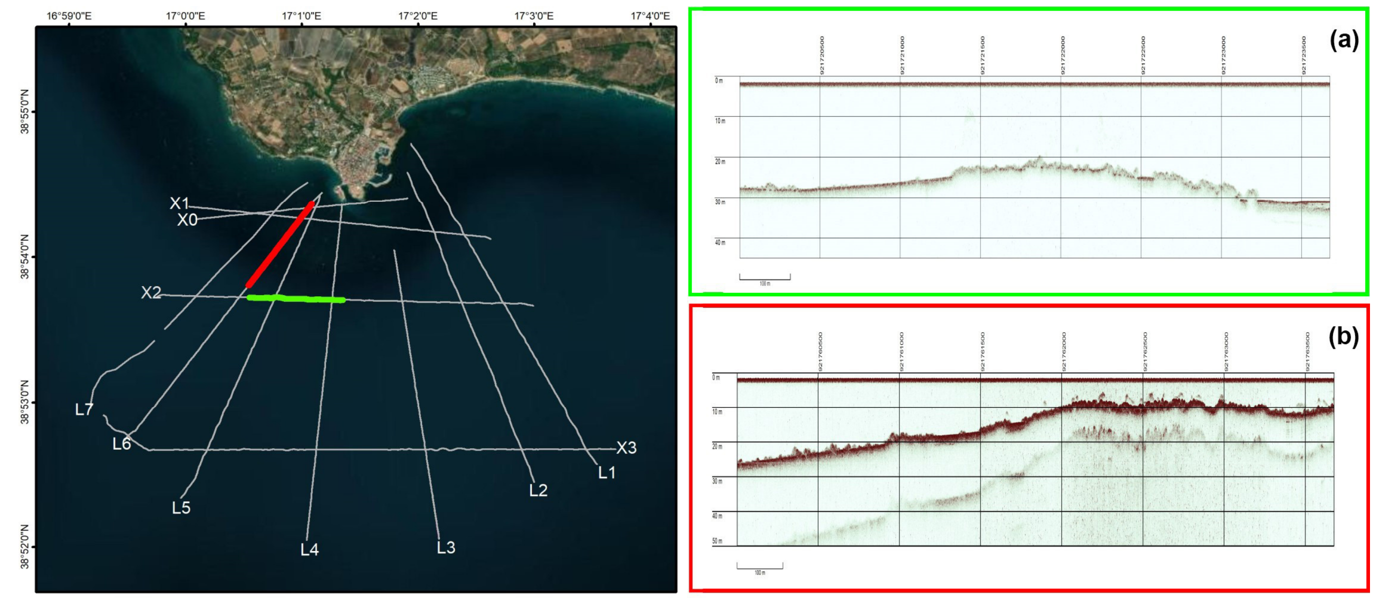

Figure 14. Marine sector in front of Le Castella, two examples of SBP profiles.

4.3. Archaeological Data

The outcomes of the explorations are also very significant from an archaeological point of view, as they have allowed us to document the presence of various accumulations of extrabasinal stone materials. These are indeed extraneous to the lithology of the seabed, which in these areas is made up of calcarenites that rest directly on a substrate made up of Cutro clays.

4.3.1. Sector A

In the marine area facing the fortress (Figure 5), specifically in the sector between the southern tip of the islet and Capo Cannone, some accumulations of stones were already reported in 1988 by local diver L. Cantafora ([78] p. 551). This evidence corresponds to that described by Cooperativa Aquarius in 1988 as "a sizeable, submerged rubble-work which constitutes the extension of the eastern limit of the castle, for at least 150 metres" and which appears to be made "of a layer of cobbles of various sizes" which "appear to have been partly obtained by splitting stone blocks" ([79] p. 12), ([7] p. 341), ([8] p. 542), ([5] pp. 325–326). Our surveys confirmed the presence of this accumulation of extrabasinal cobbles and specified more clearly its topography, which does not have an E-W orientation ([79] p. 13) but an N-S. Furthermore, compared to the 150 m previously reported ([79] p. 13), our surveys documented the rubble work for a length of only 76 m (Figure 15).

In the first part, the accumulation begins at a depth of 3.2 m and for about 50 m it follows the side of the so-called islet in parallel at a distance of just 20 m, with a path oriented in an N-S direction. Subsequently, it bends a few degrees in an S-W direction and ultimately disappears at the maximum depth of 5.9 m. Along its route, the structure shows a non-homogeneous physiognomy and a variable width that does not exceed 5–6 m. In the northernmost sector, where the seabed in the small port is flat and less cluttered with blocks of calcarenite, the pile of stones is levelled on the seabed, but after about twenty metres, its contours become clearer and it stands out from the seabed by more than a metre. In the southern section, located in a deeper area, the structure becomes discontinuous, and the seabed is no longer flat and is cluttered with metre-sized blocks of calcarenite, with heaps of stones that fill some depressions among the rocks. The stone materials have no traces of mortar, and in the area where it reaches a notable height, it is held in place only by marine concretions (Figure 16).

Figure 15. Le Castella, Sector A. The yellow arrows indicate the location of the submerged stones piles (Google Earth satellite image).

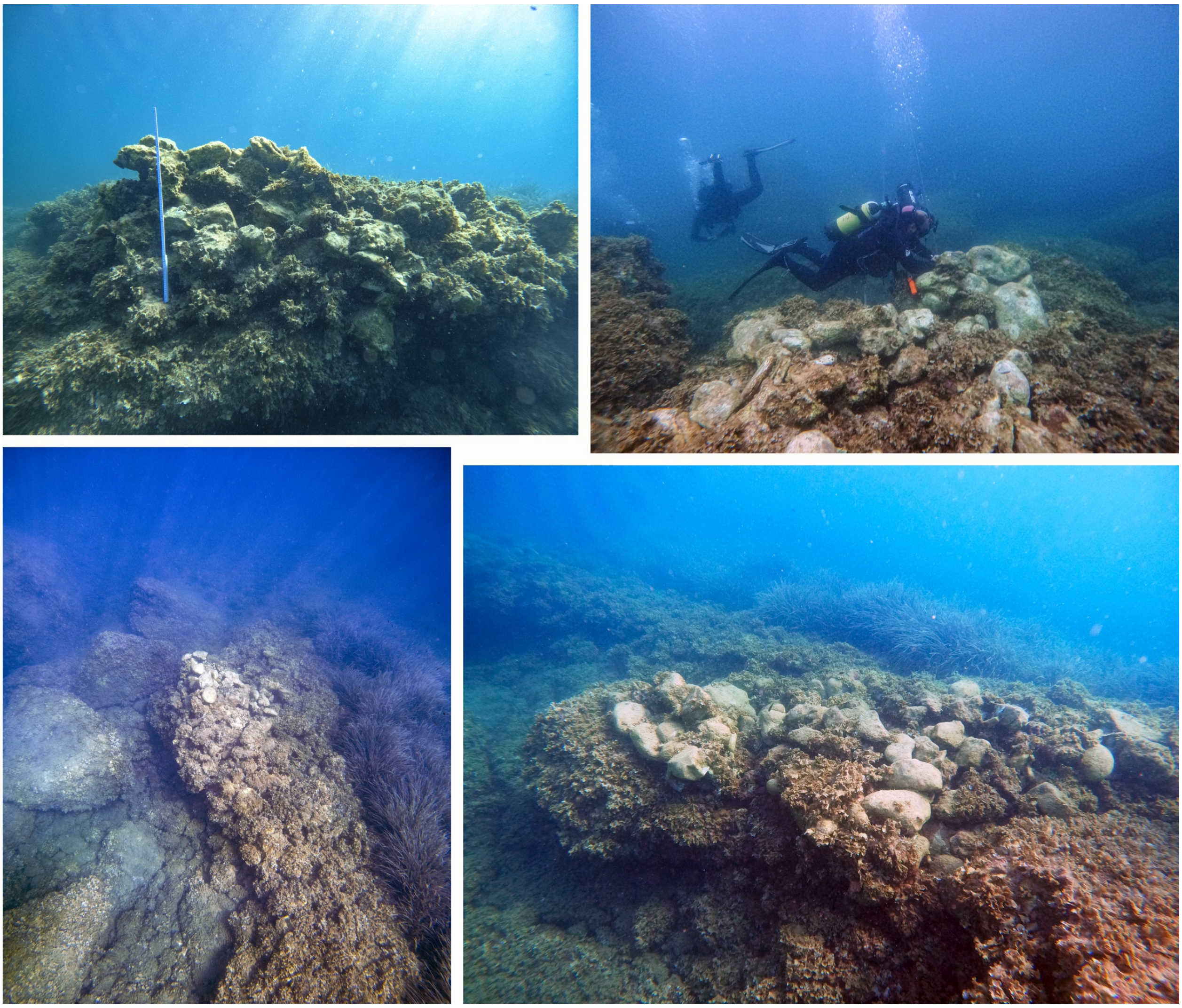

Figure 16. Le Castella, Sector A. Photos of the piles made up of the extrabasinal materials along the eastern flank of the islet.

The materials that make up the piles are small in size and usually do not exceed 40–50 cm in length. They are covered by a thin, nutbrown or off-white encrusting patina. During the surveys, some pottery fragments were spotted among the stones. This was confirmed by research conducted in the 1980s when fragments of ceramics and amphorae dating back to the Greek and late Roman ages were found among the stones (but also at their base). The late Imperial materials are clearly a *terminus post quem* for its building, which should be dated between the Byzantine and late Medieval ages ([5] p. 326).

4.3.2. Sector B

Even in the wider sector (Figure 5), at a depth between 6.9 and 9 metres, there are numerous accumulations of extrabasinal stone materials, already mentioned in the section dedicated to previous research (see Section 1).

Specifically, they are made up of rough stone of both natural and artificial sizing, mostly covered by a patina of biological calcareous encrustations that give the individual elements a yellowish, hazelnut or off-white colour. The stones are heterogeneous and normally do not exceed 50–60 cm in length, in sharp contrast to the metre- to decimetre-sized megablocks of calcarenite (Figures 17 and 18).

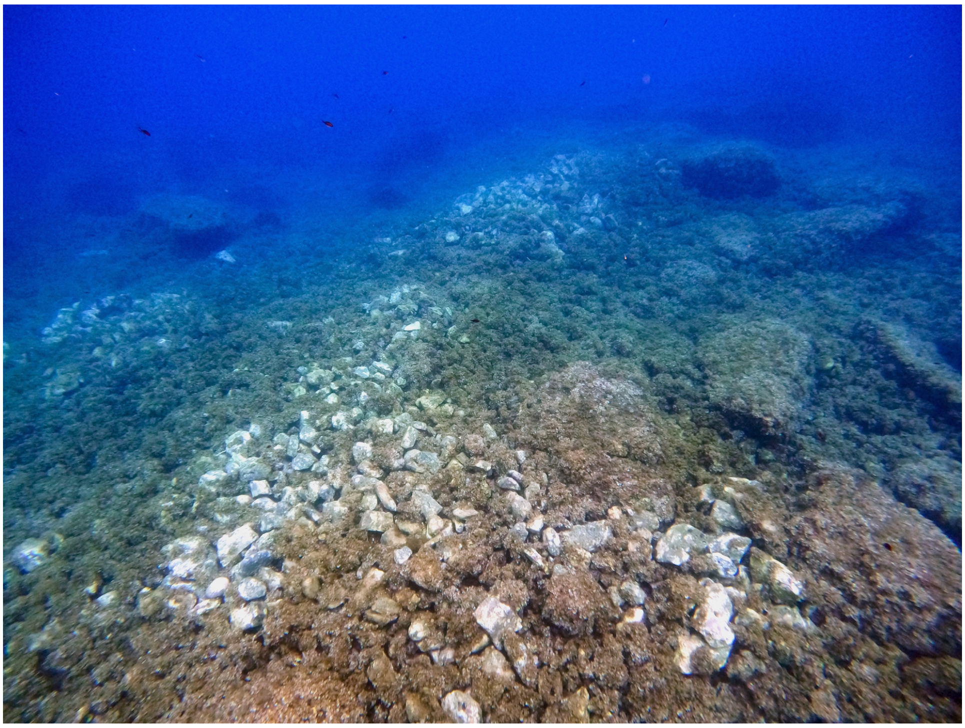

Figure 17. Le Castella, Sector B. The extrabasinal materials scattered on the seabed.

Figure 18. Le Castella, Sector B. The extrabasinal materials scattered on the seabed.

The arrangement of the stones on the seabed appears chaotic and indefinite, as there are piles that cover a few dozen square metres and others that are much larger. Both types of piles retain the pre-existing topography of the seabed, arranging themselves in such a way as to cover small depressions placed between the blocks of biocalcarenite without any particular order. In addition, the heaps are not always contiguous; sometimes, they are separated from each other by several metres. The largest pile of stones, measuring approximately 100 square metres, is located almost at the centre of the area under examination, on a small plateau where the large-sized calcarenite rocks become rarer (Figure 19). It should be pointed out that the stones do not show any trace of mortar and that the piles can reach a thickness of about 1 metre in the best-preserved areas. The identification of the limits of the stone piles and, more generally, the planimetric interpretation of the complex, is further complicated by the presence, especially in the eastern sector of the area under examination, of extensive beds of *Posidonia oceanica* that have rooted and developed directly above the piles.

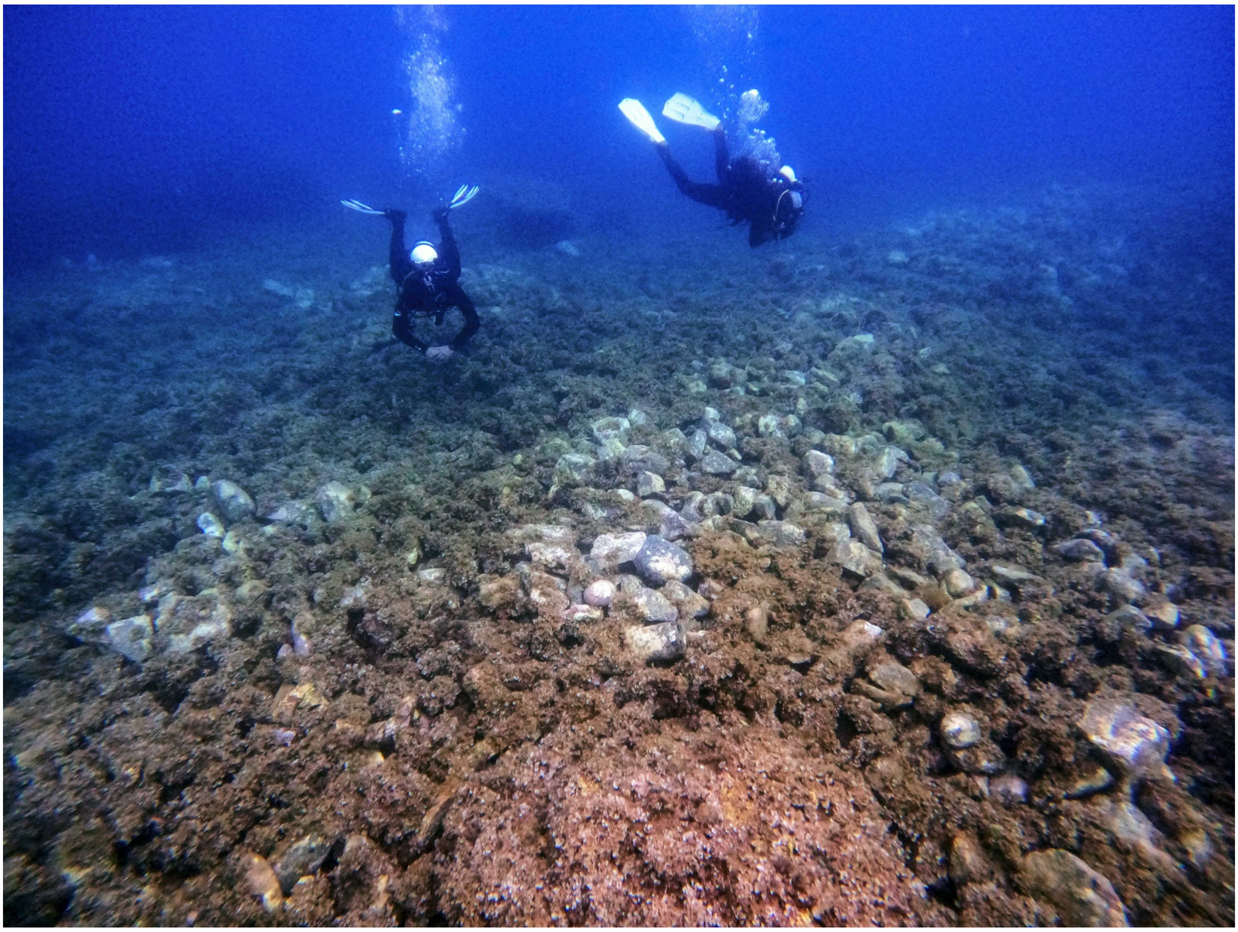

Figure 19. Le Castella, Sector B. The extrabasinal materials scattered on the seabed.

Nevertheless, it is possible to state that the stones are distributed over a stretch of seabed just over 150 m long, with a rather clear orientation in an NW-SE direction. It is much more difficult to define the width of this stretch of extrabasinal material in an SW-NE direction, as the sides are very jagged and irregular, and *Posidonia oceanica* colonised almost the entire E side (Figure 20).

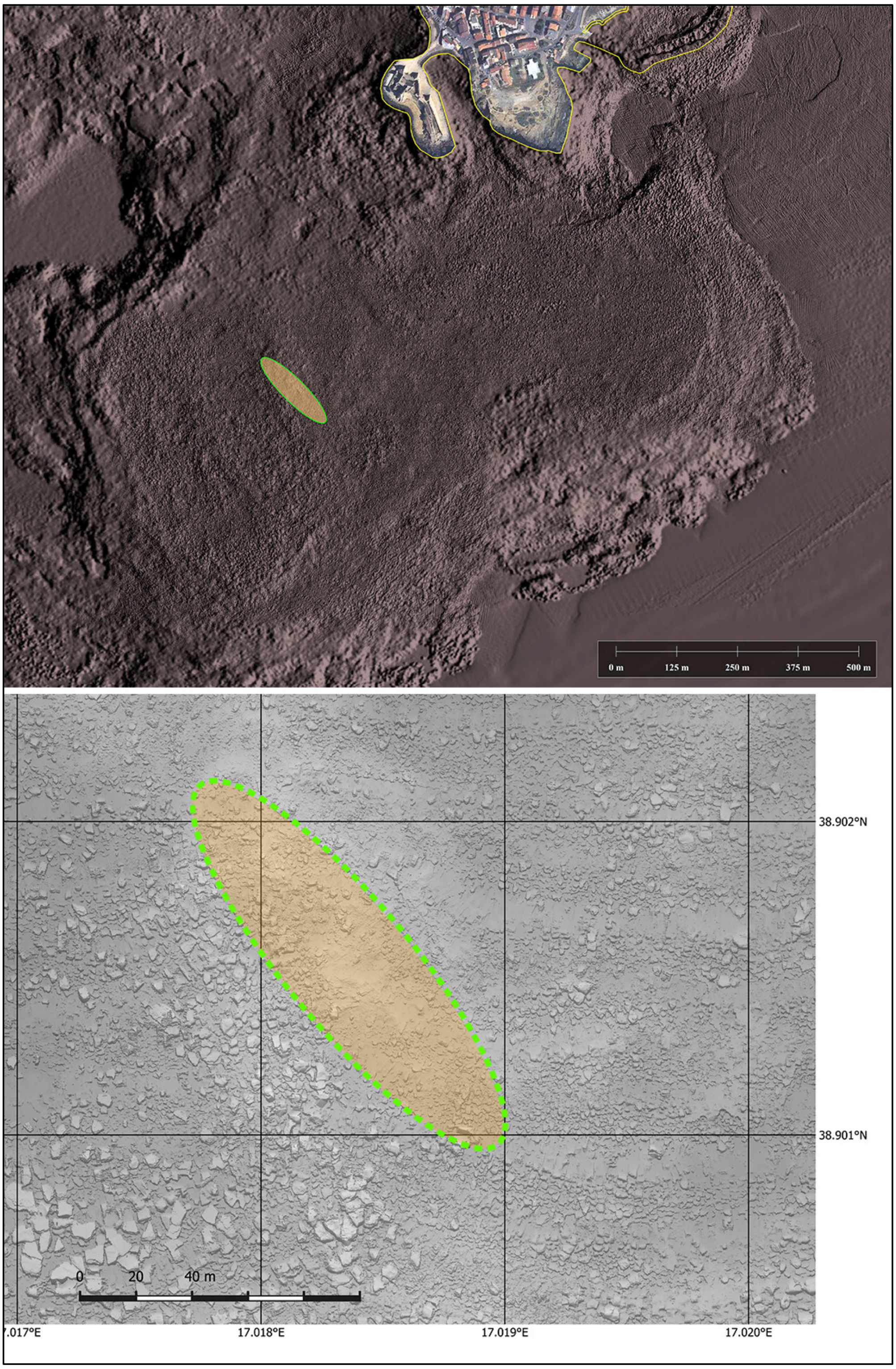

Figure 20. Le Castella, Area B. The figures show the approximate location of the extrabasinal stone piles. The presence of *Posidonia oceanica* prevents the exact demarcation of the site's boundaries (indicated by a dashed line).

5. Discussion

5.1. The Submerged Promontory of Le Castella

The outlines of a submerged elevation approximately 3.5 km long are recognisable on the seabed in front of the Aragonese castle, up to a depth of 40 m. This structure may be interpreted as the continuation of the MIS 3 marine terrace of Le Castella, which can be dated between 40 and 60 thousand years ago [43,45,80]. Its presence was already hypothesised on the basis of MBES and LiDAR maps acquired in 2005 from ISPRA—as part of the collaboration on the SIC-CARLIT Project implemented by CRSM—ARPA Calabria—along with its structural continuity with the calcarenite deposits on the mainland (Figure 21). The new investigations, supported by higher resolution MBES maps, allowed for obtaining a much more accurate description of this submerged elevation and, in general, of the paleo-coastlines of Le Castella (Figure 13).

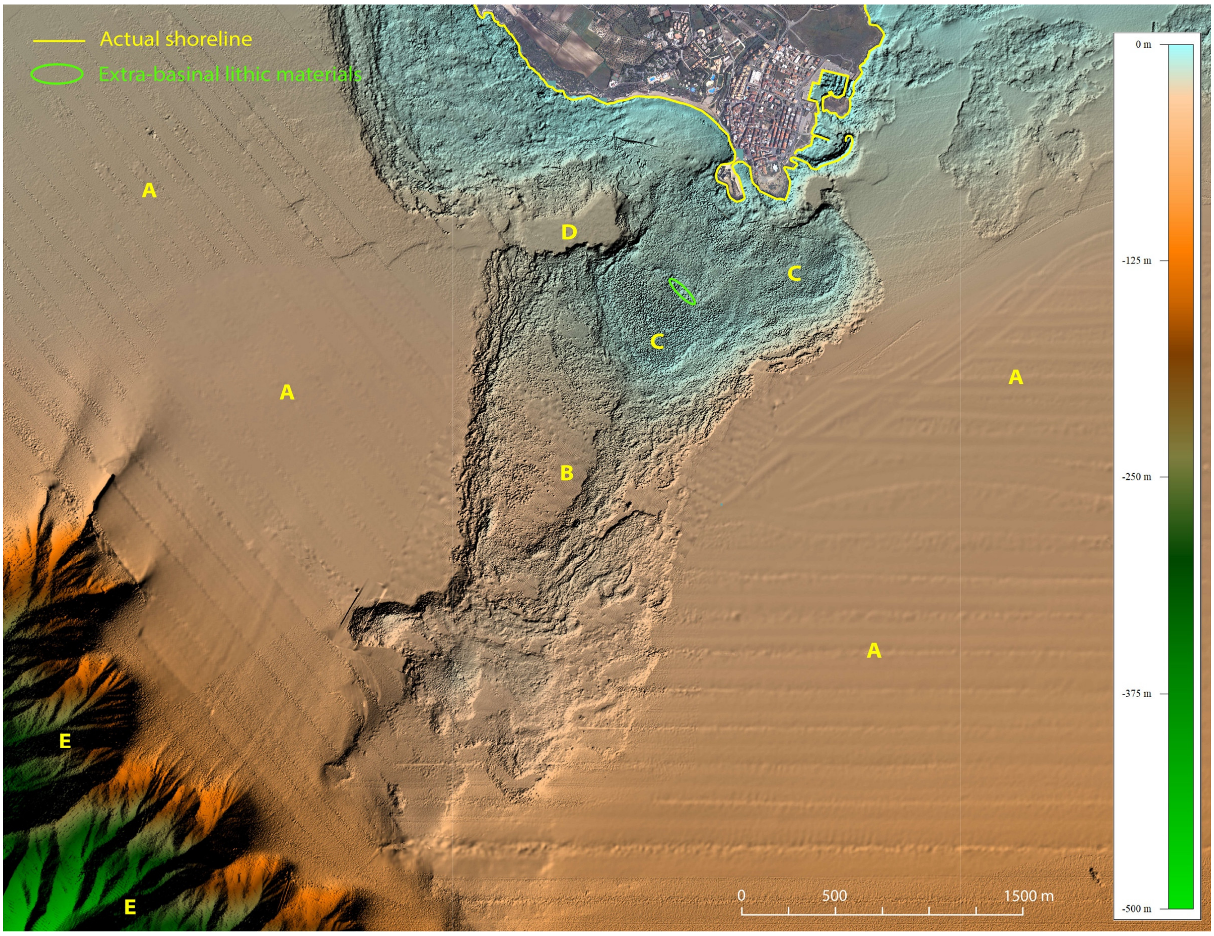

Figure 21. The submerged elevation mapped with MBES and LiDAR surveys by the PON–MAMPIRA (Monitoring of Marine Protected Areas Affected by Environmental Crimes) project revised by ISPRA and with MBES by ARPA Calabria. (**A**) The mobile seafloor composed of Cutro clays; (**B**) the depression characterised by the exposed base of clays; (**C**) the extensive debris plateau; (**D**) the depression likely related to the paleo-mouth of the Acquavrara torrent; and (**E**) the gullies belonging to the continental margin.

The elevation develops along the NNE-SSW axis and appears 2.1 km wide in its widest part where it meets the mainland and 1.1 km in its narrowest part, i.e., towards the open sea. By examining in detail the MBES maps, the submerged elevation is clearly distinguishable from the surrounding mobile seabeds, which are characterised by the presence of Cutro clays (Figure 21A) and paleo-cliffs that can exceed 20 m in height (Figure 22).

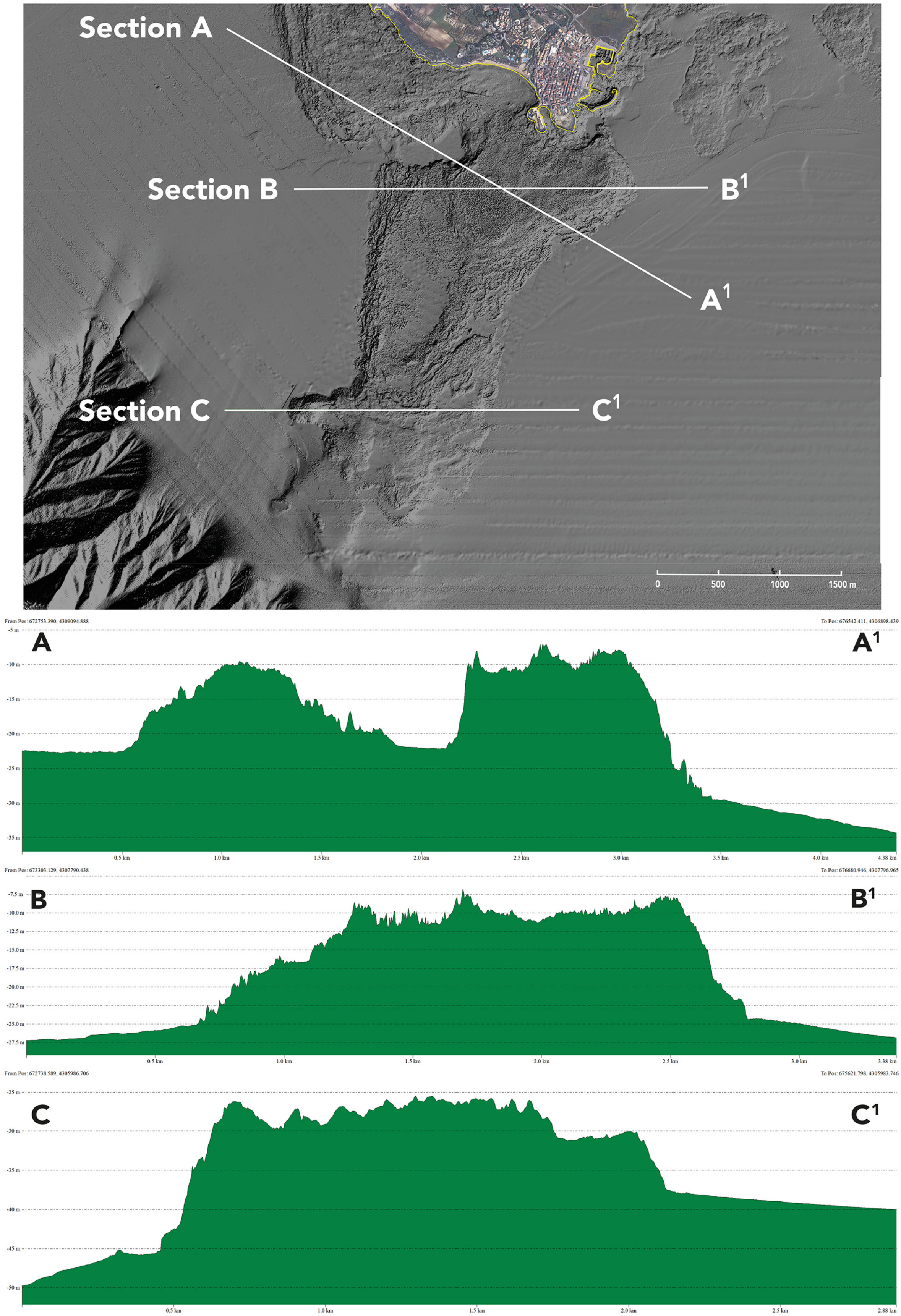

Figure 22. The sections of the submerged elevation south of Le Castella.

In the central-southern portion of the elevation, a discontinuity can be observed where the rocky seabed leaves space for a sort of half-moon-shaped hollow characterised by the exposed base of clays (Figure 21B). Right to the S of the castle, the submerged elevation shows an extensive plateau (Figure 21C). This plateau, in fact, represents the shallowest area of the submerged relief and, therefore, was the last to be submerged during the Holocene rise in sea level. This debris layer is concentrated on the plateau at an average depth of about 10 m and is the product of the most recent erosional phase. The latter, triggered by sea waves, has dismantled the geologically weak layers at the base of the cliffs (clays), causing the rapid collapse of the top terrace deposits that lie on the seabed in a geometrically coherent manner. These calcarenite deposits are smoother and less fragmented on deeper seafloors.

Another morphologically distinct feature of the submerged elevation is the presence of two sharp depressions approximately 20 m deep, both in the north-western section and in the northeastern section close to Punta Cannone. These could be considered to be hollows generated by the erosive action of paleo-watercourses. In particular, the largest depression at the north-west (200 × 700 m) seems to have been generated by the paleo-mouth of the Acquavrara torrent, which currently flows into the sea at approximately 250 m in a NW direction from the islet of Le Castella (Figures 21D and 22, section A–A^1).

Finally, moving in an SSW direction with respect to the Aragonese castle and towards the open sea, the end of the promontory precedes the cut in the slope by the gullies (Figures 21E and 22) belonging to the continental margin.

5.2. Macroscopic Geological Observations

A series of accurate observations were conducted on the stone materials of the heaps in order to identify their lithological nature (Figure 23). The stone material of the various piles laying on the seabed has already been indicated as extrabasinal ([9] pp. 356–357) ([10,12] p. 59). The sampling and the following observation allowed for identifying phyllites, schists, sandstones, and radiolarites. Quarrying sites are not to be found along the coastal strip of the Crotone peninsula but could be identified in some inland areas of Calabria. Lithologies compatible with the samples are distributed over a wide NS-oriented strip located at the cut-in slope between the Sila plateau and the more recent downstream sedimentary basins. This area is located between 300 and 700 m above sea level. In particular, the origin of these materials could be hypothesised as an area approximately between the villages of Savelli to the north and Belcastro to the south.

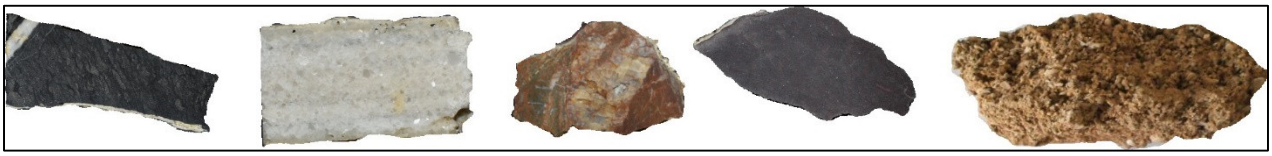

Figure 23. Le Castella, Area A. Comparison among some extrabasinal stones (from left to right, 1 to 4) and calcarenite found in megablocks (right).

This area is intercepted upstream by the complex hydrographic network of the Tacina and Neto rivers and their numerous tributaries (Vitravo, Lese, Soleo, etc.). In this part of Calabria, numerous conglomeratic units can be found with highly assorted clasts, both in shape (rounded) and size, compatible with the samples. The Silan origin of the samples can be inferred from the presence of metamorphic rocks, widespread in the Calabrian–Peloritan mountain range and almost absent in the rest of the Apennines range (e.g., Igneous-Metamorphic Complex of Ampollino Lake), attributable to an Alpine-type metamorphism [81,82]. This is particularly visible to the north of the area that is supposed to be the quarrying source, where limestones and dolomites with chert and radiolarites (Tortonian/Lower Messinian, Miocene) emerge. From northwest to west, there are emerging Alpine series with gneisses, migmatites, schists and porphyries (Triassic), as well as granites/granodiorites (Triassic). However, it must be noted that among the areas with outcrops lithologically compatible with the rocks of Le Castella, the closest is found along the middle valley of the Tacina River, which, among other things, crosses all of the mentioned basins [8] (p. 537).

5.3. Did Two Islands Actually Disappear off the Coast of Le Castella?

The spatial distribution of the stone accumulations identified in Sectors A and B, together with their extrabasinal nature, indicates its anthropogenic origin. Despite this hardly-confutable observation, there are still many doubts about the identification of their specific functions, especially for their chaotic state. The lack of mortar on the stone materials of both complexes, already observed during the surveys conducted by Cooperativa Aquarius on behalf of the Superintendency in 1988 and 1994, should certainly be taken into account.

In regards to the evidence within Sector A, it should be pointed out that the structure does not have an E-W alignment as previously claimed. Therefore, it can't be considered as a protection for the entrance to the small port. On the contrary, its N-S orientation seems to constitute a barrier (or a platform) that flanked the rocky side of the calcarenite formation on which the fortress was built. As this formation should have been more stretched towards an S direction in the past, the work might have been intended as a coastal defence. In contemporary marine engineering jargon, it would fall within the category of 'adherent defences' aimed to protect the surface of the shore profile. Therefore, it may be possible that this mattress was an extension of the presumably sandy shoreline in order to create a stable perimeter strip that could perhaps fight erosion and improve the functionality of the natural harbour. The latter, although small-sized and with a limited draught, was used since ancient times ([5] p. 330–331), ([16] pp. 34–35) and played a significant role in the economy of the area between the late Middle Ages and the modern age, as confirmed by a number of portolan charts and archival documents [83].

However, the submerged evidence pertaining to Sector A poses far more complex questions. First, we must reject the hypothesis by A. Guerricchio, who identified the materials with "a paving slab of an ancient road" ([11] p. 49), ([9] p. 536), ([10] p. 24).

First and foremost, it should be noted that the underwater cartographic surveys demonstrate that the archaeological evidence related to Sector B is located on a shoal, which corresponds to one of the most elevated sectors of the submerged relief that extends itself in a S-SE direction from Le Castella. The top of this shoal can be found at a depth of only 2.6 m, measured on the top of one of the multi-metre-sized calcarenite blocks scattered near the extrabasinal stone accumulations (Figure 24).

Since it is reasonable to assume that the archaeological structure was built on an emerged part of the seabed, or at most in a tidal zone, this sector of the seabed can be clearly identified with one of the islets previously mentioned in numerous historical maps and portolan charts.

Another fact to take into consideration is the difficulty in dating the complex due to the absence of significant archaeological indicators in the area. Fortunately, the lack of data on the function and the chronological framing of the submerged structure is partly mitigated by the comparison both with the Sector A complex and with another underwater site located near Capo Rizzuto, 3.2 nautical miles east of Le Castella. Both areas were built with the same extrabasinal material and the same construction technique observed in Sector B. There is no need to dwell on Sector A as it has been thoroughly examined in the previous sections.

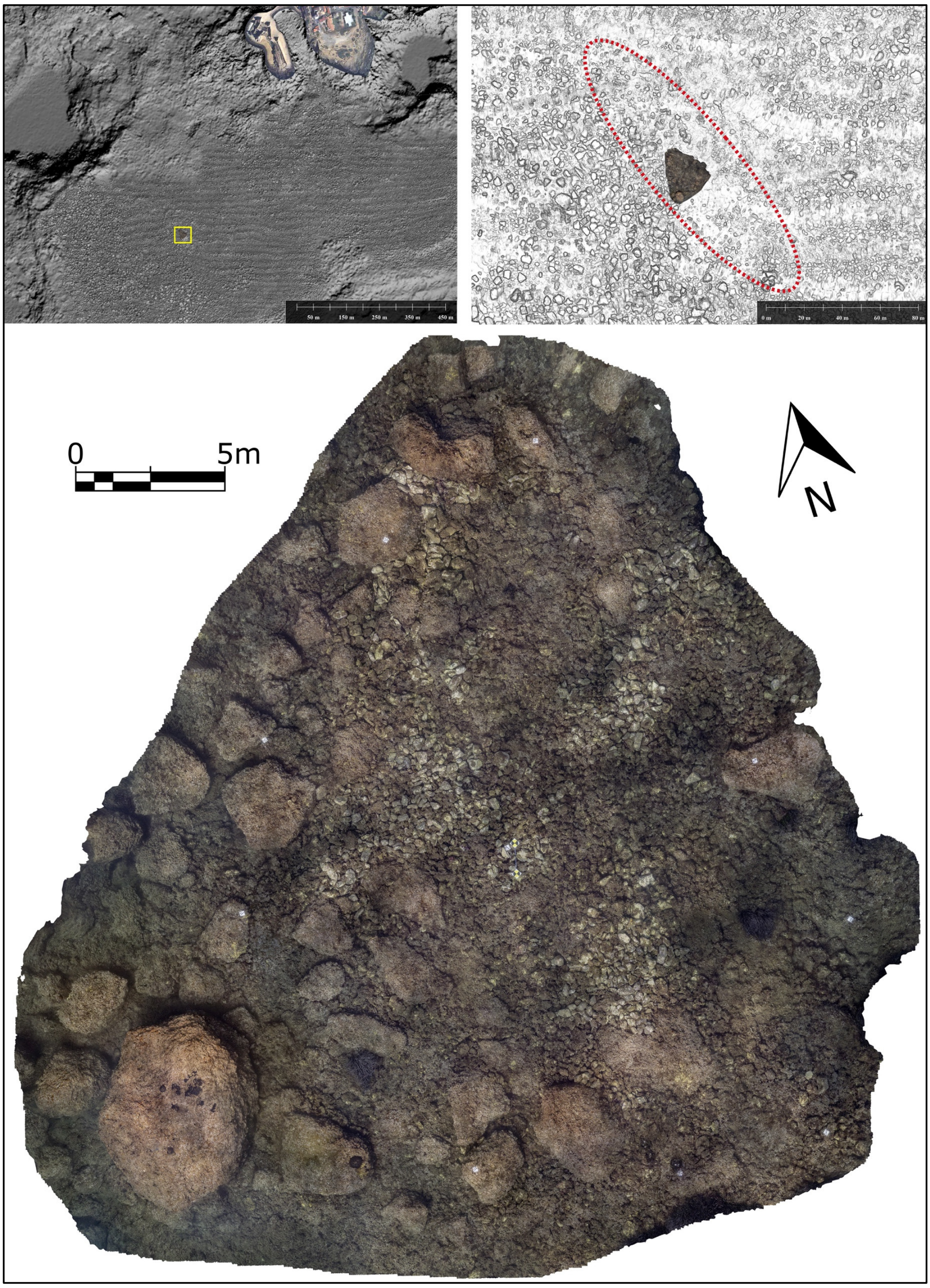

Figure 24. Le Castella. An orto-photogrammetric reconstruction from 3D optical surveys showing one of the submerged areas featuring the extrabasinal materials within Sector B.

The second comparison, very stringent as well, should be made with the western side of the promontory of Capo Rizzuto and, precisely, in an area to be identified with the disappeared Πόρτο Τρουβάτο (or Turvatu), mentioned in the portolan chart *Vaticanus Ottobonianus graecus* 150 and in *Kitab-iBahriyye* by Piri Reis. There is also a very rare testimony of *Porto Trovado* in the Navigation Chart by Zuan di Soligo dating back to 1489 or shortly after, which was made in Venice and is now kept at the British Library (ms. Egerton MS 73 [84]. In any case, the memory of this port was still alive at least until the end of the 18th century, as in 1795 Alfano reported about the western side of the promontory of Capo

Rizzuto: "[. . .] under the water [. . .] the remains of a wall, which shows that there had been some Port" ([85] p. 102), ([8] p. 541), ([5] p. 340). Even at present, in front of the coast and at low depths, there is a large dispersion of extrabasinal stone material composed of phyllites, schists, micaschists, and other lithologies coming from the inland, very similar to those of Le Castella ([8] pp. 537–538). The size of the clasts is also very close to that of the evidence found in the aforementioned Sectors A and B (Figure 25).

Figure 25. Capo Rizzuto. The localisation of the extrabasinal materials pertaining to a supposedly Byzantine marine facility.

The main arm of the Capo Rizzuto submerged complex extends off the coast (strongly subject to erosion) for almost 200 m in an E-W direction. Among the remains of this complex—perhaps to be identified with the pier or a breakwater of a port—there are numerous fragments of ceramics and amphorae datable between the end of the 5th and the 7th century AD. It has been hypothesised that the structure, perhaps part of a coastal garrison, could have been built in the context of military infrastructures for strengthening the eastern Byzantine maritime frontier of the *Brittius* [8].

As mentioned in the previous sections, the archaeological evidence consisting of extrabasinal stone piles off the coast of Le Castella (Sector B) is currently located at a depth that does not exceed 9 m. The coastal area of Le Castella has undergone heavy changes due to the complex interaction of seismic-tectonic and gravitational dynamics, often on variable temporal and spatial scales from the Pleistocene up to now [41,44,80,86].

Although the movements that affected the seabed were not linear, we tried to simulate a lowering of the sea level on the basis of the data acquired with the MBES at a depth of 9.5 m (slightly exceeding the lowest level on which the extrabasinal materials are placed). The maximum level corresponds to the deepest archaeological evidence documented to date. The result, which obviously should be taken as indicative and purely illustrative, shows that two areas with jagged conformations would be created: the one hosting the archaeological evidence and a smaller one located a few hundred meters in an E-NE direction (Figure 26).

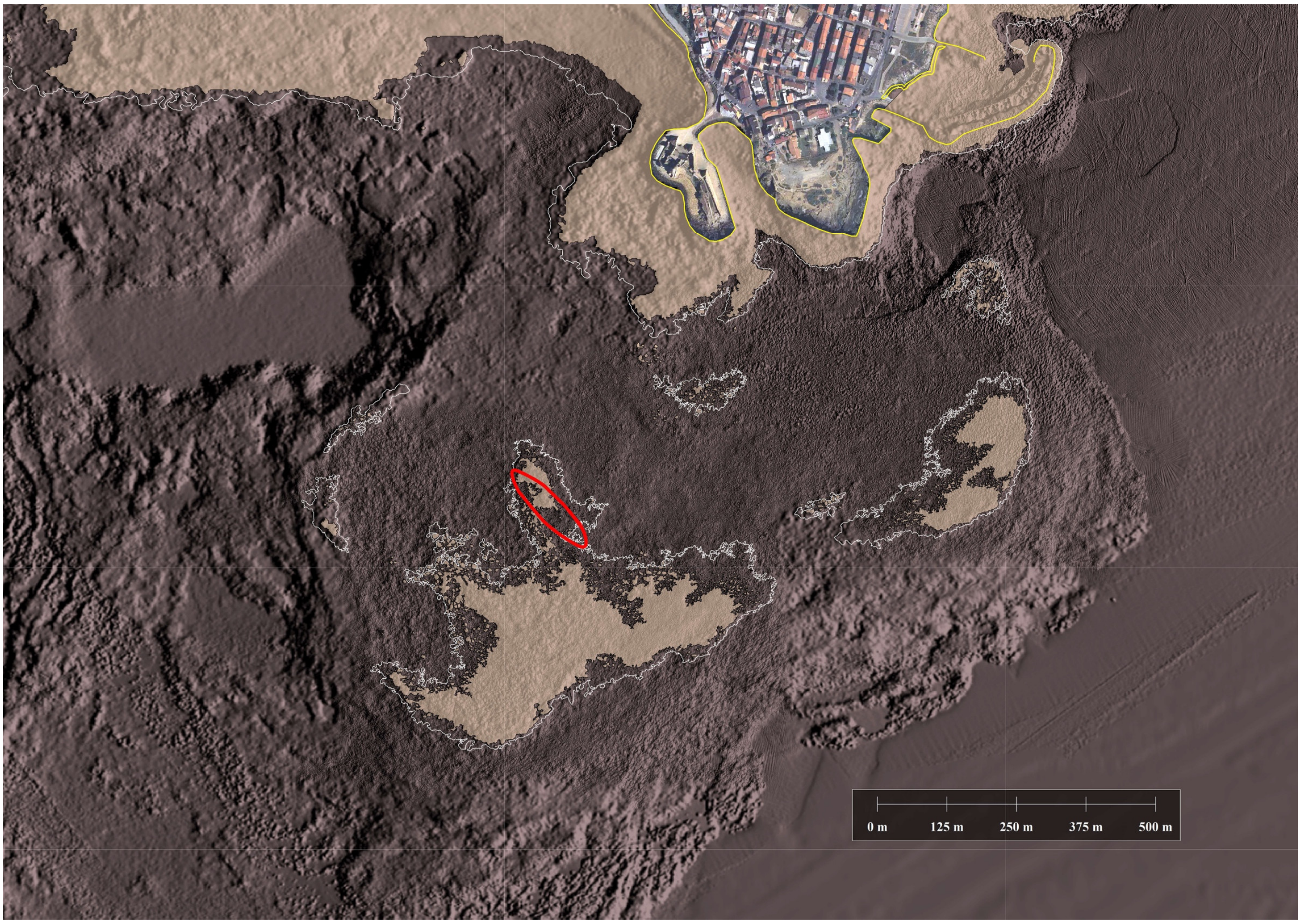

Figure 26. The DTM from MBES with the outcomes of the paleo-geographic simulation of the area with a sea level lower than 9.5 m, considering both the local uplift and sliding (for details, see Geological setting). The white isobath indicates a fixed isoline created with GlobalMapper and rigidly placed at −9.5 m, while the light beige fill indicates the result of an algorithm that hypothesises the water drainage on a 3D surface. In this last model, we used the "Simulate Water Level Rise/Flooding" of Global Mapper. To improve the readability of the plan, we have excluded the closed isolines with a perimeter of less than 300 m. The red ellipse roughly outlines the localisation of the extrabasinal materials, as shown in Figure 19. Simulation elab. by F. Mauri.

Therefore, we can trace some parallels between our simulation and what is reported in portolan charts and historical maps. In this regard, the similarities between the two simulated emerged areas and the two islets depicted in the early 15th-century Ottoman charts by Piri Re'is are particularly suggestive (Figure 11).

We could theorise the conformation of the two islets during the Modern age, i.e., the historical phase to which most of the evidence can be attributed. Useful paleotopographical data are to be found in the portolan chart attributed to Alvise da Cà da Mosto, from the

Kitab-iBahriyye, from the ms. Magliabecchiano XIII, 77 and from the portolan chart of Gorgoglione. In these documents, the perimeter of the islets is mentioned as being dotted with rocks and the seabed is described as “bad”, “poor” or “harsh”, according to the typical terminology used in such documents. Indeed, the composition of the seabed shows clearly that these two emerged areas should have had a rather harsh and rocky appearance. The perimeter of these islets, constantly battered by the waves, was a biocalcarenite platform subject to cracks and structural failures that generated the metre-sized lithoclasts still observable on the seabed. It is no coincidence that the historical accounts sometimes defined these rock bodies as islets, while other times classified them as outcropping shoals. This means that there was a transition phase, roughly between the 16th and 17th centuries, when these formations were reduced to shoals with semi-emergent rocks and about to be submerged and ultimately dismantled by the waves.

To better assess the submerged complexes off the coast of Le Castella from a geo-archaeological perspective, it must be considered that these are not the only areas demonstrating the processes that triggered the change in the coastlines in the area of Crotone in the Late Holocene. Further archaeological indicators related to the presence of unmovable structures are to be found south of Crotone in the Irto area where, between 0.5 and 3.6 m of depth, there is an ancient, submerged quarry from which blocks and column drums of biocalcarenite were extracted [87]. Further south, in the area called Scifo, approximately 250 m off the coast and at a depth of 13 m, a concentration of blocks attributed to a Greek port has been reported ([88] pp. 54–57), ([89] pp. 133–135), ([90] pp. 816–817). However, it is important to point out that further investigations on this site would be appropriate to attest with greater certainty its real anthropic and, consequently, archaeological nature [91].

Going further south, three other submerged areas related to ancient biocalcarenite quarries where blocks and sometimes column drums were extracted have been identified in the areas of Valle Perrotta (between −1 and −4 m), Punta Fratte (between −3 and −7 m) and Le Castella [92]. This last site, located in the stretch of sea facing the western side of the Aragonese castle, is undoubtedly the most significant archaeological indicator of the changes in the coastal geomorphology of the area. On the rocky seabed, up to a maximum depth of 7.5 m, there is an extensive stoneworking area of approximately 10,000 m^2 intended for quarrying parallelepiped blocks. Indeed, the submerged calcarenitic rocks present quarry faces with stepped cuts, and many of them show traces of blocks that were partially quarried and left in situ, as well as abandoned finished blocks. This quarry area can be dated back to the Greek Age and, more precisely, to a period between the end of the 4th and the first half of the 3rd century BC. ([92] p. 27); ([5] pp. 324–325).

6. Conclusions

The hypothesis that this shoal and these extrabasinal materials could once have constituted an island is certainly not a new one. Already in a note from 1845—overlooked in the literature—G. Francesco Pugliese stated the following about Le Castella and the location of the islands mentioned by Pliny: “But wasn’t it the shoal that is a short distance away the famous little island, now submerged by the waves and by so many natural catastrophes over the centuries?” [4,93]. Moreover, long before the Superintendency conducted surveys in 1994 to investigate in a report, other authors, since the early 1970s, had already mentioned the presence of submerged wall ruins approximately one kilometre from the islet of Le Castella [1–3]. Later on, other scholars linked the evidence in question with local subsidence phenomena, thus sparking a debate on the changes undergone by the local shoreline throughout history [9–11].

In fact, the submerged evidence of Le Castella in Sector B (Figure 20) is located on a shoal approximately 500 m in a SW direction from the Aragonese fortress, at a point whose topography is perfectly compatible with the data contained in historical maps and portolan charts regarding one or two islets, which have nowadays disappeared.

Since modern portolan charts have defined these formations in a variable manner, sometimes as islands and sometimes as perilous shoals, it is plausible that between the

16th and 17th centuries they could have already been partially submerged, yet still visible as semi-emergent reefs, thus generating confusion about their actual nature. This is further confirmed by a notary deed kept at the Archivio di Stato of Catanzaro, in which a shipwreck that occurred in February 1751 near Le Castella is described in detail. The strong winds struck a Neapolitan ship that was loaded with goods in Taranto and headed for the ports of Leghorn and Genoa. In an attempt to seek refuge in the small port of Le Castella, it was pushed out towards the open sea and had to drop anchor near the shoals (and not the islets), where it broke its moorings and sank (ASC, b. 1069, 1751, ff. 3-4; notary Bruno Pagano).

Returning to the question of extrabasinal materials, we must leave aside the hypothesis that these could have originated from the loss or the intentional release of the ballast of a ship, as the position of the piles appears too extensive and irregular. The only plausible conclusion is that this deposit is the result of a voluntary action, presumably done when this area of the seabed was above sea level (Figure 27).

Figure 27. Le Castella. An underwater operator carrying out the 3D optical survey of Figure 23.

The lack of dating materials hinders the chronological definition of the site. However, as we have already observed, the strong similarity between the two submerged sites located at a relatively short distance leads us to assume that the structure should be dated to the post-classical age, perhaps between the 6th and 7th centuries AD. In fact, this was the earlier attribution of the submerged evidence located on the southern end of the islet of Le Castella (Sector A) and those pertaining to the western side of the promontory of Capo Rizzuto [5,8]. For all three areas, it has been hypothesised that they should be classified as "infrastructures of collective interest" due to the required economic effort and some political-military function in connection with the defences of the Byzantine maritime *limes* established along the coast south of Crotone [8].

However, though there are several fairly convincing elements about the nature of the structures of Capo Rizzuto and Le Castella-Sector A, the exact function of the complex off the coast of Le Castella (Sector B) remains obscure and requires further studies. About the latter, it must be considered that the lack of a binding agent and its narrow, long conformation will be key in guiding the development of future research. Another fact to be taken into account is the strong similarity with the submerged evidence located in Sector A, which we hypothesised as the function of a barrier for coastal defence. Another element that will drive future research is the fact that the structure located on the shoal of Sector B has a clear NW-SE orientation, i.e., the trajectory of the south-westerly side wind coming from the third quadrant. In fact, south-westerly and southerly side winds were often reported in historical portolan charts as potentially dangerous winds at Le Castella (see, for example, the *Codice Capponiano* 141, kept at the Vatican Apostolic Library, the handwritten portolan chart by Zaccaria Rispolo at the Biblioteca de Catalunya, the *Agrigentinus* at the Biblioteca Lucchesiana di Girgenti, and the handwritten portolan chart by Francesco Monno at the library of Prague, etc.). Even today, they are the most damaging winds, causing significant damage during very violent storms. On the basis of such circumstances, further research shall take into account the hypothesis that the long accumulation of loose stones may have stood as a barrier to break the wave motion at a few hundred metres off the coast. It could have mitigated the force of the sea coming from the SW to make the small port entrance safer.

An element to which we are not able to give an explanation is the reason why the three submerged works (Le Castella Sectors A and B; Isola di Capo Rizzuto) were built with extrabasinal materials sourced from an inland area of Calabria, therefore discarding the calcarenites which are abundant along the coast of the Crotone peninsula and would have required a much lesser economic effort. A likely justification may be related to the different technical properties of the materials. Since calcarenites are relatively soft rocks, perhaps they lacked the necessary mechanical properties for their intended use. In any case, calcarenites constitute a notable part of the soils upon which the village of Le Castella stands and, since their emplacement between 60 and 40 ka, have undergone a strong uplift that has given rise to the marine terrace. Considering both the relative rise of the eustatic sea level during the Holocene [94] and the tectonic movements, we can assume the complete emergence of the terrace at a date between 10 and 8 ka. Moreover, during the emergence of the promontory, the seabed could have been approximately aligned with the horizontal plane. Subsequently, the tectonic-structural subsidence in an offshore direction, also favoured by the submerged normal fault that cuts the terrace in two (Figure 2c), with the consequent inclination of the base plane [89,95,96], led to the sinking underwater and dismantling of part of the marine terrace in its southern section, as well.

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