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Dipping Tidal Notch (DTN): Exposed vs. Sheltered Morphometry

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Abstract: Tidal notches, long regarded as reliable indicators of mean sea level, have been extensively studied along carbonate coasts in the central Mediterranean Sea. Previous studies revealed a correlation between the genesis of tidal notches and tidal range, lithology, cliff foot depth, and wave energy. In the 2020 Geoswim campaigns at Lampedusa, the southernmost island of the Pelagie archipelago (Italy), and in Gozo Island (Malta), 'anomalous' tidal notches were identified. Unlike normal notches observed elsewhere, those in Lampedusa's southern bays exhibited a particular behaviour—constantly deepening in the inner part of the bays, reaching a maximum depth of approximately 30 cm below sea level and narrowing inwards. Similar phenomena were previously observed near Marseille (France). As confirmed by the literature, all these areas are tectonically stable. Time-lapse images, alongside measurements of morphometric parameters, were collected during the survey. Our hypothesis indicates that a combination of marine factors influenced by local marine conditions driven by the local morphology of the small bays exposed to southern quadrants contribute to the formation of these unique landforms. The latter manifests higher lowering erosion rates slightly below the mean sea level in sheltered areas, challenging conventional notions about tidal notch formation.

Keywords: coastal landforms; rock coast geomorphology; Mediterranean Sea; tidal notches; sea level markers

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1. Introduction

Tidal notches are horizontal grooves found on sea cliffs, typically at the mid-tide mark, and they serve as geological markers and recorders of past sea levels [1]. The formation of tidal notches is a result of the erosive action of waves, as well as the chemical and biological weathering of the rocks [1]. A seminal work by Antonioli et al. [2] examined 73 coastal sites in the central Mediterranean Sea and provided a comprehensive overview of all the previous studies about tidal notches. The authors measured notch widths and depths, reported the biological rim characteristics, and established correlations with wave energy, tidal range, and rock lithology. The Geoswim program, as part of an ongoing field of work [3,4], sought to collect visual observations and instrumental data across extensive rocky coast sectors, emphasising the correlation of these data with sea level changes. Therefore, very detailed observations and surveys of coastal landforms were carried out in the Mediterranean area, including the dipping tidal notches discussed in this paper. Previously, Antonioli et al. [5] reported "anomalous" tidal notches, i.e., what we call dipping tidal notches (DTNs). The authors observed that the maximum retreat point of tidal notches gradually deepened from exposed to sheltered locations within ria. They suggested that these landforms result from various processes, influencing the cliff's lowering at different rates.

Recently, Vacchi et al. [6] described in a sheltered coastal area in the Frioul Archipelago (southern France) a submerged notch at −0.35 m. The authors did not tell the roof notch above the submerged one. They attributed the genesis of the submerged notch to the sea level elevation between 1.5 ka and 1.0 ka, the Little Ice Age (LIA) cool period, or about −0.5 m below the modern sea level. It was also carved in a sheltered area without waves and other boring species. Regarding the interpretation of the submerged notch at the Frioul Archipelago provided by [6], the authors wrote that at the sheltered sites, the relative absence of mechanical wave action and bio-erosion were not instrumental in the formation of the notch in the last millennium. The absence of the aforementioned major erosional processes also influenced the shape of the notch, which, in contrast to the exposed site in which the notch occurs, presents both the roof and the floor. The authors suggested that the floor has probably been preserved due to the increase in sea level rise rates in the last millennium, which lowered the erosion rates observed in the previous 400 years, which consisted of relative sea-level stability. On the contrary, at Cassis, Antonioli et al. [5] wrote that at the time of surveys, MTN displayed a homogeneous and continuous morphology at the mouth of a small ria at an exposed site. In contrast, the inner part of the ria, its width is 0.28 m, and it was completely submerged. Lithodome bores carve limestone above the notch, and they were probably drilled during the last interglacial at an altitude from 3 m to 5 m a.s.l. The authors [7] also reported the presence of a layer of freshwater on the sea surface, with a thickness of some cm. Here, the mean sea level was marked by a crust of coralline red algae placed at the base of the notch (see Supplementary Materials).

Our study delves into a particularly intriguing geomorphological context, or the innermost sectors of two narrow rias of the Mediterranean basin in areas characterised by tectonic stability, in particular at Lampedusa Island (Pelagie islands, Italy) and Gozo Island (Malta), both of which are located in the central Mediterranean Sea (Figure 1) were new DTNs have been discovered. Our exploration aims to unravel these tidal notches' intricate dynamics, mainly focusing on their anomalous behaviours observed in the study area. Moreover, we compare our data with observations carried out by Antonioli et al. [5] at Cassis (southern France, Figure 1) and data published by Vacchi et al. [6]. We seek to contribute to the evolving understanding of sea level indicators and their geological implications through detailed surveys and data collection.

Figure 1. Overview of the studied areas. (**a**) A map of the Mediterranean area and the location of the studied sites of Lampedusa (Pelagie Islands) and Gozo (Malta). We also added the site of Cassis (southern France) studied by Antonioli et al. [5] where first observations of DTN were reported; (**b**) the study site at Lampedusa Island (southern Italy) with the lithostratigraphic and geomorphological map (modified from [7]); and (**c**) the studied site of Mġarr ix-Xini in the island of Gozo (Malta) with the lithostratigraphic map.

2. Study Area

2.1. Lampedusa Island (Italy)

Lampedusa, the southernmost island in Italy, belongs to the Pelagie Archipelago, which is located in the southern sector of the Sicily Channel. Spanning 10 km in the east–

west direction, the island covers 20 km^2 and boasts a rugged coastline extending over 33 km (Figure 1a). The study area encompasses a small bay, Cala Madonna, located at the southern coast of the island (Figure 1b).

From a geological point of view, Lampedusa island is the emerging portion of a wide, WNW-ESE trending plateau [8] where the Tortonian to Messinian succession of Porites coral bound stones and bioclastic calcarenites with abundant fossil content (mollusca, bryozoan, echinoid and algal fragment) outcrop [7,9]. The island is composed of a Neogene–Quaternary carbonate sequence horst structure [7] (Figure 1b). The study area is characterised by carbonate lithoclast breccias (Pleistocene–Holocene), wave-cut platforms and sand-raised beaches belonging to the late Pleistocene (Tyrrhenian Age). The area is made up of Capo Grecale and Cala Pisana members of the Tortonian Early Messinian Age, where the major tectonics lineaments of Lampedusa can be found [7]. The island belongs to the undeformed African foreland, and the overall attitude of Late Miocene sedimentary strata as well as the elevation of MIS 5.5 infralittoral deposits [8] at Cala Creta and Cala Pisana (Figure 1b), both suggest general tectonic stability during Quaternary era [7], except for vertical displacement, which mostly occurred during the Calabrian (Early Pleistocene) time interval [10,11].

The tide amplitude at Lampedusa is about 40 cm. Wind data from 1999 to 2022 [12] sourced from ENEA Lampedusa [13] "https://www.lampedusa.enea.it/ (accessed on 23 January 2024)", indicate prevailing winds from the northwest, notably the Mistral wind.

Lampedusa's precipitation pattern follows a distinct seasonal trend, with December being the wettest month, registering 61 mm, while July is the driest month with no recorded precipitation [12].

2.2. Gozo Island (Malta)

Gozo is the northernmost island of the Maltese archipelago, which is located in the northern sector of the Sicily Channel [14]. Spanning 13.3 km in the east–west direction, the island covers 65.79 km^2 and boasts a rugged coastline extending over about 60 km (Figure 1b). The study area encompasses a small ria called Mġarr ix-Xini on the southern coast of the island (Figure 1b).

From a geological point of view, a sedimentary sequence composed of carbonate rocks spanning in time from Upper Oligocene to Upper Miocene crops out in Malta and Gozo. Along the coast, there are four portions of the outcrop (Figure 1c): Lower Coralline Limestone Formation (Chattian), Globigerina Limestone Formation (Aquitanian–Early Langhian), Blue Clay Formation (Langhian–Tortonian) and Upper Coralline Limestone Formation (Late Tortonian–Early Messinian) [15]. The topography of Gozo is controlled by the horst and graben system, expanded during the Miocene and Plio-Quaternary extensional stages [14].

Most valleys are rias, previously excavated by fluvial processes, but today are practically inactive [16]. No marine and lagoonal deposits have been found at Gozo [17]. The climate is Mediterranean and is strongly influenced by the sea [18]. The relatively flat morphology of the islands does not favour rainfall formation. On average, the island receives 530 mm of yearly rainfall [19]. Many small submarine freshwater springs have been surveyed along the island during the 2013 Geoswim campaign by Furlani et al. [20]. The island is affected by long fetches, mainly in the second and fourth quadrants and dominant winds from NW [21].

Tidal oscillations, predominantly semidiurnal, reach a maximum range of 20.6 cm on average for spring tides and are reduced to 4.6 cm during neap tides [22].

3. Short Overview of Marine Notches

As we navigate this investigation, we draw on the [22] definition, describing coastal notches (littoral notch, marine notch, coastal notch, or wave-cut notch, visor, etc.) as deep, narrow cuts or hollows along the base of sea cliffs near the high-water mark, with the depth being smaller than its width.

Modern tidal notches (MTNs) on rocky coasts are well developed in the Mediterranean Sea because of its microtidal regime, and they can be found along most of its perimeter. Antonioli et al. [2] and references therein described the morphometric parameters of 73 MTNs in the Mediterranean area. They attributed the occurrence of MTNs to a range of marine processes, such as bio-weathering, chemical dissolution, and wave action that act together, eroding rocks at the mid-tide level. The authors in [2] suggest that over the last 6.8 ka, MTNs have changed their shape following the relative sea level rise, causing sea cliff retreat. Fossil tidal notches (FTNs) are laterally extending hollows below or above the sea level (Figure 2a) that were carved in the past when the relative sea level was at the elevation of the notches. When the base of the notch is missing, such as in Istria (Croatia) [23,24] or in Gozo (Malta) [20], it is called a roof notch (RN).

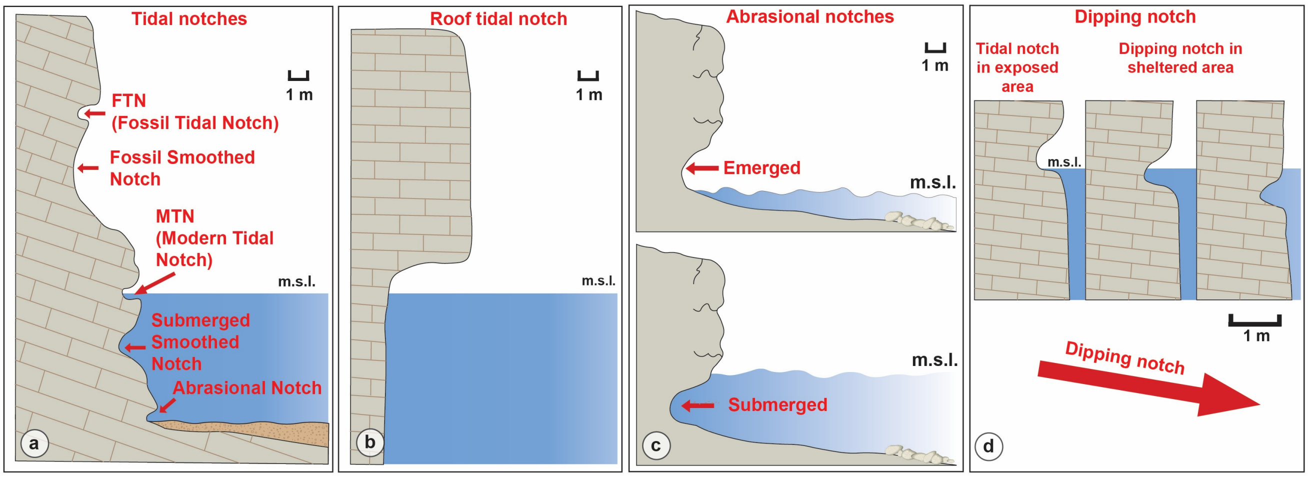

Figure 2. Sketch of the notches described in paragraph 2: (**a**) modern tidal notches (MTNs) and coupled submerged smoothed notches. Above the fossil tidal notches (FTNs) and the coupled fossil smoothed notch, there is the (**b**) roof notch (RN); (**c**) the abrasional notch (AN) at the sea level and below the sea level; and (**d**) the dipping tidal notch (DTN), as described by [25], inward to outward.

Roof notches (RN) (Figure 2b) are often observed in carbonate rocks, and they can result from various processes, such as biological agents, wetting and drying cycles coupled with salt weathering, karst processes, and mechanical erosion [2].

Double notches, or a kind of fossil notch coupled with a fossil or modern one (Figure 2a), have been described by Antonioli et al. [25] at some sites, such as at Orosei Gulf (Sardinia, Italy) in the Mediterranean Sea (see Supplementary Materials). The two notches show an average vertical separation of roughly 2–4 m. They have been systematically observed at an elevation of a few meters above the present-day sea level on tectonically stable coastal sites, mainly in western Italy (Figure 3a,e). The upper notch has a morphology like the one developed at present-day mean sea levels under the current tidal regime. The lower notch is smoother than the upper notch and shows a larger vertical size with respect to the upper one. This is the smoothed tidal notch (STN, Figure 2a). Moreover, it is pervasively bored by *Lithophaga lithophaga* and other boring species. They have been observed below MTN (Figure 3b–d). Fossil notches (FTs) have been attributed to the MIS 5.5 stage (last interglacial) based on a quantitative assessment of the glacial isostatic adjustment (GIA) expected at each site from updated models. The authors in [26] argued that both notches within the couplet were formed during a single high stand of the Marine Isotopic Stage (MIS) 5.5 substage, and the superposed morphology resulted from the isostatic component.

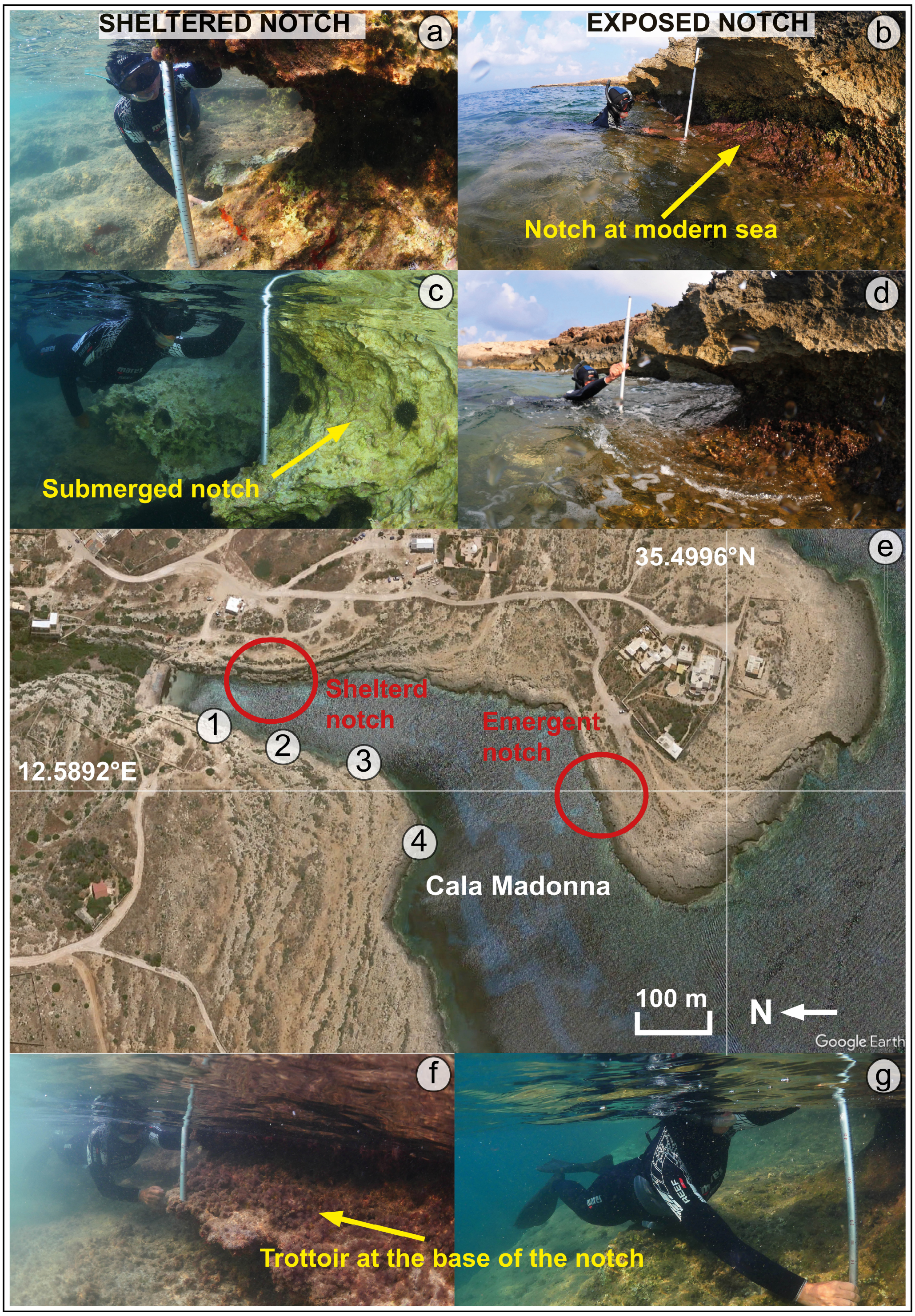

Figure 3. Collection of images at the Lampedusa site. (**a**) DTN at sheltered site, (**b**) TN at exposed site, (**c**) DTN in the innermost part of the ria of Cala Madonna, corresponding to numbers 1 and 2; (**d**) show the exposed and present-day tidal notch at the mean sea level, in the outermost part of the bay, corresponding to numbers 3 and 4 in the map (**e**); (**f**) show the red algae trottoir visible at the base of the present-day tidal notch (TN), (**g**) measurements at the present-day tidal notch (TN).

To sum up, based on the observations of Antonioli et al. [2,25,26], when carbonates are very conservative and resistant to erosion, such as in the sites described in the central Tyrrhenian Sea by the authors, the following succession of notches from the top to bottom, as illustrated in Figure 1a, can be found: FTN, smoothed notch, MTN, and smoothed submerged notch. The latter always shows widths lower than the fossil notch.

Abrasional notches (ANs) are lateral extending hollows developing above or below the modern sea level due to wave action at the sea bottom and are favoured by the presence of sand or pebbles. They can occur up to 25–30 m in depth, depending on the local tide and wave energy (Figure 2c).

Dipping tidal notches (DTNs) are present-day notches that dip below the mean sea level, moving inwards in some small ria, as reported by [5] at Cassis (Figure 2d).

4. Methods

The studied sites have been investigated through swim surveys performed close to the coast, as described in [3,4]. The approach consists of coastal surveys of selected sectors of rocky coasts, mainly plunging cliffs or sloping coasts, carried out by a set of instruments equipped on a small raft. The latter is pushed by swimming parallel to the coastline. The instrumentation is generally composed of a set of cameras to collect videos and time-lapse images, such as GPS, CTD probes, an echosounder, a metric iron bar, a lamp, etc. During field surveys, both instrumental and observational data are collected [4].

The occurrences of MTN and roof MTN were located and mapped, and notch morphometry was measured by fixed or extensional rods, following Antonioli et al. [2]. The data reported in Table 1 were corrected for tides and pressure using the methodology described in [27], using tidal data from the nearest tide gauge station [28] (www.mareografico.it; ioc-sealevelmonitoring.org/, accessed on 5 March 2024), in particular at Lampedusa, where measured data were collected, while positions were estimated at the surface by GPS hand-held receivers.

The tide corrections were provided by the Lampedusa monitoring station, which is part of the National Tide Gauge Network from the Istituto Superiore per la Protezionee la Ricerca Ambientale (ISPRA). The tide gauge is located at ~1.5 km from the ria of Cala Madonna, and it provides online data from 2010. Regarding Gozo (Malta), we used data provided by the website https://seatemperature.info/gozo-tides.html# (accessed on 30 May 2024) [29].

We performed photographic acquisition to model the MTNs studied here. These models were used to compare MTNs and DTNs at the reviewed sites. These high-resolution (HR) images were taken above and below the waterline, as described by Furlani et al. [30], using GoPro Hero 6 Black cameras (Data: GoPro, Inc., 3000 Clearview Way, San Mateo, CA, USA). A total of 534 images of the emergent part and 534 of the submerged part were acquired and processed separately using the software Agisoft MetashapeTM (Agisoft LLC, St. Petersburg, Russia, version 2.0.2 build 16404, 64 bit) to produce the dense point cloud and 3D models. It includes structure-from-motion algorithms that allow the user to align the images and calculate their relative position to each other during the camera alignment phase. The outcome of the camera alignment process was a sparse point cloud of the investigated stretch of coast. Agisoft Metashape software facilitated the integration of 3D models depicting a specific section of Mġarr ix-Xini Bay. Then, they were utilised to reconstruct separate 3D models. The merging process relied on depth maps generated from these models. The resulting composite 3D model was geolocated and dimensionally measurable, with all procedures executed within the same software platform. The finalised merged model was exported in .obj format and subsequently analysed in Cloud Compare software (v. 2.13.beta (Oct 2023 64 bit)) to derive topographic profiles of its outermost region.

Table 1. MTN and DTN at the surveyed sites: (1) site number; (2) site name; (3) local coordinates; (4) field measures, or the distance between the mean sea level and the maximum width (roof of the notch); (5) time of the survey; (6) corrections using local tide gauge data; (7) corrected altitude of the notch above the altitude corresponding to the maximum width of the tidal notch; (8) width of the tidal notch; (9) average depth at the cliff toe; (10) notch submersion, or the distance between the base of the notch to the corrected mean sea level.

1 Site [n]	2 Site Name	3 Coordinates [deg.dec]	4 Field Measures [m]	5 Time of Survey [M/D; h/m]	6 Tide Gauge Correction [m]	7 Corrected Altitude over Max Width [m]	8 Width of the Notch [m]	9 Depth at the Cliff Toe [m]	10 Notch Submersion	11 Notes
1	Cala Madonna	35.503027 12.590118	−0.50	25 November 2022 10:48	0.47	−0.03 ± 0.03	0.34	1.3	−0.37 ± 0.03	Our data
2	Cala Madonna	35.502467 12.589919	−0.30	25 November 2022 10:52	0.47	−0.17 ± 0.03	0.40	1.8	−0.27 ± 0.03	Our data
3	Cala Madonna	35.502026 12.589769	+0.10	25 November 2022 11:00	0.47	−0.10 ± 0.03	0.50	2.4	−0.13 ± 0.03	Our data
4	Cala Madonna	35.501623 12.589037	+0.8	25 November 2022 10:56	0.47	+0.08 ± 0.03	0.60	3.5	−0.05 ± 0.03	Our data
5	Mġarr ix-Xini	36.019931 14.271996	−0.50	28 October 2022 12:38	0	−0.50	/	2.5		Our data
6	Mġarr ix-Xini	36.018377 14.272638	0.0	28 October 2022 12:51	0	0.0	/	4.5		Our data
7	Cassis	43.206497 5.521458	−10	2 May 2015 14:30	0.99	−0.28	0.48	1.0	−0.38	Published by [5]
8	Cassis	43.204071 5.516312	55	2 May 2025 15:00	−0.99	0.45	45	4.5	0	Published by [5]

5. Results

We present data collected at the two sites above, respectively, at Lampedusa (par. 5.1) and Gozo Island (par 5.2).

Data collected in the field are reported in Table 1.

5.1. Cala Madonna (Southern Lampedusa Island)

At Lampedusa, MTN was observed and measured along most of its rocky coasts. At the southern side of the island, at the mouth of a small ria called Cala Madonna, the top of the roof of MTN is shown (Figure 3a–g, site 1 in Table 1).

At Cala Madonna (Figure 4a), the top of the MTN was measured at an altitude of 0.08 ± 0.025 m that corrected with a tide of 0.47 m (detail in Table 1, Figures 3e and 4e, site 4), resulting in an altitude from the bottom of MTN of 0.05 m. The shape of MTN shows the morphometric features of the notches studied by [30], with a small platform at the base. Moving towards the inside of the ria, the MTN progressively lowers up to an altitude of −0.50 below sea level (Table 1, Figures 3a,c and 4b–d). Moreover, the depth of the notch, or the carving depth, decreases from 0.60 m on the outside of the ria to 0.34 on the inside of the ria. At site one (Figures 3 and 4b), the notch always remains completely submerged after tide corrections, and it is the one located at the innermost part of the ria (Table 1, Site 1).

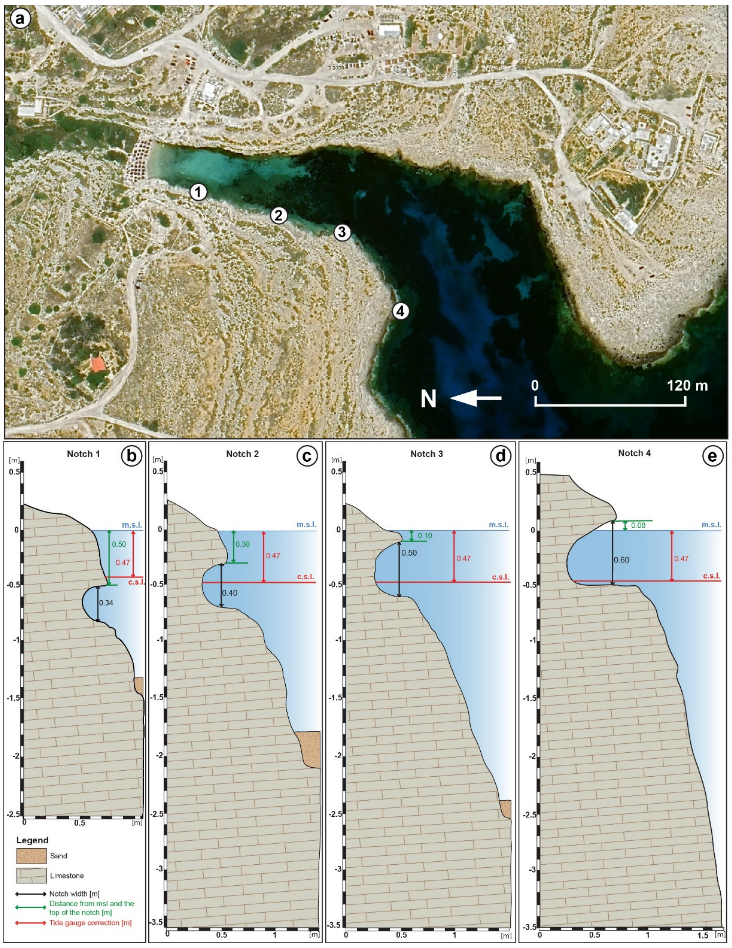

Figure 4. Tidal notches and dipping notches at Lampedusa. From the innermost part to the outermost part of the Cala Madonna Bay (from point 1 to point 4), the tidal notch goes from being submerged to emerging at the actual sea level. At the same time, it increases in concavity depth and width; (**a**) map of notches at Cala Madonna bay, (**b**) DTN in the innermost part of the bay, (**c**) DTN in the median sector of the bay, (**d**) DTN in the median sector of the bay moving toward the sea, (**e**) DTN at an exposed site of the bay. Here the notch becomes a normal TN.

From a biological point of view, the rim shows an assemblage composed mainly of calcifying red algae, both encrusting (e.g., *Goniolithon papillosum*) and erect (e.g., *Jania rubens* and *Ellisolandia elongata*) [31]. Along the subtidal, there are also numerous bioerosion scars, probably due to the action of the sea urchins Paracentrotus lividus and Arbacia lixula, frequently seen in the images. Although a Vermetid carpet is sometimes present, signs of sea urchin bioerosion are very frequent along the entire coast examined.

5.2. Mġarr ix-Xini (Southern Gozo Island)

Along the Gozitan coast, MTN was observed almost continuously around all carbonate sectors [19]. At the southern side of the island, at the mouth of the small ria called Mġarr ix-Xini (Figure 5e), the top of the roof of MTN was measured at a corrected altitude of 0.08 ± 0.025. The shape of MTN shows the morphometric features of notches studied by [31], with a small platform at the base (Figure 5a–d). Moving towards the inside of the ria, the MTN progressively lowers (Figure 5f,g) up to an estimated altitude of 0.50 below sea level (Table 1). Moreover, the depth of the notch, or the carving depth, decreases from 0.60 m on the outside of the ria to 0.34 on the inside.

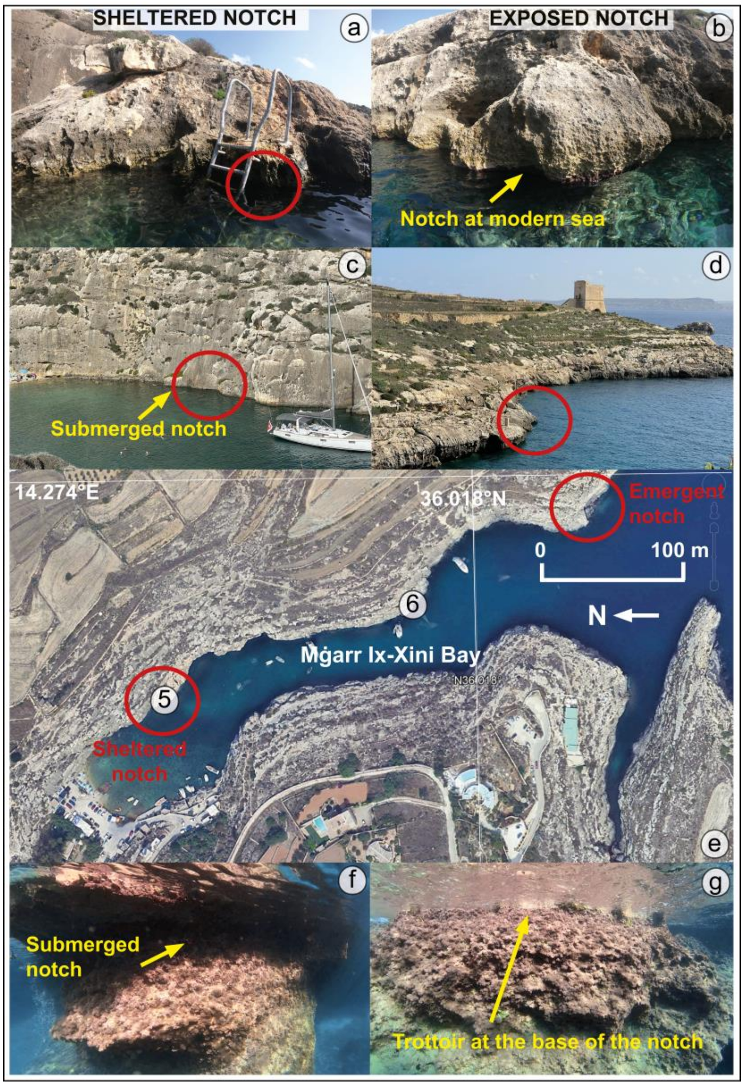

Figure 5. Collection of images at the Gozo site. (**a**) lack of the TN at the mean sea level at the site corresponding to number 5 in the map (**e**), (**b**) TN at an exposed site corresponding to number 6 in the map (**e**), (**c**) the sheltered part of the bay where the submerged notch (DTN) occurs, in the innermost part of Mġarr ix-Xini bay; (**d**) the TN in the outermost part of the bay at the mean sea level; (**e**,**f**) the submerged notch at Mġarr ix-Xini bay, (**g**) the red algal trottoir at the base of the TN.

At Mġarr ix-Xini, benthic assemblages of the subtidal area are, above all, composed of turf-forming algae intermingled with brown algae of the family Dyctiotales growing on a substrate free of encrusting red algae. Turf-forming algae are probably related to a spatial variation in the deposition of suspended sediments [32]. The intertidal assemblage, however, presents a dense encrustation of crustose calcareous algae of *Lithophyllum* and *Lithothamnium* genera, surmounted by a strip of Chlorophyceae [33]. A huge number of holes due to molluscs of the genus *Patella* is frequent along the transect.

6. Discussion

Data collected at the two sites allowed us to make the following considerations. For the first time, a continuous morphometric survey of the notch in the ria of Cala Madonna was carried out, from its sheltered to the exposed part, before the same was conducted for the latter outside the ria. The survey allowed us to highlight that the "normal" MTN located outside Cala Madonna showed the shape usually reported by several authors in the Mediterranean area [2,34]. Measurements were collected in three surveying days, as reported in Table 1. Antonioli et al. [2] described several MTNs in sheltered sites, such as Porto Badisco (Apulia, Italy), but no DTNs occurred there. The sites studied in this paper are exposed toward the south, with DTN on the innermost side. Corrected measures (Table 1) show that the transition from the DTN in the sheltered site and the MTN outside the ria occurs approximately 250 m (Figure 3). Moreover, tide gauge data collected in the period from 2021 to 2023 (Figure 4) show that the tide gauge mean sea level is about 0.15 m lower with respect to the biological mean sea level sensu [35]. This was discussed with ISPRA technicians, who informed us that the tide gauge sea level should be raised so measures could appear even lower.

Regarding the interpretation of the submerged notch at the Frioul Archipelago provided by [6], the authors wrote that at the sheltered sites, the relative absence of mechanical wave action and bio-erosion were not instrumental in the formation of the notch in the last millennium. The absence of the aforementioned major erosional processes also influenced the shape of the notch, which, in contrast to the exposed site in which the notch occurred, presented both the roof and the floor. The authors suggest that the floor has probably been preserved due to the increase in sea level rates in the last millennium, which has lowered the erosion rates observed in the previous 400 years, which consisted of relative sea-level stability. Our opinion follows the interpretation provided by Antonioli et al. [2], for which the formation of MTN follows rising sea levels. The submerged notch described in Vacchi et al. [6] (Figure 2E in the paper) could represent the Holocene STN by Antonioli et al. [25] (see Figure 2a), in which sizes are proportional to the local GIA, with lower values in Marseille and significantly higher values in Sardinia and Sicily [36]. Vacchi et al. [6] agreed with us that submerged notches form in the Frioul Archipelago only in sheltered areas, while roof notches form in exposed areas. Their measurements would be correct with respect to the Marseille tide gauge data, even though they are no longer available. They attribute the carving of the roof notch to the mechanisms of relative rises in sea levels already described in [2,37], with a close relation between past sea levels and roof notches. Regarding the submerged notch, they attribute its carving to the fluctuation of the LIA (Little Ice Age), between 1000 and 1500 years BP, as mentioned in [38], when the rates of rising sea levels were significantly lower than today (as described in Figure 5 of paper [6]). The authors also added very low rates in mm/year of GIA [39]. Regarding the sheltered sites in the Frioul Islands, they write that data are in good agreement with those reported by [40] in the northern Adriatic, where a relict submerged tidal notch formed during the post-Roman sea-level stabilisation. So, the roof notch rose with the sea, and the submerged one, due to the lack of coralline algae and reefs, recorded the Little Ice Age at −35 cm. Then, it stopped forming. Therefore, tectonics does not play a significant role in the tilting of the notch, first because the study areas are tectonically stable [2,5,41] and second because all the bays show the same behaviour, but neighbouring bays do not exhibit DTNs.

Starting from our measurements and comparing them with data published by [6], we suggest that the present-day GIA in southern France and Lampedusa are similar, and they range between 0.1 m and 0.2 m. Also, the annual rainfall at Frioul Islands is roughly the same as in the Lampedusa Islands, as reported by [42]. Our observations in the Lampedusa and Gozo islands are continuous, so we could observe the elevation of the notch gradually submerging towards the innermost part of the rias, with a total lowering of 0.58 m toward the innermost part of the rias, as seen at Mġarr ix-Xini in Gozo (Figure 6).

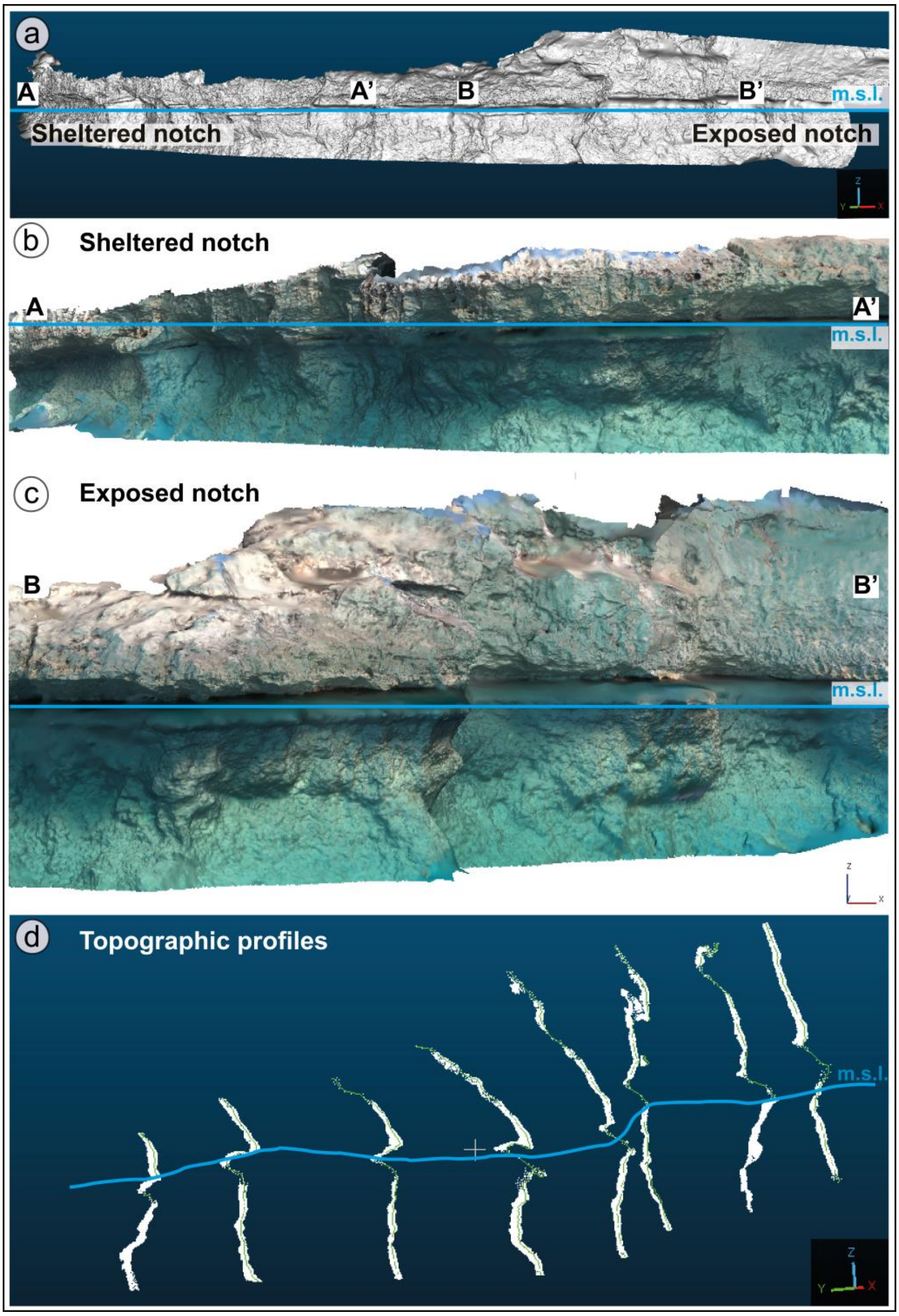

Figure 6. The southern side of the Mġarr ix-Xini bay: (**a**) 3D model of the entire southern sector of the ria. The waterline shows where the notch emerges, or the tidal notch (TN) and submerged, dipping tidal notch (DTN). A-A′ represent the starting and ending point of the zoom in subfigure (**b**), while B

and B′ represent the starting and ending point of the zoom in subfigure (**c**); (**b**) zoom of the sheltered sector of the bay with the dipped notch; (**c**) another zoom of the exposed sector of the bay with the dipped notch; (**d**) topographic profiles of the dipping tidal notch and tidal notch obtained from the 3D model on one side of the ria. On the right, the exposed part of the bay is modelled, while on the left, the sheltered one can be seen.

It is noteworthy that Furlani and Cucchi [43] highlighted that lowering rates increase slightly below the mean sea level in a sheltered site, such as a small harbour in the Gulf of Trieste. Data collected by Furlani et al. [20] during the Geoswim expedition in 2013 in Gozo showed that several submarine springs occur along the island and also during summer periods, and the swim surveyors reported one in the Mġarr ix-Xini ria. Even if Cala Madonna was not surveyed during the Geoswim expedition, it could be possible that it was due to low summer precipitation. For the RN, the term "visor" has been proposed by Evelpidou et al. [44], which ascribes erosion to dissolution by a freshwater spring undercutting a limestone cliff at sea level. Our data are not in agreement with this genesis for the RN because we did not observe the presence of freshwater springs at either the sheltered or exposed sites along the Frioul archipelago. Unlike the sheltered areas described by Vacchi et al. [6], in Cala Madonna and Mġarr iX-Xini, the coralline algae reef at the mean sea level are continuous along the ria cliffs, and they are similar to the exposed sites in which the 'normal' MTN occurs. The biological features of the sites under examination, although coming from geographically distant areas, can probably depend on a well-known set of both abiotic and biotic factors. While in the intertidal zone, typical assemblages of encrusting or erect calcareous red algae are often present, in the first subtidal, the presence of a barren without algal cover is probably due both to grazing by sea urchins, as shown frequently in the images, and to a differential sedimentation rate. The effects of increased surface temperatures, which appear to have the ability to maintain a barren that has formed biologically through the action of grazer species, and the presence of freshwater should also be assessed.

7. Conclusions

The occurrence of DTNs in southward exposed bays represents a specific phenomenon related to localised sites in the central Mediterranean basin. Considering the observations and measurements carried out at these sites, our tentative hypothesis suggests that a combination of marine factors, influenced by local winds and waves driven by the topography and morphology of the small bays exposed to southern quadrants, contributes to the formation of these anomalous notches. These unique landforms manifest under specific conditions, including higher lowering erosion rates slightly below mean sea level in sheltered areas, challenging conventional genesis about tidal notch formation. Considering that TNs are widely used as a very precise sea level marker, the description and interpretation of the genesis of DTNs are fundamental for coastal geomorphological studies.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/geosciences14060157/s1. Figure S1: Examples of tidal notches in the Mediterranean area; (a) measuring a Fossil Tidal Notches (FTNs) at Capo Caccia (Sardinia, Italy); (b) a submerged smoothed notch at Gaeta, Italy; (c) a submerged smoothed notch at Capri Island (Italy); (d) a submerged smoothed notch at Pan di Zucchero, SW Sardinia (Italy); (e) a fossil tidal notch into the Grotta dei Cavalli, NW Sicily (Italy). The red arrows indicate the smoothed isostatic notch sensu Antonioli et al. [25]. Figure S2: Tidal notches described by Antonioli et al. [5] at the ria of Cassis; (a) the ria of Cassis. Measurements were collected at the end of the harbour within the ria; (b) sea cliffs at the mouth of the ria with MTN at the sea level; (c) MTN at the mouth of the ria; (d) the trottoir with coralline algae and at the MTN; (e,f) in the sheltered part of the Cassis ria, only DTN occurs within the Cassis ria.

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Abbreviations

The following abbreviations are used in the manuscript:

DTN	dipping tidal notch
MTN	modern tidal notch
FTN	fossil tidal notch
RN	roof notch
GIA	glacial isostatic adjustment
STN	smoothed tidal notch
MIS	marine isotopic stage
LIA	Little Ice Age

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