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Posted Date: 7 October 2024

doi: 10.20944/preprints202410.0500.v1

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Identifying Anthropogenic versus Natural Submerged Prehistoric Landscapes: Two Case Studies from the Sicilian Channel

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Abstract: In submerged landscapes, distinguishing anthropogenic features versus natural ones, is often challenging. We have developed a set of criteria to validate the identification of submerged anthropogenic remains that include, examining the geological context, sea-level considerations, associated archaeological finds (including coastal survey), and documenting the broader archaeological context. Furthermore, our experience demonstrates that, while progress has been made in applying remote-sensing technologies to detect anthropogenic features on the seabed, there is no substitute for direct, visual assessment by an underwater archaeologist for verification of their anthropogenic status. We have applied these criteria to examine two published case studies detailing suspected anthropogenic stone features on the seabed in the Sicilian Channel. Our examination has led us to conclude that both localities are not anthropogenic features. The Pantelleria Vecchia Bank features represent natural outcrops on a submerged paleo-landscape that were shaped by depositional and erosional processes, during transgression and regression periods. The suspected Lampedusa cultic site, comprises natural features that are located on a submerged neo-landscape formed due to erosion and retreat of the coastal cliff since the Mid -Holocene, when sea level reached its present level.

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1. Introduction

The post-glacial rise in sea level (ca. 20,000 to 5,000 years BP) inundated large regions of previously dry coastal plains resulting in submerged areas of the continental shelf [1,2]. These included areas that had been occupied by people since the Early Paleolithic period e.g. [3–6]. As early as 1937, A.C. Blanc, who studied the west coast of Italy [7], hypothesized that prehistoric materials and terrestrial landscapes could be preserved on the submerged continental shelf, and indeed, in the past 80 plus years, thousands of prehistoric sites have been found underwater, representing a unique environmental and cultural record [8–14]. However, identification of submerged anthropogenic sites is often challenging since underwater features of natural origin can sometimes be misconstrued as human-made (i.e. pseudo-archaeological). This, as submerged natural stone features, resulting from erosional or depositional processes, frequently exhibit symmetrical or repetitive forms whose origin can be misleading. Notable examples of suspected submerged anthropogenic sites are the localities of Yanuguni and Kerama, in southern Japan [14,15]. These are two submerged rock formations identified as anthropogenic by amateur archaeologists but never confirmed as such by professional

 doi:10.20944/preprints202410.0500.v1

scholars. Conspicuously, neither site has yielded in situ, diagnostic archaeological fingerprints (e.g., tools or tool marks or archaeological remains), raising suspicions that they are just impressive natural structures.

Establishing a set of validation parameters based on archaeological considerations, in combination with studies of factors related to earth sciences, is crucial to ensuring the accurate and correct identification of submerged anthropogenic sites and features. Factors to be considered in the verification process include, identifying distinct patterns of deliberate material selection (such as slabs or elongated stones) to exclude those which can occur naturally, determining the provenance of the stones (local or non-local), and analyzing the arrangement patterns of rocks and stones [10,16–19]. Critically, finds should never be studied in isolation. Characterization of the geological substrate establishes the age of the rock formations in the research area and their relation to the suspected anthropogenic remains, while observations of sea-level and tectonic activities that may have affected the area at the time of the proposed human occupation are also necessary in order to understand site formation processes. Additionally, geomorphological observations can reconstruct depositional and erosional processes and indicate signatures that are anthropogenic versus those that are natural. For example, natural agents (e.g., rivers, waves, tsunamis) or anthropogenic ones (e.g., ships) may have brought artifacts found on the seabed to their find location, while sedimentation, erosion, and abrasion processes may generate anthropogenic-like features, cover or destroy sites. It should be noted that by themselves, none of these earth science datasets are enough to unambiguously establish the anthropogenic origin of a site. The presence of indicators clearly linked to human activity (e.g., artifacts- made of stone, bone, organic materials, flint tools, production waste, charcoal, faunal and floral remains), are the key elements needed to confirm an anthropogenic origin [10,16–19]. These items can be found through direct observation, survey and/or excavation of anthropogenic material on the sea bottom by underwater archaeologists. In recent years, remote sensing technologies have been commonly used to explore and map the currently submerged paleo-landscapes in search of prehistoric sites. Although these methods provide unique and useful information, as will be detailed below, their findings need to be corroborated by detailed archaeological research as there is no substitute for the knowledge and direct examination by an underwater archaeologist.

In this study, we discuss two published examples that deal with stone features that are suspected as anthropogenic in origin. Both are, located on the sea bed of the Sicilian Channel: (i) The Pantelleria Vecchia Bank stone ridges and monolith, and (ii) stone arrangements situated off Lampedusa Island (Figure 1). In each instance the, features were first studied (without the aid of professional archaeologists) by geologists and recreational divers using remote-sensing technologies, and interpreted as anthropogenic in origin. With this work, we want to test the hypotheses proposed through the application of the archaeological and geoarchaeological methodologies outlined above.

In order to evaluate whether these submerged localities are natural or anthropogenic, we have analyzed the data presented by the discoverers and complemented these data with underwater and coastal surveys at the suspected site off Lampedusa (carried out by two of the authors). Although the Pantelleria Vecchia Bank was not surveyed by us, due to accessibility limitations, the published data is critically assessed here. We present our findings which serve as an example of the inadequacy of remote-sensing technologies, and the need for rigorous, hands-on examination of suspected anthropogenic sites by experienced underwater archaeologists.

1.1. History of Submerged Prehistory

The field of submerged prehistory emerged following finds of faunal and lithic remains that were dredged up in trawler nets in the North Sea [20], while terrestrial forests were identified in various intertidal areas of the United Kingdom and France [21–24]. Additionally, sporadic finds by recreational divers helped to trigger interest in this research. For example, in the 1960's, the first reports of finds of Neolithic objects from the submerged locality of Tel Hreiz, situated off the Mediterranean coast of Israel [25,26], then led to the discovery of more than 16 concentrations of submerged Neolithic sites and the test excavation of the coastal sector of the submerged Pottery Neolithic site of Neve Yam [9,19,26–28]. These discoveries contributed to the development of pioneering excavation methods of submerged prehistoric Mediterranean sites (e.g., Neolithic sites of Atlit-Yam and Kfar Samir; 19,29), complemented by multidisciplinary studies of the archaeological finds (e.g., sediments, flint tools, pollen, floral, faunal and human remains). The methods used were later consolidated as the Israeli Model for the detection, identification, and investigation of submerged prehistoric remains [19,30]. Parallel to this, similar processes were taking place in other parts of the world. One early example was the use of a systematic methodology to study the sub-bottom and seabed in search of possible prehistoric remains, following extensive industrial work on the sea bottom of the Gulf of Mexico [31]. For this, remote sensing methods were applied to produce bathymetric and sub-bottom profiles. This data was corroborated by sediment samples which helped to reconstruct the terrestrial paleoenvironment. These identifiable landforms were correlated with known archaeological features on land to generate predictive models. If a possible site was identified, further sediment samples, underwater documentation, and diver investigations were undertaken [31,32]. The basic methodologies used in the 1970's in the Gulf of Mexico, have since benefitted from improvements in technology and intensive work in the field [23,37,38]. Another example is the Danish Model developed by Fisher [33–35], aimed at locating submerged prehistoric sites by identifying submerged landforms similar to terrestrial counterparts that were known to be rich in archaeological remains.

The need to investigate areas currently covered by thick layers of sediment, has guided investigations to look for anthropogenic signatures beyond the presence of human-made artifacts, including finds related to paleoenvironmental proxies such as charcoal, faunal remains, and pollen [24,36,37]. The accumulation of more than 40 years of experience since the first conference (1981) and publication of the first book relating to the topic of submerged prehistoric sites and landscapes [3], has resulted in general models and recommendations for the investigation of submerged landscapes and prehistoric sites, offering robust protocols for their detection/identification, investigation, and preservation, as detailed below. Direct-contact diving surveys are usually conducted in shallow areas, where snorkeling and scuba diving is possible, while remote sensing studies are undertaken in deep water and sediment-covered areas.

1.2. Citizen Sources

Despite the extensive work that has been undertaken to produce efficient models and research strategies, most often submerged prehistoric remains are reported based on citizen observations - with the naked eye, or found by a fisherman's net [19,33,34,40,41]. Thus, gathering data from citizen sources like industrial, military and recreational divers, and fisherfolk, is essential.

1.3. Depth Dependent Likelihood of Detecting Prehistoric Sites

The inundation and drying (terrestrial conditions) of a submerged landscape is generally conditioned by Pleistocene sea levels. Analyzing the available global sea-level curves suggest that areas situated at greater depths on the seabed experienced shorter periods of exposure during low-sea level phases. Thus, the likelihood of encountering preserved prehistoric sites diminishes in deeper locations [17,19]. Additionally, the last time the continental shelf was exposed beyond a depth of 50 meters dates back to 13,000 years BP. These landscapes would have been inhabited by hunter-gatherer communities whose sites lacked substantial architecture and whose ephemeral activities are unlikely to be preserved or found [17,19]. On the other hand, in shallow waters, the likelihood of discovering submerged prehistoric deposits and architecture increases, as these relate to more recent periods when the paleosols were exposed for longer periods of time and also occupied by sedentary communities. Regrettably, modern human activities (development, building, quarrying) and consequent marine erosion pose great threats to these areas, leading to their heightened destruction. Moreover, excavating in extremely shallow water the intertidal and surf zones (0-5m) presents extremely difficult working conditions due to changing sea conditions, rapid erosion, and sedimentation of the excavated area [10,12,13,17,19,42].

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1.4. Models for Detecting Sites

Generating models for prehistoric site detection mainly focuses on producing a comprehensive picture of the paleo-landscape by applying sea-level considerations and using remote sensing technologies enabling high-resolution reconstruction of prehistoric landscapes. However, choosing the most appropriate method for detecting, surveying and researching sites are also crucial, and often the use of simple, low-tech methods is no less effective than costly sophisticated technologies. Together with archaeological information from adjacent terrestrial areas (site distribution patterns, site layout, chrono-cultural entities, etc.) and geological data of the studied region (river outlets, raw material sources, detection of cultural or biological relics relating to ancient sea levels etc.), can be used to produce models to detect areas of potential interest [18,19,33–35,37,43–46]. Additionally, current research efforts have seen the development of methods that explore a broad range of anthropogenic signatures aside from the presence of items of material culture, and this includes investigation of finds related to paleoenvironmental proxies such as charcoal, faunal remains, and pollen [24,36,37].

1.5. The Utilization of Paleosols and Rocky Coastal Areas by Prehistoric Populations

In the Mediterranean Basin, submerged remains of early agropastoral societies (Neolithic-Chalcolithic) are generally associated with paleosols that developed under terrestrial environments. However, paleosols may also be affected by high sediment input that cover sites and make them difficult to detect and access [10,12,13,19,47,48]. The use of rocky coastal areas by past peoples since the Paleolithic may be underestimated in prehistoric research due to the scarcity of evidence for such use, though they were generally less sustainable for agro-pastoral human occupation due to the lack of arable land. Intense abrasion that affects such areas during inundation and periods of high-stand sea levels, have probably destroyed much of the remains [10,12,13,19].

1.6. The Importance of Archaeological Investigations to Corroborate the Anthropogenic Nature of a Site

Acquisition of submerged landscape data by remote sensing and geophysical technologies has developed extraordinarily quickly. Using innovative and sophisticated technologies often helps to detect and document in great detail underwater features, and reconstruct the paleo-landscape which is currently submerged [24]. However, these techniques do not provide information on a site's archaeological setting and stratigraphy. Such archaeological data, in addition to finds of material culture (e.g., stone, bone and wood artifacts, flint tools, architecture elements, stone arrangements), and anthropogenic associated finds (charcoal, dung, ash, human remains, faunal remains with butchery marks) can only be obtained by archaeological survey and excavation [17–19,44,49–51]. Such data are crucial for establishing whether a site is anthropogenic in origin or not.

2. Materials and Methods

The sites discussed and re-evaluated in this article were investigated using different research strategies. In assessing the Pantelleria Vecchia features we could only use material available in publications, and field survey was not possible because access to the site is restricted. In contrast, the submerged Lampedusa site could be accessed and surveyed. In both sites sea-level and tectonic considerations were assessed, deposits from the MIS5e isotopic stage were checked to gauge tectonic stability, and data regarding the dating of geological and archaeological features was considered. The published data from the petrography and thin sections from the Lampedusa Vecchia site were checked, and the availability of human-made finds and traces (charcoal, faunal and floral remains as well as flint, bone and stone artifacts) in the suspected anthropogenic sites were considered. In addition, we deliberated whether the studied sites are submerged paleo-landscapes that potentially could have been occupied by humans in prehistoric times, versus submerged neo-landscapes which are relatively young, and so could not have been occupied during prehistoric times.

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3. Results

3.1. The Pantelleria Vecchia Bank

- Archaeological setting:

The earliest signs of human habitation on the island of Pantelleria trace back to the Neolithic era around the 8th millennium BP. Archeological findings, such as a workshop for crafting obsidian located at Punta Fram near Pantelleria city's modern cemetery, suggest early human activity [52]. Various artifacts like tools, ornaments, and weapons crafted from Pantelleria obsidian, discovered across Sicily, Malta, Tunisia, Southern France, and other Mediterranean regions, indicate a sustained human presence and a vast exchange network during the Neolithic period [53]. Concrete evidence of permanent settlement emerges during the Bronze Age, particularly from the late-5th to late-4th millennia BP, notably with the Mursìa village and the Sesi necropolis [52]. Subsequently, Pantelleria's history reflects influences from various cultures, including the Phoenicians and the Romans [53,54].

- Geological setting:

The Pantelleria Vecchia Bank is situated on the Adventure Plateau, between western Sicily and Pantelleria island (Figure 1). It is a submerged landscape, currently at 35-50m depth, which was connected to Sicily during low sea stand of the glacial periods. During the Younger Dryas (ca. 11500 yr. BP), when global sea level was ca. 55m lower, the area was an archipelago of six dispersed islands located off the southwestern coast of Sicily, while at the end of the 1B Melt Water Pulses (ca. 11.200 BP) the sea level was ca. 40m lower and the islands were smaller [55]. Analyses of geomorphological markers [55,56] have shown that the north-western Sicilian Channel is tectonically stable at least since the Late Pleistocene (with estimated vertical change of ±0.04 mm/yr). This was confirmed by independent measurements derived from semi-permanent GPS stations [57] which do not reveal significant present-day tectonic activity in this region.

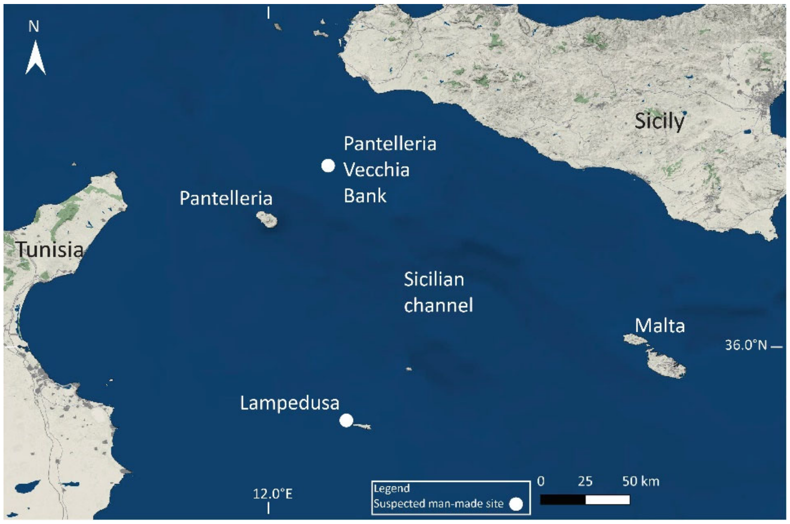

Figure 1. Location of the two studied sites modified after [58]. (Map: Terrain background layer, with black coastline overlay by EOX-4326).

- Past studies:

Two submerged enigmatic stone ridges and a stone monolith in the Pantelleria Vecchia Bank (NW Sicilian Channel) were studied by Lodolo and colleagues [58] and Lodolo and Ben Avraham [59] (their 2015 and 2023 papers). In a third paper from 2024, Lodolo and colleagues describe a few undated ridges, in the form of a half-ring, on the Pantelleria Vecchia Bank (Figure 2D) [60]. The underwater features are located tens of kilometers offshore, between Pantelleria and Sicily, at a depth of ca. 35-40m on the seabed, (Figures 2 and 3). In their studies the researchers used a multibeam swath bathymetry and high-resolution seismic reflection data, radiocarbon dates, and petrographic thin sections of rock samples. Documentation, photography and sampling were carried out by technical

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divers. Radiocarbon ages for four rock samples, analyzed in two different laboratories, all fell within MIS3 i.e. Late Pleistocene (39,960±500 cal. BP to 44,560±1270 cal. BP) [59] (Table 1) and are close to the limit for radiocarbon [59] (p. 399). In the three articles, the authors tentatively suggest that these features (Ridges 1, 2, the Monolith and the half-ring ridges) could be anthropogenic in origin and propose that they are respectively, Neolithic and Mesolithic in age [58–60].

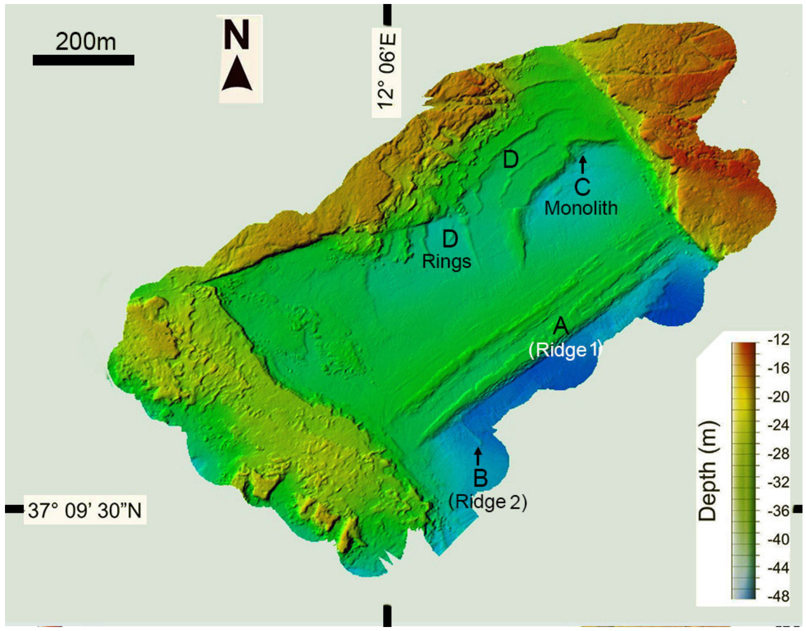

Figure 2. A multibeam image of the Pantelleria Vecchia Bank modified after [58.

1. Ridge 1; is an 820m long stone ridge whose lower part is covered with sediment while the upper part comprises what Lodolo et al. (58) describe as "horizontally arranged" stone blocks 0.5m thick, some rectangular in shape, with the largest measuring ~3.4m (Figures 2A and 3). Based on thin section petrography analysis of samples collected from the features, their lithology was classified as bioclastic sandstone (SI Table S1). The ridge was interpreted as having been initially embedded in coarse sand during a low sea-level stand some 40,000 BP. Lodolo et al. (58) suggest that later, ~9000 BP, the natural deposit was modified and stone blocks intentionally erected by prehistoric inhabitants of the region to serve as a coastal defense against sea-level rise.

Figure 3. Rock blocks on Ridge 1 after [58].

2. Ridge 2; is an 82m long and 6–8m wide stone feature that lies perpendicular to, and 100 m north-east of the west end of Ridge 1 (Figures 2B and 4). It too is characterized by rectangular stone

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blocks that rise 1m above the surrounding seafloor. Based on thin section petrography analysis of samples collected from the features, their lithology was classified as bioclastic sandstone (SI Table 1). In their 2023 paper [58], Lodolo and Ben Avraham suggested that *"It seems unlikely that this concentration of peculiar and geometrically regular structures would develop by natural processes in this small (~0.5 km) study area. …………… In view of the above, it seems possible that the two ridges are associated with human occupation"*.

Figure 4. Rock blocks on Ridge 2 after [58].

3. The stone Monolith is located at 35m depth, some 200 m north of Ridge 1. It is described in the 2015 paper [59] as a ~12m long stone Monolith that broke into three stone blocks that are now arranged in a line (Figures 2C and 5). Based on thin section petrography analysis of samples collected from the features, its lithology was classified as bioclastic sandstone, similar to Ridge 1 described above (SI Table S1). In three different places on this rock, there are holes, one which runs through the rock from side to side. The authors suggest that the rock represents a broken human-made megalith, associated with a Mesolithic culture that occupied the Pantelleria Vecchia Bank during low sea-level ~13,000 years BP, that was probably placed in a erect position. They therefore assume that people extracted the rock and transported it some 300m from Ridge 1 and then erected it. The following features were offered by them to support the anthropogenic origin of the Monolith: 1) It is made of the same rock and is the same age as Ridge 1; 2) there is no natural process that could create the three symmetrical holes of similar size (diameter) that are found in specific locations at the top and side of the Monolith; 3) the location of the rock and its isolated position would have made it stand out in the landscape.

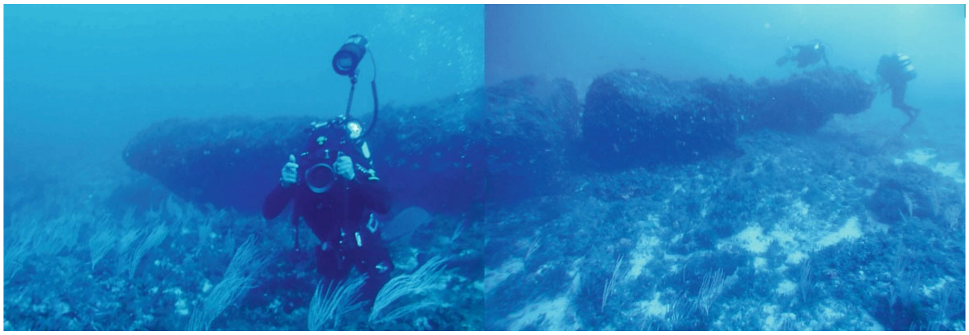

Figure 5. The isolated Monolith after [59] (Figure 4: lateral view from S-W).

4. The half-ring features are sequence of blocks (up to 3m long and 0.5m thick) accumulations forming parallel, curved, ridges stretching a few hundred meters to the north of Ridges 1 and 2. Based on thin section petrographic analysis of samples collected from the half-ring features (see SI Table S1), their lithology was classified as bioclastic limestone dated to the Late Miocene (Tortonian) [59,60]. The rock type of the half-rings ridges is identical to the surrounding rocks

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forming the Pantelleria Vecchia Bank. Lodolo and colleagues excluded the possibility that the concentric half-rings were formed by natural processes and suggest that they were originally part of humanmade structures functioning either as, fortifications, anchorage, fishing installation, archeological trasses, or used for ritual practices [60].

3.2. The Lampedusa Site

- Archaeological setting:

The initial occupation of the island of Lampedusa dates back to the Neolithic period, circa 6000 BP, with the earliest evidence for human presence from the site of Cala Pisana, excavated by the University of Pisa [61]. The island, which was investigated by Thomas Ashby in 1909 and by the Natural History Department of the University of Pisa in 1971, is abundant in late prehistoric or early Bronze Age architectural remains characterized by circular-shaped stone structures. The period and purpose of these structures remain unclear and they have been interpreted as agricultural installations or dwellings [62]. From 1000 B.C. until modern times, the island has been influenced by various cultures, including the Phoenicians, Greeks, Romans, and World War II events [63].

In publications from 2014 and 2019, Diego Ratti tentatively proposed that he had found a possible submerged prehistoric place of worship off the north-west coast of the island of Lampedusa [64,65].

- Geological setting:

The suspected megalithic installation was detected off the northwestern coast of Lampedusa, at the foot of a cliff, more than 100m high (Figures 6 and 7). Grasso and Pedley [66] conducted a detailed geological survey of the elongated east-west oriented island. They reported on a northwest-southeast trending Late Miocene fault (a monoclinical flexture) which divides the island into two morphological units: To the west all strata are horizontal, with up to 100m high vertical cliffs on the coast. The southern and southeastern shores are ria-type, with well-developed, drowned river valleys and small bays. While rapid headward erosion has destroyed much of the original pre-Tyrrhenian coastline in the western promontory and northern coasts, no such destruction has occurred at the southern and southeastern sides of the island [66]. Unlike the ria-like eastern and southeastern sectors of the island, this region is characterized by active coastal erosion creating coastal cliffs and numerous landslides. Erosion of the bedrock reveals two main layers on the section of the coastal cliff: white chalkstone at the bottom of the cliff and darker yellow limestone on its top.

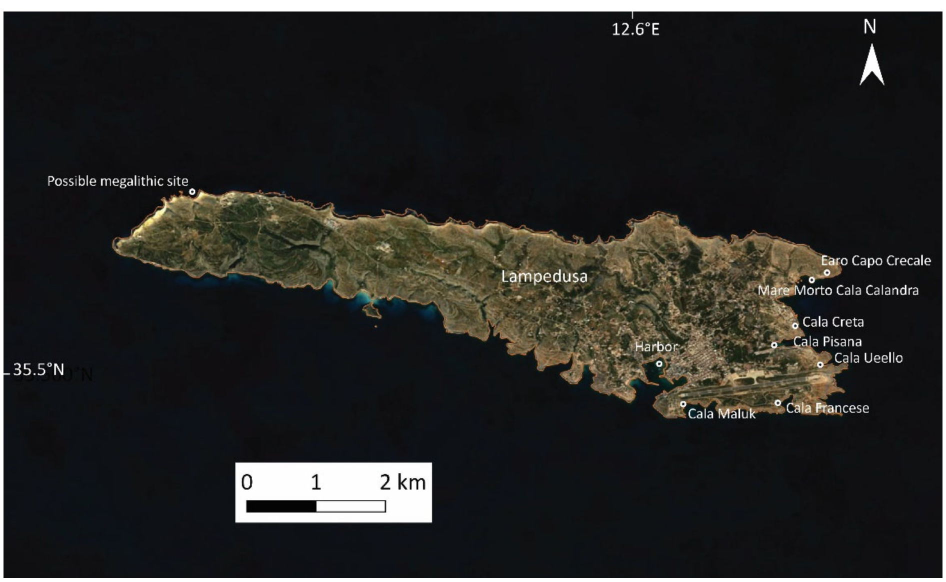

Figure 6. Lampedusa Island and the location of sites mentioned (Map: Modified after Sentinel-2 cloudless layer for 2023, with bright overlay layer by EOX – 4326).

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- Past and present studies:

The suspected megalithic site at Lampedusa was initially explored by recreational divers [64] using multibeam images and aerial and underwater photographs. In 2019, two of the authors (EG and IOR) investigated the site and associated features, with the purpose of inspecting the submerged landscape and the suspected anthropogenic nature features in the site. The underwater surveys were carried out using a diving boat and standard scuba, underwater camera, measuring and sampling devices. A complementary coastal survey was also carried out aimed at identifying possible parallel human-made structures on land, and archaeological and geological features that could be used as indicators of ancient sea levels vertical tectonic changes.

Figure 7. Active cliff retreat in the studied site creating caves, sea stack and submerged neo-landscapes (E. Galili).

In his publications, Diego Ratti described features made of stone boulders off the northwest coast of the island at an average depth of -11m below sea level (Figures 8–10). His underwater surveys close to the foot of the cliff, yielded two circular stone formations, bounded to the north by a bedrock plateau (Figure 10: 3). The size of the stones ranged approximately from 1.5 to 5m. A 50cm deep probe made by us into the carbonate sand within the circle installation (and tested by hand fanning), was aimed at finding anthropogenic remains like stone tools, imported stones, charcoal or bones, but yielded no finds. Initially, Ratti had thought these structures were simply a random set of broken rocks that had rolled from the nearby cliff following natural coastal erosion. However, after various diving surveys and aerial photos, Ratti perceived that the rocks formed circular and elliptic enclosures, similar to those of a prehistoric place of worship with an area of rock cut steps [64,65].

Figure 8. Boulders on sea bottom at the suspected cultic site off Lampedusa (for location see below Figure 10 nos. 1, 2) (E. Galili).

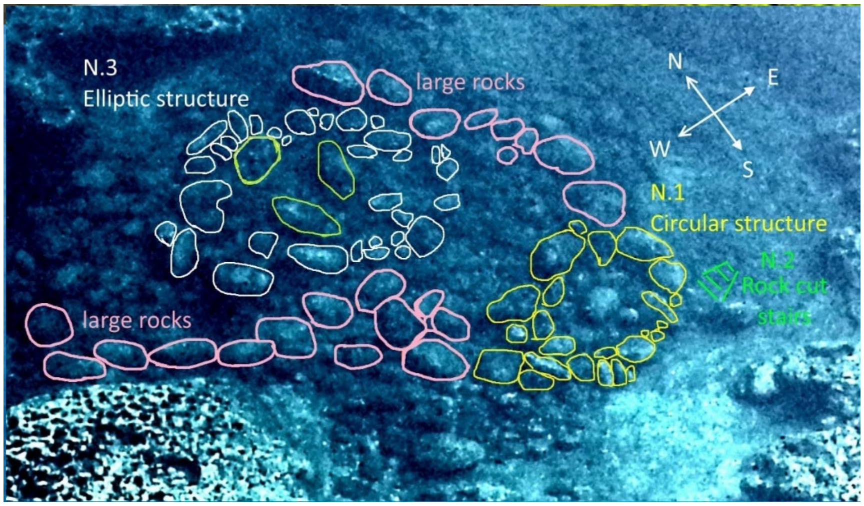

Figure 9. Plan of the suspected cultic site (courtesy Diego Ratti, after 62: Figure 2.88).

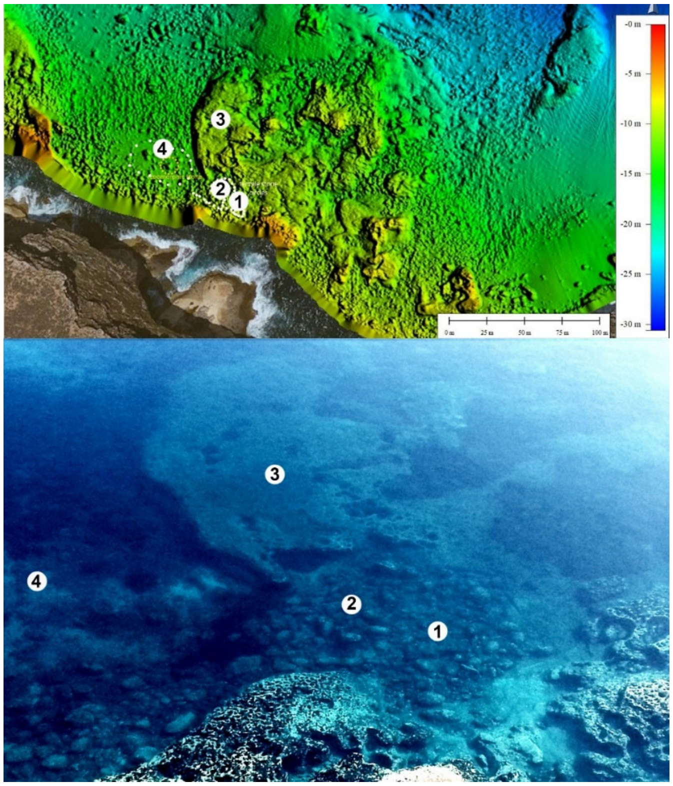

Figure 10. Above: multi beam image of the site with location of the main features: 1, 2 - concentrations of boulders suspected to represent cultic circles, 3 – flat surface of in-situ eroded rock, 4 - Suspected zoomorphic feature or natural erosional feature (courtesy Diego Ratti and CNR Centro Nazionale delle Ricerche), Below: Aerial photo of the suspected site (courtesy Diego Ratti).

Additionally, a protruding rock on the seabed, located ~30m north-west of the boulder concentrations, was suspected to be a zoomorphic sculpture (Figure 10 no. 4 and 11).

South of the site Ratti identified pits in a submerged cliff that he suspected represented rock cut tombs, while west of the site were rocks that are zoomorphic in shape (Figure 8).

In 2019, the data collected by Diego Ratti was complemented by underwater and coastal surveys led by two of the authors (E.G. and I.O.R.) together with Diego Ratti, Pietro Ratti, Fabio Giovanetti, Anna Sardone and Giuseppe Sorrenti. Samples were taken from the boulders, the sea bottom and the

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supposed zoomorphic rock, and were examined with the naked eye. During the underwater surveys in and around the suspected anthropogenic site, two main rock features were identified on the sea bottom, at ~10-15 m depth:

1. Clusters of boulders of various sizes and shapes, which had collapsed from the coastal cliff. These are scattered in a random pattern on the shallow (1-12m deep) sea bottom, close to the foot of the coastal escarpment as usually can be found in colluvial deposits and landslides (Figure 7). Of the hundreds of boulders found there (Figure 9), some stone clusters may resemble human-made "stone arrangements".
2. Rock features protruding from the original in-situ rocky deposit on the sea bottom. These are the remains of rock deposits which were more resistant, thus underwent erosion and remained in their original location. Some of these are isolated, vertical protrusions (Figure 10 no. 4), while others are large (up to 50x30x3m) rock surfaces (Figure 10 no. 3). Galili and Ogloblin-Ramirez [67] summarized their research in an unpublished report, in which they noted that the boulders concentrations on the sea bottom are situated close to (10m or more) the foot of the coastal cliff, and that the numerous features identified on the sea bottom are typical products of a coastal escarpment under erosion (Figure 6).

Figure 11. Suspected zoomorphic feature or erosional feature at the Lampedusa site (for location see Figure 10 no. 4) (E. Galili).

In their observations, they note that one boulder concentration comprised mainly local limestone from the upper stratum of the cliff, while the second concentration was a mix of chalk and limestone originating from both strata of the cliff (Figure 12). The proposed zoomorphic rock feature is composed of an in-situ deposit of chalkstone. The underwater surveys in and around the site revealed no clear human traces, neither artifacts nor tool marks. Galili and Ogloblin Ramirez [67] concluded, that the stones that make up the suspected ritual structure actually represent natural boulders which fell from the cliff, as initially suggested by Ratti. In 2022, Ratti published a new version of his 2015 book "Lampedusa Preistorica" [68] (pp. 182–204) accepting the natural origin of the suspected megalithic site, as proposed by Galili and Ogloblin Ramirez [67].

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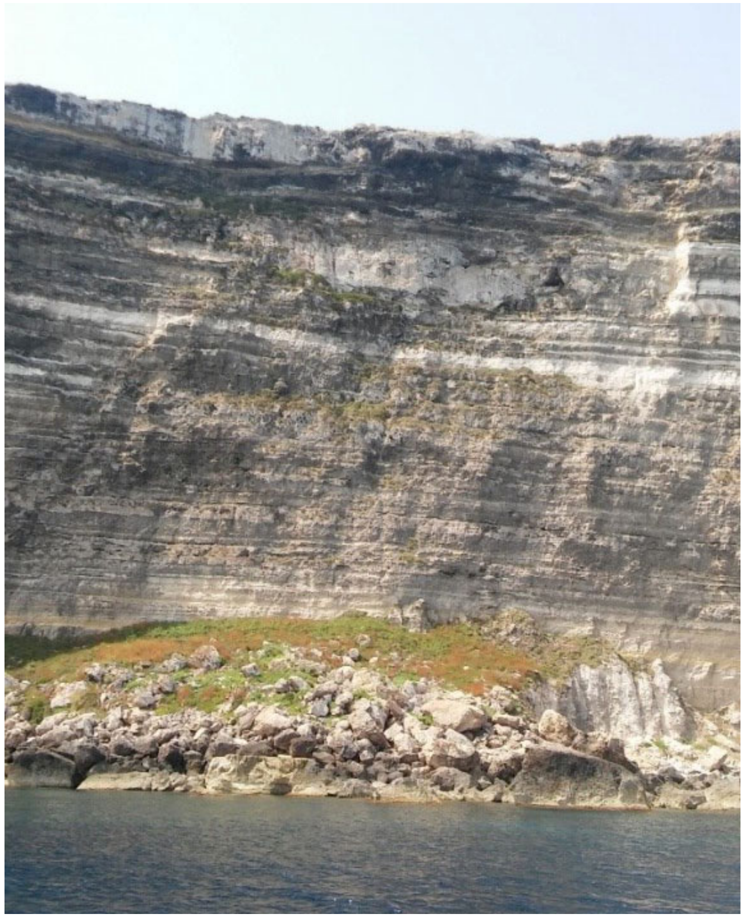

Figure 12. Typical landscape and cliff retreat on the west and north-west coast of Lampedusa site - the retreating coastal escarpment and fresh landslides (E. Galili).

4. Discussion

4.1. The Pantelleria Vecchia Bank Site

Already in 2015, Tusa et al. [69]. published a detailed rebuttal (in Italian) of the Lodolo and Ben-Avraham [59] paper, presenting extensive geomorphological, contextual and archaeological data to refute their claim of having found a large anthropogenic megalith. However, Lodolo and Ben-Avraham were apparently unconvinced and presented the same arguments in two additional articles [58,60]. Consequently, we have felt compelled to re-examine the issues raised by Lodolo and colleagues relating to the anthropogenic nature of their finds. With reference to examples from the Mediterranean coast, we explain why in our view (and as previously noted by Tusa et al.) [69], the rock formations they describe on the Pantelleria Vecchia Bank, do not support their claim that these are human-made constructions, but rather confirm that these are natural features.

- Geomorphological considerations:

Based on the thin sections shown in the publications of Lodolo and colleagues, they proposed that both Ridge 1 and Ridge 2 are composed of bioclastic rocks, (either beachrock or consolidated beach deposits), and that the elongated Ridge 1 that blocks the submerged bay, is probably a beachrock that was consolidated and embedded in the intertidal zone during a low sea- stand, some 45-50ka BP, as the 14C dates indicate. This interpretation is supported by the sea-level curves [70–72], suggesting that the sea bottom in the Sicilian Channel was dry land between ca. 75,000 to 10,000 BP. It is emphasized here, that the dates presented by them, reflect the timing of beachrock consolidation and not that of suspected anthropogenic activities.

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Beachrock is a common formation in the Mediterranean Sea and often forms on sandy coasts. As already noted by Tusa et al. [69], beachrocks (our translation from Italian follows) *"often detach from the rocky basin of origin due to coastal erosion, depositing themselves in the Mediterranean Sea between +1 and -5 meters with respect to the coastline (they are known and dated up to a depth of 60 meters in Sardinia, Turkey, Sicily, Greece, Croatia and Liguria)"* for example see [73,74]. Thus, various features and patterns resulting from coastal erosion of beachrock and beach deposits (e.g., chimneys, detached rectilinear blocks) are common in coastal environments.

- Sea level and tectonic considerations:

Vertical earth crust changes due to tectonic activity, isostasy or structural changes, may have changed the relative sea level in the research area. However, given that the area is considered relatively stable [56] such changes, if they occurred during the Holocene, would have only have resulted in a displacement of a few meters. Thus, the height of the reported finds relative to sea level, and the deposition and erosion processes of the beachrocks under coastal/shallow marine conditions, have not changed considerably. Notably, according to the sea-level curves, the two stone ridges were exposed to coastal/intertidal/shallow marine conditions circa 10ky, 75ky and possibly 50ky before present (Figure 13: 1, 2, 3). We contend that during these events, the beachrock Ridges most probably underwent significant erosion resulting in the rectangular forms observed.

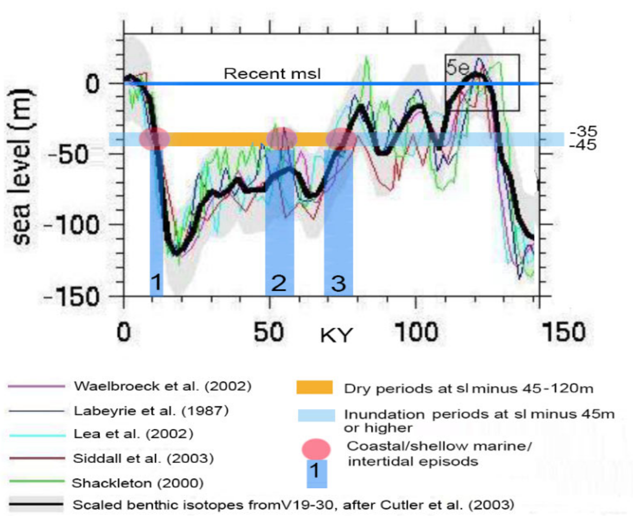

Figure 13. Global sea level changes in the last 150 Ky. Periods of dry land on the Pantaleria Vecchia Bank during low sea level of 0 to -45 m below recent sea level are marked blue (0 to 13,000 YBP), periods of submergence of the Pantaleria Vecchia Bank during sea level lower than -45 m (13,000 to 75,000 YBP) are marked in brown, and episodes of coastal/shallow marine/intertidal conditions in the Pantaleria Vecchia Bank are marked by red elliptic features (1, 2, 3) modified after [75] and references therein.

Ridge 1 is currently located in situ, at the site of its deposition. Thus, the most parsimonious explanation for the presence of the "horizontally arranged stone blocks" noted by Lodolo and colleagues, is that these rectangular shaped blocks are the result of post-depositional erosion of the stone, followed by the ridge cracking and settling on its southern sea side. The weathering and collapse of large sections of a beachrock ridge usually occurs due to erosion and scoring of underlying sediments on its sea side, or due to a landside [76] (Figures 1 and11d). Such beachrock erosion is common in coastal environments, and can be seen for example, on the Israeli Mediterranean Sea coast at Ashkelon (on the seaside of the beachrock outcrop) – [76] (Figure 3) or at Akko on the landside of the beachrock outcrop (Figures 14 and 15) as well as in other localities e.g., south-east Africa [77] (Figure 16).

Lodolo and colleagues suggest that these "block" features may be the result of human modification, although they cite the publication of Shinn [78] who outlined in some detail the "*simple*

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mechanism that can produce beach-rock geometries" similar to those characteristics observed on the seaward side of Ridge 1, namely "*Exposure to sunlight and constant wetting and drying break the rock down into individual slabs, like to a concrete road. The size of the individual slabs is determined by the thickness of the rock. Uncemented sand under the rock also promotes cracking as the rock settles, much like ice on a frozen pond*." Shinn [78] gives an entirely plausible, natural explanation for the shape as well as the location of stone blocks similar to those observed on the Pantaleria Vecchia Bank.

Likewise, the possibility of modification of Ridge 2 by people some 9500 BP, i.e. the building of a wall-like structure with stone blocks as proposed by Lodolo and Ben Avraham [58], is not supported by any archaeological or geoarchaeological information presented by the authors. A more parsimonious explanation is that Ridge 2 was deposited at an earlier stage, under different environmental and sea conditions prevailing during the deposition of Ridge 1, creating a different paleo-coastline. Thus, Ridge 2 may represent a natural relic of one of the half-ring ridges, rather than being a human-made feature.

Figure 14. Blocks of beachrock outcrop under coastal, landward erosion north of Akko (Israeli coast), looking north. (E. Galili).

Figure 15. Blocks of beachrock outcrop under coastal, landward erosion north of Akko (Israeli coast), looking south-west (E. Galili).

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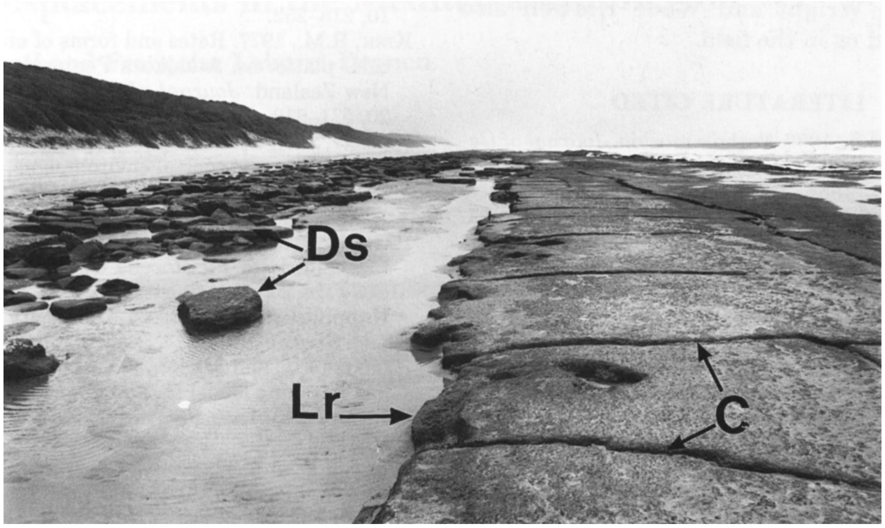

Figure 16. Lingoid ridge (Lr) developed on a Type 3 intertidal platform; (C refers to transversal cracks in the beachrock plates; Ds refers to detached blocks of beachrock washed shoreward) After [77] (Plate 13).

Regarding the so-called Monolith, Lodolo and Ben-Avraham [59] state that "the monolith is made from stone other than those which constitute all the neighboring outcrops …", but they also state that "the lithology and age of the rock that makes up the monolith are similar to those that make up the blocks of the rectilinear ridge closing the embayment." Thus, the Monolith probably originated from the neighboring eroded beachrock Ridge 1 which is located some 300m to the south. It is feasible that when the bay was flooded some 9500-9200 years BP [59] (Figure 8), a large, elongated piece of rock broke off Ridge 1 and was washed inland (northward) by a tsunami or by storm waves and was later broken up into three separate blocks by erosion.

As to the possibility that the half-ring ridges are anthropogenic in origin, as in the case of the other features discussed above, this statement is not supported by any archaeological or geoarchaeological information presented by the authors.

- Holes and "chimney" features on intertidal, rocky environment:

Lodolo and Ben-Avraham [59] state that "the monolith has three regular holes of similar diameter, one that crosses it completely on its top, and another two at two sides of the monolith". We reiterate here the counter arguments first raised by Tusa et al. [69] concerning the holes in the rocks, since these appear to have gone unnoticed in the literature or by Lodolo and colleagues in their 2015 and subsequent papers. Tusa et al. rightly contended that these are typical products of coastal erosion of beachrock, either by plant or else by water action when the rock was exposed in the highly energetic palaeo-intertidal zone.

Careful observations of figure 4 in the Lodolo and Ben-Avraham 2015 article [59] depicting the stones, indicates that the holes are of different size and are not regular in shape. Indeed, they appear to be natural in origin; one is a through perforation and two appear to be cavities. In the intertidal and supratidal zones, a variety of process can cause erosion of rock, such as physical or chemical erosion, bio-erosion, and algal induration [76,77,79]. Round holes, cavities, geyser chimneys (Figure 17) and craters are scoured and abraded by water under the influence of currents waves and are typical of high energy, intertidal, rocky environments. In their rebuttal, Tusa et al. [69] also note that even perfectly cylindrical holes can be created by natural action. They further suggest that natural erosion, due to plant action, can create similar holes: *"over 5 m long and with a section compatible with those shown in Lodolo and Ben-Avraham [59], and are found in large numbers along the coasts of the Black Sea, on lithologies similar to that of the "monolith" [e.g., Erginal et al. 80]"*.

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Figure 17. Water emerging from a geyser chimney (pipe/hole) on a rocky (aeolianite sandstone-Kurkar) section of the Israeli coast, near Kibbutz Neve Yam (E. Galili).

- Dating considerations:

Lodolo and colleagues present the dating of the stones composing the Monolith and the Ridges (SI Table S1). The dates represent the period of deposition and consolidation of the bioclastic rocks, and so are not pertinent to the issue of whether these features are anthropogenic in origin or natural.

The proposed dating of the Monolith, which according to Lodolo and Ben-Avraham [59] implies an anthropogenic origin, and the possible modification of the two beachrock/consolidated beach deposits ridges by humans [58] is based by them purely on sea-level considerations and speculations. The sea-level curves cited [71,81,82] suggest that some 9200-9500 YBP, the sea level in the Sicilian Channel was ca. 40 m lower than today (Figure 13) and the Pantelleria Vecchia Bank was a small island between Pantelleria and the Sicilian coast. Thus, the ridges and Monolith were under coastal/shallow marine conditions at the beginning of the Holocene. Lodolo and colleagues note that this palaeo-coastal area would have been accessible to humans during certain prehistoric periods. However, this situation is also valid for thousands of other square kilometers of continental shelves around the globe, down to a depth of 40 m. Consequently, basing human intervention on a speculative argument of possible accessibility to the area where the ridges and monolith were found, cannot be considered as scientific proof to support a Mesolithic anthropogenic origin for the monolith stone feature - as suggested by Lodolo and Ben-Avraham [59], nor for the modification of the ridges during the early Neolithic -as proposed by Lodolo et al. [58].

- Archaeological considerations:

In their discussion of the rock formations of Pantelleria, Tusa et al. [69] detail why, on archaeological grounds, the presence of a monolith, that can be compared or traced to the central Mediterranean megalithic tradition in these locations, is not feasible. In addition, they also refute the proposed dating suggested by Lodolo and colleagues for Pantelleria Vecchia Bank. It should be noted here, that Lodolo and colleagues did not involve a professional archaeologist, who may have related to the existence or nonexistence of anthropogenic fingerprints and finds of material culture.

In general, the possibility of finding unique stone structures in archaeological sites, cannot be ruled out. However, usually the raw materials used in their construction, or manner in which they were built, have parallels in other contemporaneous sites in the same region. In the case of the Pantelleria Vecchia Bank features, we do not know of any contemporaneous (i.e. Mesolithic), terrestrial parallels in Italy for structures made with the same raw materials, with similar-sized large blocks, or that resemble the form of the submerged features documented by Lodolo and colleagues. It is also unlikely that such a monumental ancient structure would have been built on a remote, offshore island, with no developed cultural center that could have supported such a project, leaving no anthropogenic fingerprints. Tusa et al. [69] refute the comparisons made by Lodolo and Ben

Avraham [59] to the monolithic cultures of Malta and Gobekli Tepe in Turkey, which are both chronologically and culturally distant from Sicily. As Tusa et al. conclude: *"…it is absolutely methodologically incorrect to compare distant and independent historical dynamics to justify the alleged presence of absolutely unjustifiable artifacts in their correct geographical reference context."*

- The absence of human-made finds in the suspected anthropogenic site:

It is expected that a prehistoric culture capable of producing gigantic megaliths and mega-constructions, would leave behind at least a few anthropogenic finds of distinctive material culture (e.g., flint implements, bones, wood, charcoal, ash). The absence of such finds is perhaps the strongest argument against the Ridges and Monolith being anthropogenic in nature. For example, stone tools, faunal remains, and even a hearth feature were discovered adjacent to a Neolithic seawall made of large boulders off the Israeli coast, corroborating that this structure was definitely human-made [19]. At the very least, flint artifacts that are highly resistant to erosion even in underwater conditions (as attested to at hundreds of submerged prehistoric sites discovered worldwide) e.g., [4,5,83], are expected to have been preserved and discovered in association with at least one of the features described at the Pantelleria Vecchia Bank. The feasibility of this is highlighted by the presence of human-made artifacts recovered underwater near the Pantelleria Island [84].

4.2. The Lampedusa Site

- Possible parallel archaeological features on Lampedusa, Malta and Sicily:

Megalithic constructions are not uncommon in the European Bronze Age. In fact, such structures can be found in the Central Mediterranean islands, Malta and Sicily, with some smaller ones reported also on the Central and Eastern parts of Lampedusa Island [62,68]. This cultural connection has deep roots, as the two groups of islands shared cultural traces since the Neolithic (~5500BC) when the first attested colonists from Sicily established themselves in Malta [85]. The two groups kept cultural ties alive for millennia as shown by parallels in their pottery traditions, flint, obsidian and ocher trades, as well as cultural and religious practices [see 86–88]. While these early cultural trends seem to have originated on the main island of Sicily and were introduced to Malta, scholars propose that the opposite is true for the Early Bronze Age megalithic traditions [89–91]. Megalithic building seems to have started in Malta ~3500BC and was connected, to new ritual practices including group burials. Only later was it brought to Sicily see [91]. Similar group burial practices are suggested in Sicily for the dolmen structures appearing in the third millennium in the Hyblean Plateau and in other scattered sites north and southwest of the main island of Sicily see [91,92]. In his 2014 publication, Ratti [64] (p. 18) pointed out an oval stone structure located in Lampedusa on the top of the cliff above the suspected submerged cultic site, which has never been excavated nor published (our translation from Italian) "*A stone structure of the same shape and dimensions of the underwater one can be seen on top of the cliff (110 m above sea level) exactly above the submerged one*". This structure is also depicted in his 2022 edition [68] (Figure 2.85). During a field survey we conducted on the top of the cliff, some stone arrangement and structures were identified. However, unlike the boulders found in the suspected submerged megalithic structure (the latter weighing up to a few tons each), the terrestrial structure is built of smaller stones arranged in patterns that differ markedly from the underwater feature. Thus, the yet unexcavated and undated stone structures on top of the cliff, and the other megalithic structures on the island do not represent possible parallels to the suspected submerged structures.

- The MIS5e deposits and the archaeological sea-level markers used for testing tectonic stability and sea-level changes:

To estimate changes in the local relative sea-level and possible tectonic uplift of Lampedusa, two sets of sea-level indicators were investigated. Marine Isotope Stage 5e (MIS5e) beach deposits dated to the last interglacial high stand (124 ka) were identified based on fossil indicators (e.g. mollusk species: *Strobilus boboniou, Patella fereginous* and *Arca noa*)[1]. The find elevations of these mollusks relative to modern sea level was documented for the methodology and examples see [56,93–98]. This

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[1] The index fossil species *Patella ferruginous* and *Arca noa* were identified by the local geologist Giuseppe Sorrenti (personal communication)

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parameter was of use to our understanding of the relative sea level during the Mid-Pleistocene when the global sea level was ca. 6 to 12m higher than today, and facilitated evaluation of the long-term vertical changes of the island since the deposition of these beach deposits. The heights of coastal installations (e.g. rock-cut bollards to which boats were tied) relative to sea-level today, provided sea-level information during historical periods. These Upper Pleistocene and Late Holocene geological and archaeological indicators (respectively) enable evaluation of the relative sea-level height and tectonic stability of the region during prehistoric and historic times.

Previously, Segre [99] and Grasso and Pedly [66] located Tyrrhenian terraces and MIS5e deposits while producing the geological map of Lampedusa. East of the monocline, on the ria-coastline (from Cala Greca to Cala Creta see Figure 2), Tyrrhenian features consisting of beach deposits containing the mollusk *Strombus bubonius*, lie at ca.+2m above present sea level [99] (p. 138). West of the monocline, prehistoric caves were identified by Segre [99] (pp. 145-147, Figure 7: d) at elevation of ca 35m above sea level. Grasso and Pedly [66] suggested that these caves are related to the same Tyrrhenian episode identified on the east side of the island, and that the tectonic movement associated with the monoclinal flexure was completed by Late Pleistocene times.

Following these studies, we rechecked the deposits in some key sites on the island of Lampedusa. In Cala Ucello Bay, a clear MIS5e beach deposit with at least four individuals of the index fossil *Strombus bubonius* in a good state of preservation, were identified (Figure 18). The maximum elevation (inner edge) of this deposit was 2.20m asl (at 6.30 pm on 3 August 2019). In Cala Maluk, a MIS5e beach deposit formation was identified on the western side of the bay. In this case, other index fossils, *Patella ferruginous* and *Arca noa* mollusks, were observed. The maximum elevation of the deposit was 1.60 m asl (at 7.00 pm). Another MIS5e deposit at a similar elevation containing *Strombus bubonious* was identified in Cala Pisana. Overall, all the MIS5e/Tyrrhenian deposits studied do not display evidence of dramatic tectonic changes in the region during the time period of the formation of the coastal escarpment. According to Lambeck et al. [100] (Figure 6), the average rates of vertical movements in the Linosa/Pantaleria region during the Holocene, and for the last glacial cycle, has been ±0.15 mm/yr. Assuming that tectonic movement associated with the monoclinal flexure on the island was completed by Late Pleistocene time as suggested by [66], tectonics would have had very little impact on the significant erosion of the cliff above the suspected cultic site, which presumably started at the Mid-Holocene, when sea-level reached its present elevation.

Figure 18. Left: Cala Ocello Bay and location of the MIS5e deposit, center and right: close ups of *Strombus bubonius* mollusks (E. Galili).

- Mid-Holocene sea-level indicators:

These were identified in Cala Pisana Bay where a modern beachrock formation, composed of modern materials (e.g., glass, and metal), was located on the shoreline at an elevation associated with the present sea level. Important archaeological indicators identified were rock-cut bollards that are reported here for the first time (Figure 19). Of the 16 bollards located, two were in Cala Pisana Bay, and the rest were in the Porto Vecchio (Cala Palme), and Porto Nuovo (Cala Salina). Other rock-cut features such as carved channels and square installations were also identified in the harbor area, and a large quarry site, a few meters above current sea level, was observed in Cala Calandro. Although such rock-cut bollards are hard to date, and some of them are still being used (e.g., in Brucoli Sicily, lat. 37.2817 N, lon. 15.1862 E), similar installations found in well-documented archaeological sites

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[101,102] suggest that they date to the Roman-Byzantine periods. Some of those rock-cut installations were affected by sea erosion and modern coastal constructions, however, their elevation about sea level enables proper functioning, suggesting that the relative sea level has not changed dramatically in the last 2000 years, since they were cut in the stone.

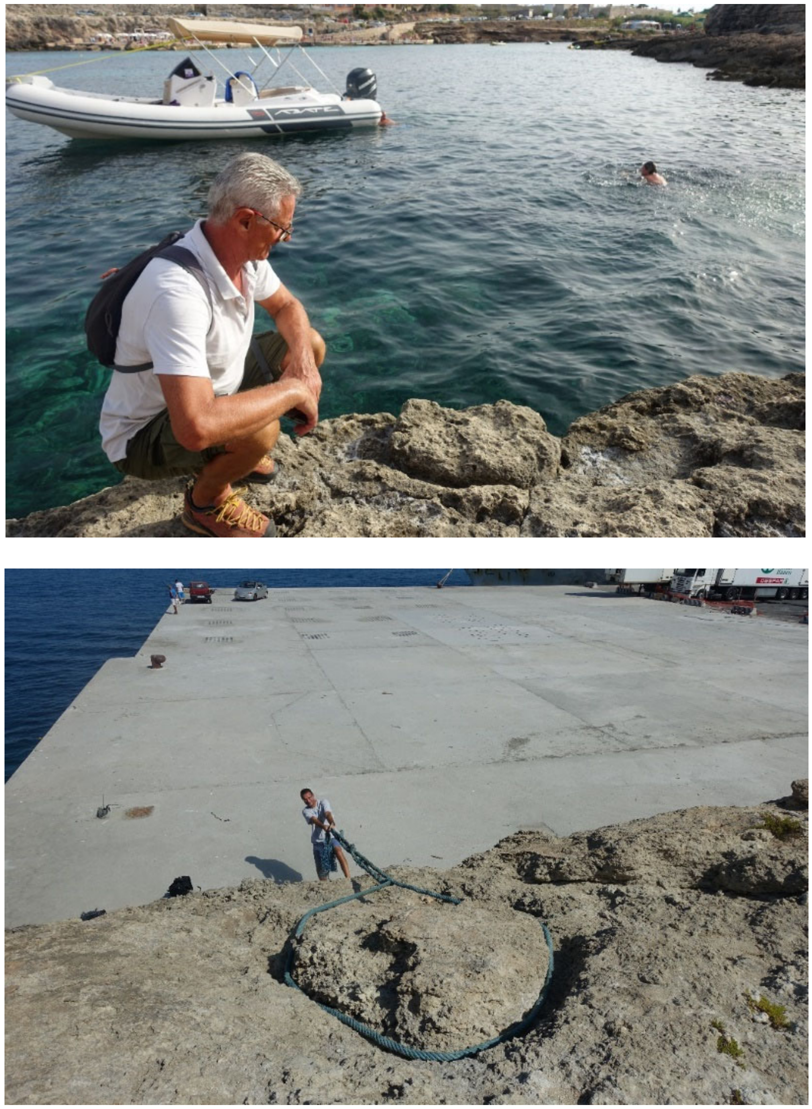

Figure 19. Top: Ancient rock-cut bollard in the modern Lampedusa harbor, Bottom: Ancient rock-cut bollard in Cala Pisana Bay (E. Galili).

- Submerged paleo-landscape versus submerged neo-landscape:

In-situ submerged prehistoric sites can be found on submerged landscapes inundated by post-glacial sea-level rise. However, some submerged landscapes are relatively new (post-prehistoric periods, hence submerged neo-landscape). Examples for such submerged neo-landscape may be at the foot of an active, retreating coastal escarpment (Figures 20 and 21), or on the surface of a consolidated lava flow which entered the sea. In situ finds discovered on such landscapes, may then be logically be attributed to a period later than the formation of the landscape. Thus, the date of the deposition of the natural rock may be used as a *terminus post quem* for the site deposited on it.

The erosion rate of the cliff and the proximity to the cliff were major arguments to rule out the possibility of the suspected Lampedusa site being anthropogenic in origin. An important geological indicator in the study area was a sea stack, probably part of the island in the past which had been separated from the present shoreline (Figures 7 and 21). The fresh landslides on the coastal

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escarpment and its active retreat suggest that the features in the studied site (the coastal cliff and caves, the adjacent sea bottom and the stack) are products of events that have occurred during the second half of the Holocene sea-level rise.

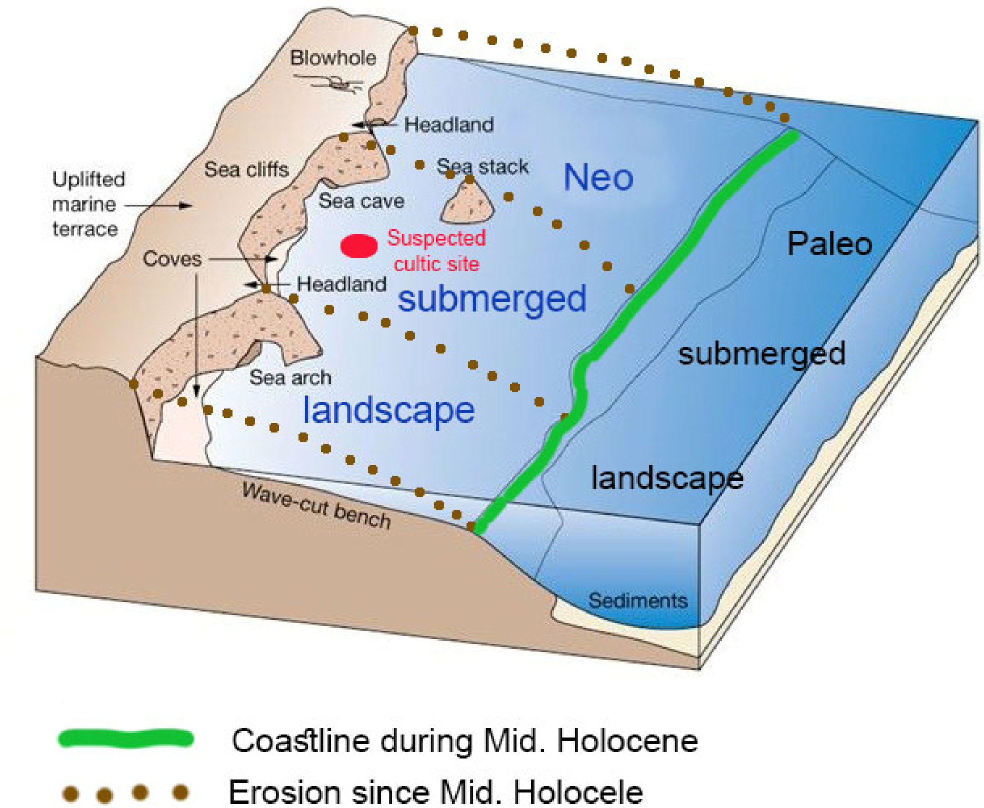

Figure 20. Coastal erosion, recent active retreat of the coastal escarpment and creation of submerged neo-landscape at the foot of the cliff modified after [103] (Figure 5).

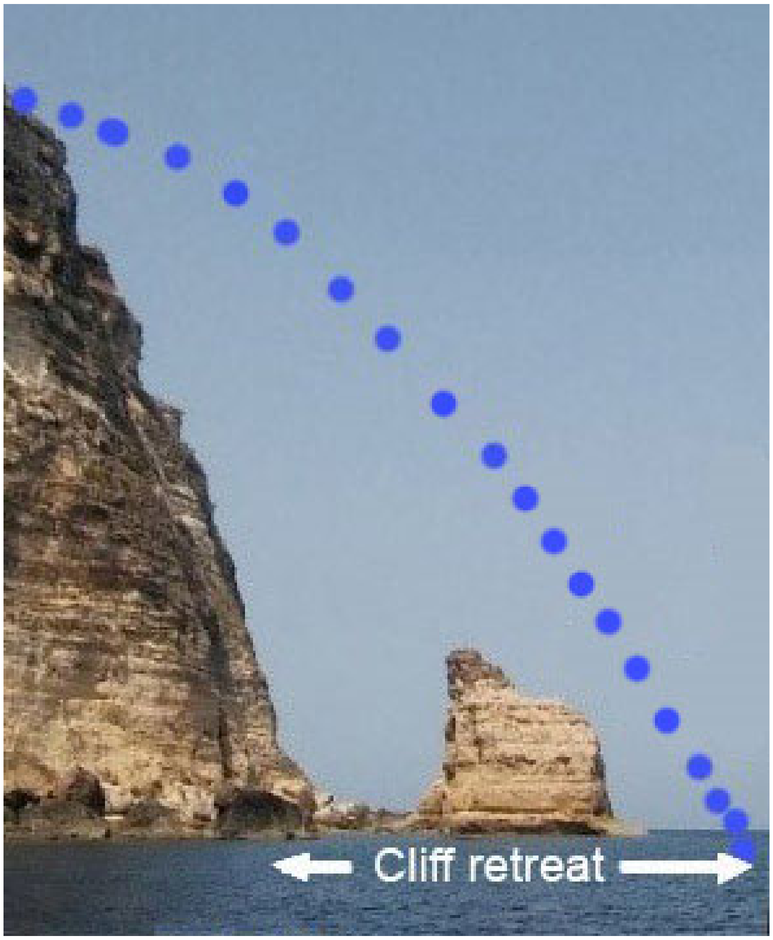

Figure 21. Coastal erosion, retreat of the coastal escarpment and creation of submerged neo-landscape at the foot of the cliff (E. Galili).

5. Conclusions

5.1. Innovative remote sensing technologies have been commonly used to explore and map the currently submerged paleo-landscapes in search of prehistoric sites.   providing unique and useful information. However, their findings need to be corroborated by detailed archaeological research as there is no substitute for the knowledge and direct examination by an underwater archaeologist.

5.2. The Submerged Features on the Pantelleria Vecchia Bank

Given all the data outlined above, we find that the suggestions for the possible anthropogenic origin of the discussed stone features, including the ridges and the elongated pierced Monolith, to be unfounded. We feel that it is apt to repeat Tusa et al's excellent summary [our translation from Italian]: "*multiple considerations both of a purely geological order, both intrinsic to the morphological characteristics of the object, both inherent to the immediate context of its position, and in reference to the broader chronological and geographical context, lead us to the natural conclusion that it is not a question of a manufactured, but rather a natural product.*" In addition, our study has shown the limitations of high-tech remote sensing techniques frequently used to identify anthropogenic sites, and confirms the need for first-hand, professional archaeological documentation and research to provide a rigorous foundation for such determinations.

5.2. The Suspected Megalithic Feature in North-Western Lampedusa

The shallow sea opposite the cliffs of western and north-western Lampedusa can be considered as a submerged neo-landscape (post-prehistoric times) formed during the second half of the Holocene i.e. since the sea-level reached its present elevation. It is suggested that, the discussed submerged megalithic structures are natural features and represent boulders which collapsed from the adjacent cliff, while the adjacent zoomorphic-like feature are erosional features that developed on these rocks.

5.4. In Case of a Doubt, There Should Be No Doubt

Generally speaking, the submerged landscapes and features described above, are extremely interesting and the geological and geomorphological formation processes that created them are worthy of investigation. However, we suggest, that the rational underlying the interpretation of features identified on submerged landscapes as anthropic, should not be symmetrical: in other words, if there is even a small doubt that a submerged feature is not human-made, we should consider that it is of natural origin. The reasoning behind this asymmetry is that, worldwide, there are only a small number of prehistoric megalithic stone features that were human-made. Statistically speaking, the probability for the existence of symmetrical rock features or stone arrangements on a submerged landscape that may be human-made (even if their formation processes are yet unclear), is negligible. Moreover, the presence of a suspected feature cannot by itself point to an anthropogenic origin. To determine the anthropogenic origin of such features, a detailed archaeological investigation yielding finds that clearly connect the object to human manufacture, should be presented. Thus, in cases that there is neither clear archaeological evidence for an anthropogenic origin of a submerged site (e. g., artifacts, debris, use marks or production marks, charcoal, faunal remains), or signs of intentional shaping of the stone, the site should be considered of natural origin. In such unclear cases, instead of stating that "we cannot rule out the possibility of an anthropogenic origin" we should rule out such origin, until it is supported by solid archaeological evidence.

Supplementary Materials: The following supporting information can be downloaded at the website of this paper posted on Preprints.org.

Acknowledgments: The authors wish to thank Diego Ratti and Pietro Ratti for their kind hospitality, for founding the research on the Lampedusa Island and for providing Figures 9 and 10 and the permission to publish them, to Diego Ratti, Fabio Giovanetti, Anna Sardone and Giuseppe Sorrenti for participating in the underwater and coastal research on the Lampedusa Island, to the geologist Giuseppe Sorrenti, who participated in the underwater and coastal research and identified the sediments, the beach deposits and the index fossils, to Nino Taranto From the Lampedusa archive for providing photos and information regarding the history of the Lampedusa Island, to Emmanuel Lodolo and Tzvi Ben Avraham for providing Figures 2–5 and the permission to publish them, and to Luo, E.C.R. for the permission to publish Figure 20 depicting formation of beach profile, and to Miller, W.R.; Mason, T.R. for the permission to publish Figure 16 depicting erosional features of coastal beachrock and aeolianite outcrops in Natal and Zululand, South Africa.

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