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Coastal Quarries as Relative Sea-Level Markers: A Methodological Approach Applied in the Apulia Region (Southern Italy)

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Abstract: The assessment of past sea-level positions requires a multidisciplinary approach that involves both scientific and historical humanistic fields. The use of a multidisciplinary approach allows us to obtain reliable information on the relative sea-level position, the determination of which requires the evaluation of the eustatic and steric components as well as an assessment of the vertical ground displacements, such as the isostatic adjustments and tectonic movements. In this context, coastal geoarchaeological markers play a fundamental role since their architectural height (generally defined as functional height) was relative to the sea level at the time of their construction. Thus, a comparison between the current elevation of geoarchaeological structures (or depth in the case they are currently submerged) with their estimated functional height allows us to obtain the relative sea-level variation. In this study, we applied a methodological procedure for the evaluation of the functional height of architectural elements using modern technologies (Terrestrial Laser Scanner and GPS-Real Time Kinematic) and detailed sea-level analysis. The proposed methodology was applied to coastal quarries located along the coast of Bari (Apulia region, southern Italy). The results allowed us to confirm the functional height of the detachment surface reported in the literature and to assess the sea-level position in the fifth and fourth centuries before Christ.

Keywords: geoarchaeological markers; coastal quarries; sea-level; functional height

1. Introduction

Geoarchaeological remains, partially or completely submerged, are widely used as markers for the evaluation of Holocene sea-level change along the Mediterranean coast [1–5]. These markers can define the past sea-level position with high precision by accounting for their original elevations [6–12]. The elevations of geoarchaeological markers can be influenced by coastal changes that occurred in the Mediterranean region.

The current physiography and sedimentary settings of the Mediterranean coastal areas are the results of evolutionary processes determined by the transgression following the Last Glacial Maximum (LGM—20 (kyears) before present (BP)) [13–15]. In fact, during the LGM, the sea level was about 120 m lower than the present level; then, as a consequence of ice melting, a rapid transgression occurred, which submerged wide coastal sectors with rising rates of up to about 8 mm per year [1,16]. At about 7–6.5 kyears BP (Middle–Late Holocene), the sea-level rise underwent a deceleration of 1 mm per year, and coastal progradation occurred, mainly in the low-lying areas [17–20].

At the local scale, the sea-level changes depend on three factors: (ì) eustatic and steric contributions [8,21]; (ìì) Vertical Land Movements (VLMs), due to isostasy, tectonics, movements induced by volcanic activity, subsidence due to natural and anthropogenic processes; and (ììì) natural sedimentary compaction, also influenced by human activities [22–26]. The integrated contribution of these components determines variable sea-level changes in the different coastal areas of the Mediterranean basin.

The assessment of the paleo sea-level position is strongly supported by sea-level proxies, which include geological, geomorphological, biological, stratigraphic, and archaeological markers [1,8,17,22]. According to international standards, sea-level proxies have been classified as sea-level index points (SLIPs) and limiting points [21,27–29]. The former helps to define the relationship between the marker and the paleo sea level. If a sea-level indicator does not show a clear relationship with the paleo sea level, it has to be considered as a limiting point [17], which is extremely important in constraining the paleo sea level above or below its current position.

Among sea-level proxies, coastal archaeological remains constitute a reliable marker for the evaluation of the past sea-level positions, since they allow the estimation of the sea level at the time when the archaeological structures were built [11,18,30,31]. In addition, the sea-level proxies help to quantify the local factors (in terms of VLMs) and discriminate them from the eustatic and steric components. Archaeological markers include both index and limiting points. Ancient port interface structures (e.g., quays and jetties), fish tanks, and fishponds have generally been used as index points, while due to the difficulties in establishing a relationship with a former sea level, coastal quarries, tombs, breakwaters, and coastal roads are generally used to define a terrestrial limiting point for the coeval sea level [11,17,32].

In the literature, several studies have focused on the application of geoarchaeological structures as sea-level markers in different sites along the Mediterranean coast: Morhange et al. [30] used these markers in Marseille (France), Brückner et al. [31] in Miletus (Turkey), Marriner et al. [32] in Sidon (Lebanon) and Aucelli et al. [33] in the Phlegraean Fields (southern Italy). In the coastal areas characterized by relevant VLMs, the position of archaeological structures may be significantly different compared to their original position, due to subsidence or uplift. For example, in Falsarna (Crete, Greece), the co-seismic uplift of the island in 365 AD brought a Roman port to an elevation of 8 m a.s.l. [34–36]. In several Italian coastal areas, archaeological structures are located below their original position with respect to sea level, as in the case of Baia (Pozzuoli, Italy), which has experienced a lowering of the coastal sector due to the bradyseism process that affected a wide portion of the Phlegraean sector [36–38]. Archaeological markers located in coastal areas where VLMs are present may result in the incorrect evaluation of past sea level since their current position is strongly influenced by local displacements that may have enhanced or obliterated the eustatic sea-level variation. Nevertheless, these kinds of remains are particularly useful for the assessment of the local VLM rates, and provide reliable data on the local relative sea-level changes compared with the eustatic levels of the corresponding ages from one or more Glacial Isostatic Adjustment (GIA) models [24]. However, the accuracy of information provided by archaeological markers can be significantly increased when they are combined with biological, geomorphological, and geological sea-level indicators [39].

Auriemma and Solinas [40] presented a very interesting overview of the most common archaeological sea-level indicators, which include piers and port structures, villas, fishponds, wells, quarries, and any other dateable remains, where a functional height can be determined [39]. The functional height of archaeological features is defined as the "*elevation of specific architectural parts with respect to an averaged sea-level position at the time of their construction*" [41]. The use of the functional height of the archaeological remains is useful for evaluating how much the sea level has changed since the time of their construction, considering all the uncertainties, such as the state of conservation, the temporal attribution, and the sea-weather parameters at the moment of the survey.

The assessment of types and functionalities of a given archaeological marker must therefore be investigated according to their use, as many of them were built at a certain elevation above sea level. For this reason, it is necessary to use surveys aimed at determining the functional height with respect to the current sea level with high accuracy.

In this work, a methodological approach for supporting the characterization of coastal quarries as relative sea-level markers is proposed. In particular, this work describes a high-resolution survey carried out along the coast of Bari (Apulia Region), a rocky coast characterized by low anthropogenic and/or natural vertical deformations, where a number of archaeological remains have been detected. The investigation was supported by the use of Terrestrial Laser Scanner (TLS) and Global Positioning System-Real Time Kinematic (GPS-RTK) acquisition for the open-coast quarries. The results showed how high-resolution surveys, coupled with the analysis of sea-weather data, allowed us to establish the functional height of archaeological remains, and thus to evaluate the past sea-levels.

2. Study Area

The Apulian coasts host many archaeological remains that confirm that this region has been occupied since the Bronze Age by human settlements [37,38,42–44]. Many of these remains are currently totally or partially submerged by the sea. The study area is located along the Adriatic coast of the Murgian plateau, 30 km SE from the city of Bari.

Geological evidence shows that the coastal areas of Bari and Brindisi were characterized by tectonic stability during the Holocene [11,45–48].

Recent analysis showed the absence of vertical deformations due to anthropogenic activities, so the relative sea-level in the last 4000 years has been not affected by significant VLMs such as alterations in the functional height of the coastal markers [11,47]. However, in the last few centuries, different seismic events along the coasts of Salento have been reported in historical documents. Among the most destructive earthquakes that have occurred in Apulia, several have affected the coastal areas of Bari and Brindisi, such as those that occurred on May 11, 1560 BP (Mw = 5.7, [49]) and February 20, 1743 BP [50–54].

Along the coastal stretch extending from Bari to Monopoli, adjacent to the old Via Traiana that connected Benevento to Brindisi, there are various archaeological features, from Roman quarries and fish farming pools to drainage channels (Figure 1). Some of these features are now partially submerged but during the Roman times they were at an elevation higher than the current sea level [11]. Several coastal quarries are located at a horizontal distance of 10 m from the current coastline, while at the time of their use they were located about 50 m from the coastline [11,40].

Open-air quarries very similar to those present on the coast of the province of Bari are located in other coastal sectors along the Via Traiana, such as in Torre Santa Sabina and Egnazia (Brindisi). In this case, the detachment surface is between −0.5 m and −1 m below sea level [55]. Determining the age of the coastal quarries is a difficult task, but tombs and sarcophagi found near the Egnatia site suggest a time range between the fifth and fourth centuries before Christ (BC) [40].

Furthermore, in San Vito of Polignano a Mare (Bari), in Egnazia, and in Torre Santa Sabina there are Roman pipes for the discharge of wastewater, which are currently located at an elevation of −0.80 m compared to the current sea level, lower than the functional height that was used for the discharge [11,40].

The coast of the province of Bari is affected by a tidal excursion of about 0.40 m, which determines the differential in the submersion of the archaeological features (Figure 2).

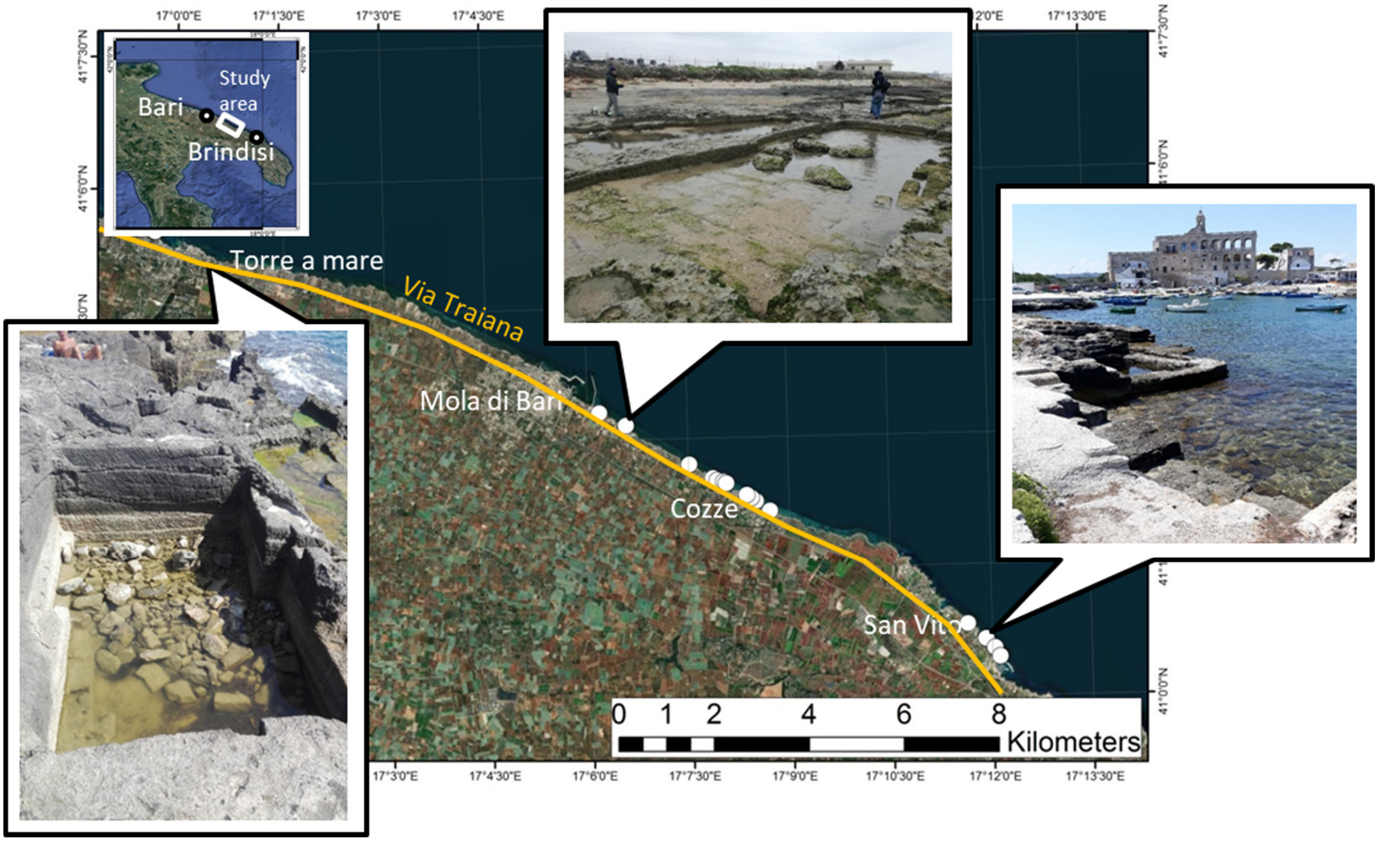

Figure 1. The coastal area of the province of Bari with the location of Roman quarries (white dots) is located near the Via Traiana (in orange).

The anemometric and wave data recorded through the stations of the Apulian Basin Authority (AdBP) and the buoys of the Italian Institute for Environmental Protection and Research (ISPRA) show that the incidence of wave motion comes from the eastern and northern-western sectors [56,57]. The continuous impact of the waves causes a temporary rise in the water column along the coast, known as wave set-up, which can be up to several centimeters [58,59]. During storm surges, significant rises in the water column result in the submersion of the coastal quarries. Sometimes the force of the storm waves is so intense that some coastal boulders are dislocated along the coast and transported to the quarries and fish farming pools [56,60].

Tectonic Setting

The geological framework of the Apulia region is determined by three main geological domains: the Apulia Foreland, the Bradanic Trough, and the Apennine Chain. These geological domains are related to the geodynamic processes that involved the Adria Plate and European Plate [61,62].

The lithology of the study area is given by the Calcarenite di Gravina Formation (Lower Pleistocene) in transgression on the Cretaceous limestones [63,64], which are characterized by joints and fractured surfaces and by several coastal springs that drain the underground water along with preferential flows in the calcarenite [65]. The morphology of the area consists of a series of marine terraces formed during the Last Interglacial period when the sea level was about 7 m higher than the present level [62,66–68]. These terraces slope gradually towards the NE until they reach the coastline. Sometimes the marine terraces are interrupted by fluvial incisions, locally called “lame”, which culminate in small pocket beaches [19,47].

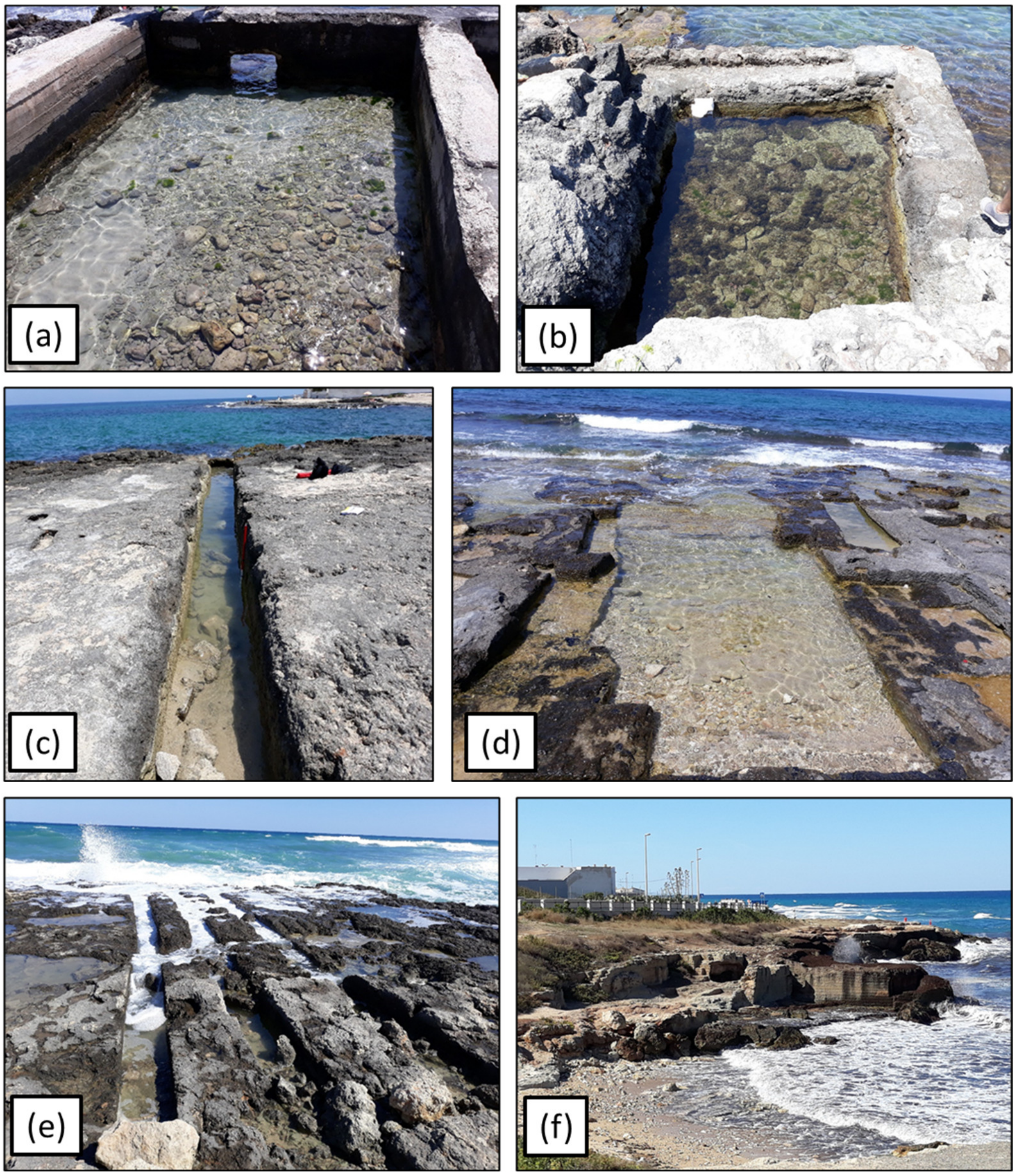

Figure 2. Geoarchaeological markers located in different coastal sites in the province of Bari: (**a**) extraction quarry with drainage channel towards the sea located in Cozze; (**b**) Roman swimming pool located in San Vito-Polignano a Mare; (**c**) channel located in San Vito-Polignano a Mare; (**d**) extraction quarry connected to the sea at the current sea-level, located in Cozze; (**e**) series of drains located at Cozze; (**f**) quarries in Torre a Mare.

The structural features of the Apulia region are located on the Adria Plate and are constituted by a main structural system of NW-SE oriented normal faults [62,69–71].

Two geodynamic phases were observed in the Apulia region during the Plio-Pleistocene [64]. In the first phase, the westernmost sectors of the Apulian Foreland underwent strong subsidence [69], which was caused by subduction under the Apennine Chain. In this context, a Bradanic Trough sedimentary cycle [61,64] began to accumulate with coastal deposits belonging to the Calcarenite di Gravina Formation [72] culminating in silty clayey hemipelagic deposits belonging to the stratigraphic argille subappennine informal unit [73]. In the second geodynamic phase (from the middle Pleistocene), the entire Apulian Foreland and Bradanic Trough were uplifted [68,73,74].

Recent instrumental records showed that the Apulia region is characterized by a general counter-clockwise motion of the Adria Plate [75]. The internal part of Adria shows minor, but not negligible, seismic activity [76,77]; in particular, this region is close to several areas where seismicity is frequent and intense. The southern part of Apulia is generally considered practically aseismic [78]. The seismic history of the Salento peninsula shows that only one event of a magnitude higher than 6.0 is reported in the historical catalogues: this earthquake, which occurred on 20 February 1743, caused maximum damage with an intensity of IX–X degrees on the Mercalli–Cancani–Sieberg scale (MCS) and also caused a tsunami [50,54].

However, Pierri et al. [51] proposed the hypothesis that the margin of the Adria Plate has undergone a buckling process [69] following the extensional rearrangement of the Apennine belt masses. The focal mechanisms obtained from instrumental seismic records [51] suggest that a tensional regime could still be active. The NE–SW active extension in this area was also previously inferred by Di Bucci et al. [74] on the basis of mesostructural analysis. This behavior is also evidenced by the elevation of marine terrace deposits, which showed differential VLMs in the study area [62,79–81]. VLMs assessed through the elevations of the Last Interglacial deposits showed uplift rates of about 0.01 mm per year [62].

3. Materials and Methods

In order to evaluate the functional height of the investigated geoarchaeological markers, the following operative procedure of analysis is proposed (Figure 3):

- Step 1: Identification of geoarchaeological markers and of the related architectural elements that determined their functionality at the time they were built

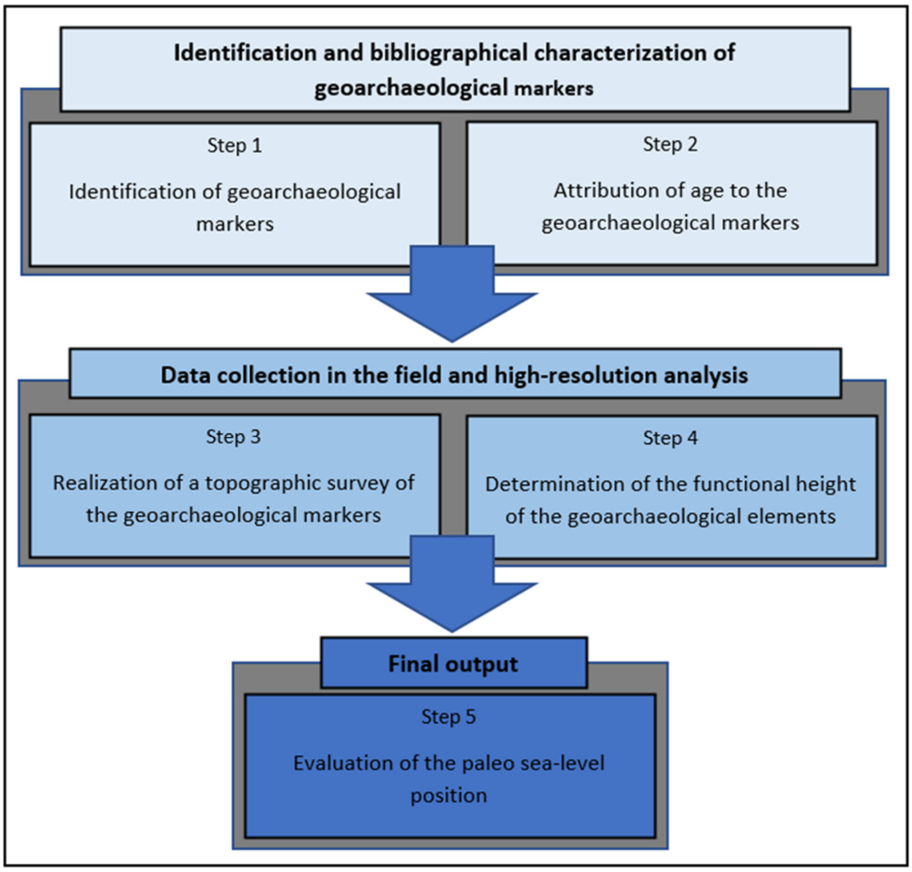

Figure 3. Steps of the proposed methodological analysis procedure to evaluate the paleo sea-level position using geoarchaeological markers.

This step requires in-situ observations carried out by a multidisciplinary team, composed at least of a geologist, a geomorphologist, and an archaeologist; the expert-based survey is fundamental for the historical contextualization of the marker and for the definition of the local physical parameters.

- Step 2: Attribution of the age to the geoarchaeological markers with relative error estimation

  This step can be supported by a deep desk review (in which peer review articles and/or grey literature available for the investigated sites can be taken into account); also, in this case, an expert-based judgment can support the age attribution to the investigated archaeological sites.

- Step 3: Realization of a topographic survey of the geoarchaeological markers

  This step consists of the definition of all the operative details required to obtain high resolution and accurate topographic data for the investigated markers.

- Step 4: Determination of the functional height of the geoarchaeological elements with respect to the tidal conditions at the time of the survey

  This step is based on the analysis of tide-gauge data available for the investigated coastal sector, performing a correction on the topographic data with the sea level measured by tide sensor and VLMs.

- Step 5: Evaluation of the paleo sea-level position

  This step consists of the integration of all the collected data for evaluating the sea-level position coeval with the investigated marker, considering the following relationship:

$$PSL = EG + FH \pm \text{ VLM} + tide\ phase \tag{1}$$

where *PSL* is the past sea-level position, *EG* is the elevation above sea level (a.s.l.) of the geoarchaeological marker, *FH* is the functional height of the geoarchaeological marker, VLM is the vertical land movement due to tectonic or anthropogenic factors, and *tide phase* represents the tide range to be considered in the assessment of the tide level in the past. In the case of uplift, the VLM value must be subtracted, while in the case of subsidence, the VLM value must be added.

In the following, the operative details related to the acquisition of topographic data and tide phases are illustrated for the assessment of the functional height of the coastal quarries of Mola di Bari (Figure 4).

A TLS survey was performed with a Faro Focus X130, a phase difference laser scanner that acquires a point cloud of the emerged surface with an accuracy of one-tenth of a millimeter at a range of 100 m. The instrument consists of an emitter that directs a laser beam towards the surrounding environment through a rotating prism. When the emitter is activated, the instrument rotates on itself to direct the laser beam in all directions. The evaluation of the distance is given by the phase difference between the incident ray and the reflected ray, which attributes a specific distance to each impacted point that corresponds to the space between the instrument and the point impacted by the laser beam. The information for each of the acquired points includes the spatial coordinates derived from a GPS integrated with the instrument, the reflectance of the laser beam, and the chromatic values acquired with the instrument's integrated camera. The correction of spatial coordinates in ellipsoid elevations was performed through Ground Control Points (GCPs) obtained through the GPS-RTK acquisitions. Next, the ellipsoid elevations were reported at the geode level using the ITALGEO 2005 grids.

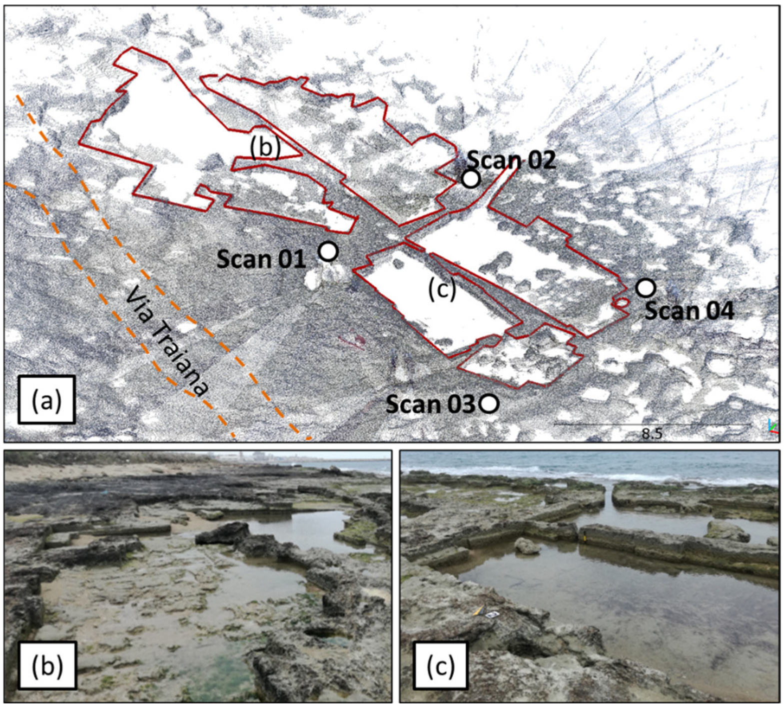

Figure 4. Topographic survey at Mola di Bari; (**a**) TLS point cloud of the coastal quarries of Mola di Bari with the delimitation of the main architectural elements that define their functional height; (**b**) quarries carved in the proximity of the Via Traiana; (**c**) quarries connected to the sea through a drainage channel.

Four scans were acquired and positioned at four vertices of a quarry in direct connection with the sea through a water distributor channel and connected to other adjacent quarries through small holes (Figure 4). The distribution of the scanning points was chosen in such a way as to fully cover the architectural elements of the coastal quarry and to also acquire the internal walls so that they are perfectly visible during the processing phase. The point clouds were cleaned of noise corresponding to humidity and atmospheric particulate matter and were subsequently merged to obtain a single general point cloud of coastal quarries. From the general point cloud, it is possible to measure and trace each scanned architectural element, to be able to analyze its dimensions, and contextualize its location compared to sea level. From the point cloud, it is possible to measure the height of the detachment surface, which was partially submerged by a water column of −0.08 to −0.1 m at the time of acquisition.

Sea-level recorded at the Brindisi tide gauge (property of the AdBP) have been analyzed to define the tide conditions during the laser surveys. The tidal data have a sampling step of 15 min with an accuracy of 1 cm, which can be compared with the uncertainty of the laser measurements. The elevation of TLS data was corrected with the sea-level position recorded by the tide sensor at the moment of the survey. To assess the tide phase that influences the coastal area, Brindisi tide records (property of AdBP) and Bari tide records (property of ISPRA) were processed through a spectral analysis to detect the frequency components of tide signals. The spectral analysis was performed through a Continuous Wavelet Transform (CWT), using the Wavelet "Morlet" [82,83] to identify the tide phases that must be considered for the assessment of functional height. The spectral analysis shows the tidal signals together with the scalograms. The scalograms represent the percentage of energy for each wavelet coefficient. The highest percentage of energy is attributed to the highest tide level reached in 2019–2020.

4. Results

Through the application of each step of the proposed protocol in Section 3, the following results were obtained:

1. Identification of geoarchaeological markers and of the related architectural elements that determined their functionality at the time they were built

Along the coasts extending between Bari and Brindisi, the most ancient settlements were attributed to the Bronze Age, in which the topography of the area allowed maritime activities for the trans-Adriatic trade [46,84,85].

An important merchant harbor was located in Egnatia, 60 km SE from Bari, where wares were moved from Apulia to Lucania and along the Via Traiana. Trade activities involved the extraction of limestone blocks, which were transported along the Via Traina [11,46,84].

Currently, the former coastal quarries are partially submerged and are characterized by a detachment/mining surface connected to with the sea through a 0.6 m wide channel that drained the rainwater. The quarries are arranged adjacent to each other, and are designed to improve the extraction of limestone blocks and to facilitate their transport both by sea and by land.

2. Attribution of the age to the geoarchaeological markers with relative error estimation

As the coastal quarries detected are similar to those located along the Via Traiana in San Vito (province of Bari) and Egnatia (province of Brindisi), they can be attributed to the fifth and fourth centuries BC [11,31,84]. On the other hand, anthropogenic items found in the tombs carved into the Egnatia coastal quarries have been found to be about 2400 years old [11,86], with an uncertainty of approximately $\pm$100 years, as derived from dating methods [42,87].

3. Realization of a topographic survey of the geoarchaeological markers

The TLS survey allowed us to obtain the scans of all the architectural elements of the investigated coastal quarries and define the elevation of the detachment/mining surfaces. A joint analysis using TLS and GPS-RTK data provided georeferenced point clouds in which each point reports the coordinates and elevations of the scanned environment, with reflectance and RGB color value. From the scans, it was possible to measure the distance from each architectural element. The detachment/mining surfaces of the quarries were used as a geoarchaeological marker for the assessment of the functional height. The depths of these surfaces were about -0.08 to -0.1 m below sea level at the time the survey was carried out on 19 March 2019.

4. Determination of the functional height of the geoarchaeological markers with respect to tide phases and VLM

The TLS survey was carried out on March 19, 2019 in low tide conditions. The Brindisi AdBP tide gauge measured a tide level equal to –0.50 m with respect to the geodetic surface. Considering that the detachment surface of the coastal quarry with respect to the tide level is located at a depth of -0.08 to -0.1 m below sea level, its relative elevation compared to the geodetic surface was equal to -0.58 to -0.60 m at the time of the survey (Figure 5). In order to assess the maximum tide level on the Mola di Bari coast, tide records for the Brindisi and Bari stations were analyzed through spectral analysis (Figure 6). The scalogram of the spectra showed that the highest tide level reached values of 0.21 $\pm$ 0.1 m in Brindisi and 0.52 $\pm$ 0.1 m in Bari (Figure 6), with a tidal range of 0.36 $\pm$ 0.1 m.

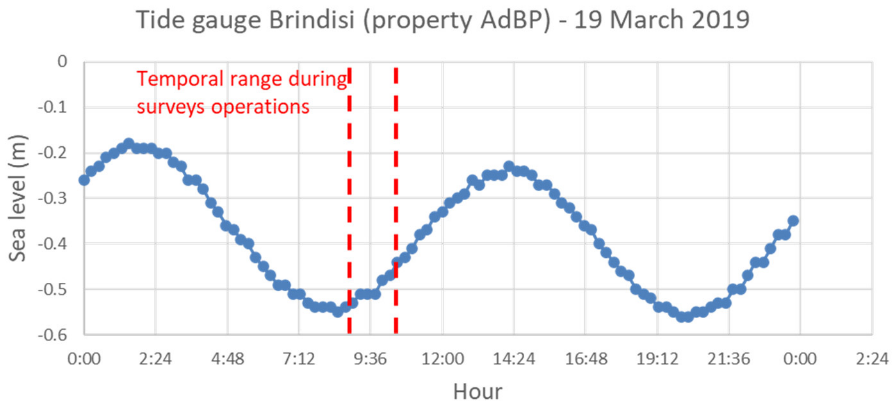

Figure 5. Records from the Brindisi tide gauge (property of AdBP) during the TLS survey on 19 March 2019.

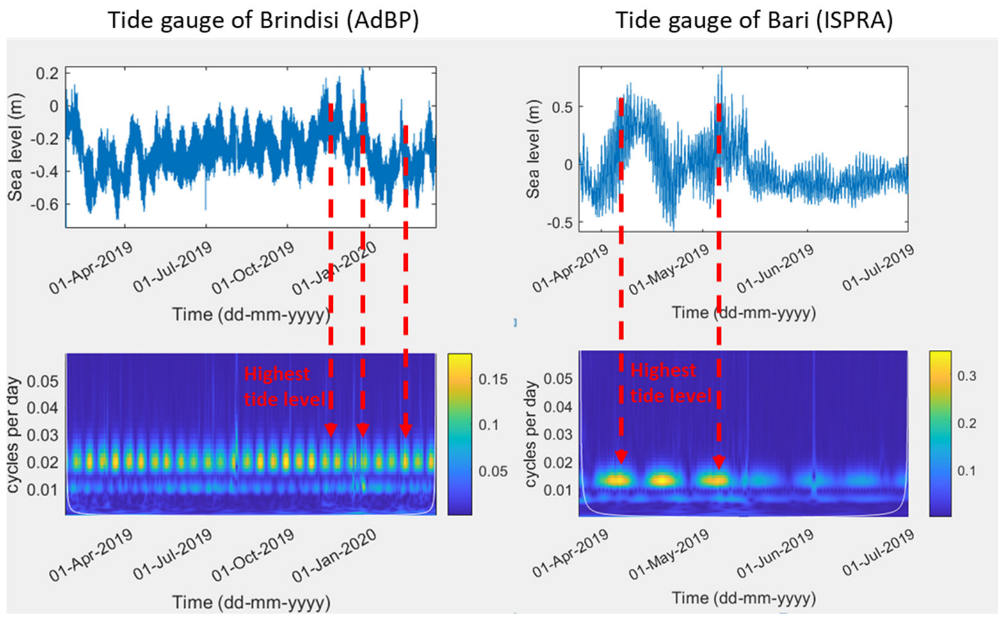

Figure 6. Spectral analysis performed on the tide gauge from Brindisi (property of AdBP) and tide gauge from Bari (property of ISPRA) showed the highest tide level reached in 2019–2020.

VLMs assessed through the elevation of Last Interglacial deposits in the area of Bari [62] showed uplift rates of about 0.01 mm per year, which allowed us to calculate a VLM of about 0.02 ± 0.01 m from the Bronze Age.

5. Evaluation of the paleo sea-level position

Based on our study of the reference literature, it emerged that the detachment surface of the Roman coastal quarries had a functional height of 0.30 ± 0.1 m above the high tide level [6,11].

The assessment of the past sea level was obtained through Equation (1) (see Step 5 in Section 3), where:

- EG is equal to 0.58 ± 0.2 m and represents the elevation of the detachment surface;
- FH is equal to 0.30 ± 0.1 m a.s.l.;
- VLM is equal to 0.02 ± 0.01 m;
- the local tide range is 0.36 ± 0.1 m;

Applying Equation (1), the past sea-level position is equal to −1.22 ± 0.3 m. Considering the temporal attributions of the open quarries located at Egnatia (Brindisi), which are similar in architectural features and are close to the Via Traiana, the quarries of Mola di

Bari could be ascribed to the same temporal range. Thus, the quarries of Mola di Bari could be ascribed to the period between the fifth and fourth century BC with a mean sea level corresponding to -1.22 ± 0.3 m lower than present levels (Figure 7).

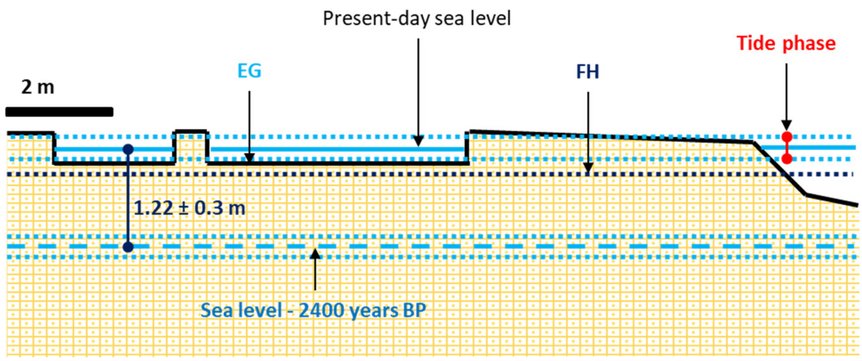

Figure 7. Sea-level assessment in 2400 years BP compared to the current sea-level measured in the coastal quarries of Mola di Bari; EG = elevation of a geoarchaeological marker, FH = functional height.

5. Discussion

In this study, the partially submerged coastal quarries located along the coast of the province of Bari (in the Apulia region) were surveyed to assess the past sea-level position. Quite similar quarries are located along the Via Traiana, which connected the city of Benevento to Brindisi; in addition, sarcophagi from the fifth and fourth century BC were found at the base of the quarries in Egnazia (Brindisi) [40]. These last findings allowed us to ascertain when the quarry stopped being used for extraction purposes as dating of the anthropogenic materials in the sarcophagi and tombs indicated an age of 2400 ± 100 years BP [11,59,88], which indicates that quarrying halted before this date. Submerged graves from the Imperial Roman age have also been found at San Vito near Polignano [89] and in Torre Santa Sabina localities [86,87]. It is not always possible to date the coastal quarries with high accuracy, even if the territorial context, the blocks module, and architectonical elements left in situ are significant archaeological indicators [40].

These coastal quarries have been affected by uplift rates during the Upper Pleistocene and Holocene, ranging from about 0.13 mm per year in the Taranto area to zero in the southernmost part of the region, although low rates of uplift along the Adriatic coast during the Holocene may have occurred [47,48,90,91]. The VLMs caused by uplift movements resulted in a vertical displacement in the functional heights of 0.02 ± 0.01 m [9,92,93]. For this reason, the combined use of sea and weather data with topographic data allows us to make a detailed analysis of the height of the detachment/mining surface of the coastal quarries with respect to the current sea level.

In previous works [1,11,17], the functional height of the detachment surface of the coastal quarries was estimated to be about 0.3 m above the high tide level. Nevertheless, the attribution of functional height is not always homogeneous in Mediterranean coastal quarries; by way of example, in Sicily, Scicchitano et al. [6] defined a functional height higher than 0.6 m. Assessment of the present-day elevation of the coastal quarries compared to their functional height in Mola di Bari provided a past-sea level of -1.22 ± 0.3 m lower than the present level at 2400 ± 100 years BP. This value is in agreement with the analysis of piezometric surfaces performed by Milella et al. [42] along the Egnatia area.

The definition of the sea level based on the functional height of an investigated archaeological marker can be used to calibrate the proposed sea-level models. In Figure 8, position data related to the geoarchaeological markers located along the coast of the Apulia region are compared with two relative sea-level curves obtained from (i) the isostatically corrected sea-level positions proposed by Lambeck et al. [2] for the investigated coastal sector (Site 25—Latitude 41.245 N, Longitude 16.507 E Greenwich), and (ii) the ICE-7G model [3,5] for the Southern Adriatic area (Latitude 41.341 N, Longitude 17.150 E Greenwich).

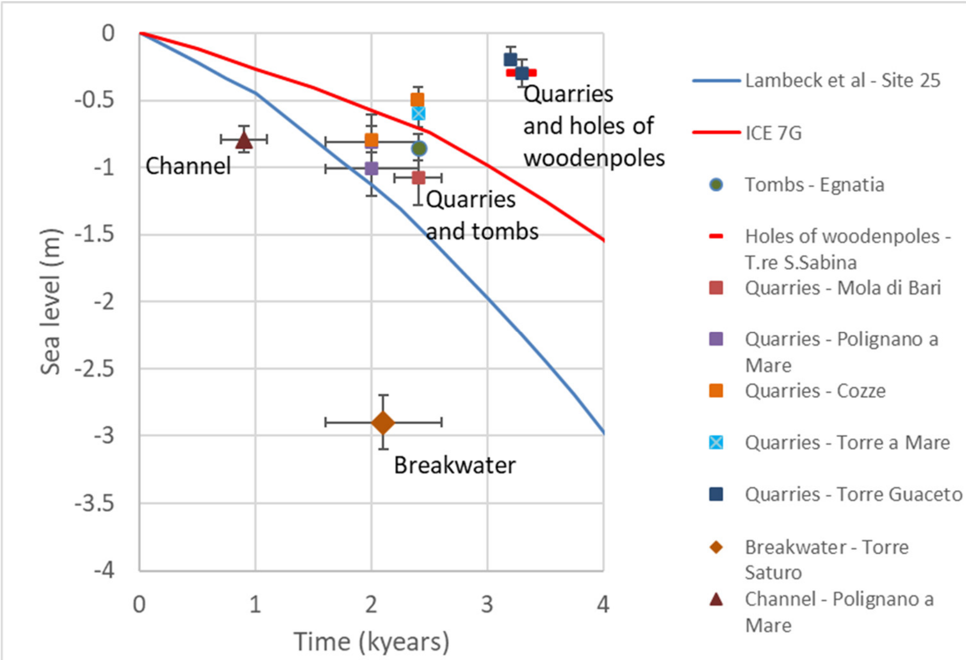

Figure 8. Comparison of sea level data from the current elevations based on geoarchaeological evidence along the coast compared with the Lambeck curve [2] and ICE-7G [3,5].

As occurred for similar markers measured along other Mediterranean coastal stretches such as open or marine-influenced lagoonal deposits, brackish environment, and beach rocks [11,17,51,89,94,95], the position of the investigated quarries falls above the Lambeck et al. [1,2] curve. This result may indicate that the glacial-isostatic model underestimates the Holocene sea-level values at the local scale. On the other hand, the ICE-7G model may overestimate the Holocene sea-level values in the investigated Mediterranean area. In fact, as shown in Figure 8, sea level data derived from the archaeological markers in the coastal sector of the province of Bari are lower than the values indicated by the model. This may be due to the specific ICE-7G model configuration since this model is calibrated on observational data concentrated in the polar areas but does not take into consideration the observational data from areas far from the glacier formations in the last 12,000 years [3,17].

This study also highlights some considerations on the use of TLS technology in the measurement of the functional heights of the geoarchaeological markers. First, compared to other methods, such as the differential GPS or total station, the use of TLS allows topographic data to be acquired more quickly, thus reducing the in situ operational efforts. In addition, the high resolution of the acquired data reduces the uncertainty in the position, performs a more detailed analysis of the functional height, and provides more reliable spatial information. Finally, the measurements of the topographic survey can be compared with a local geodetic elevation, which can be measured just as precisely by analyzing local tidal data.

6. Conclusions

In this paper, a methodological approach for the evaluation of paleo sea-level position using high-resolution topographic methods coupled with the accurate definition of the current sea level is proposed. The analysis was applied to the investigation of ancient coastal quarries located along the coastal sector of Bari. The operative implementation of all the proposed procedural steps, which include in situ marker recognition, a deep literature review, high-resolution topographic data acquisition coupled with the definition of the sea level at the time of the survey, data integration, and final data interpretation, allowed us to estimate a paleo sea-level position of -1.22 ± 0.3 m between the fifth and fourth centuries BC along the coastal area of Bari.

In addition, this work shows that the use of the TLS survey allows the estimation of the functional heights of archaeological structures with very high resolution. On the other hand, the uncertainty about the age of geoarchaeological elements is greater than the errors of topographic data, as modern dating methods are affected by random errors, and the most reliable sources for attributing an age to archaeological finds are historical archival documents.

In conclusion, despite the inherent difficulties in obtaining reliable data, the study testifies to the advantages of an integrated archaeological and geological approach, which helps to obtain an indication of the local relative paleo sea-level position. These results are very useful for supporting the local calibration of models, and for the definition of paleo sea-level curves.

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References

1. Lambeck, K.; Anzidei, M.; Antonioli, F.; Benini, A.; Esposito, A. Sea level in Roman time in the Central Mediterranean and implications for recent change. *Earth Planet. Sci. Lett.* **2004**, *224*, 563–575. [CrossRef]
2. Lambeck, K.; Antonioli, F.; Anzidei, M.; Ferranti, L.; Leoni, G.; Scicchitano, G.; Silenzi, S. Sea level change along the Italian coast during the Holocene and projections for the future. *Quat. Int.* **2011**, *232*, 250–257. [CrossRef]
3. Peltier, W. Global glacial isostasy and the surface of the ice-age Earth: The ICE-5G (VM2) Model and GRACE. *Annu. Rev. Earth Planet. Sci.* **2004**, *32*, 111–149. [CrossRef]
4. Anzidei, M.; Lambeck, K.; Antonioli, F.; Furlani, S.; Mastronuzzi, G.; Serpelloni, E.; Vannucci, G. Coastal structure, sea-level changes and vertical motion of the land in the Mediterranean. *Geol. Soc. Lond. Spec. Publ.* **2014**, *388*, 453–479. [CrossRef]
5. Roy, K.; Peltier, W.R. Relative sea level in the Western Mediterranean Basin: A regional test of the ICE-7G_NA (VM7) model and a constraint on late holocene antarctic deglaciation. *Quat. Sci. Rev.* **2018**, *183*, 76–87. [CrossRef]
6. Scicchitano, G.; Antonioli, F.; Berlinghieri, E.F.C.; Dutton, A.; Monaco, C. Submerged archaeological sites along the ionian coast of Southeastern Sicily (Italy) and implications for the holocene relative sea-level change. *Quat. Res.* **2008**, *70*, 26–39. [CrossRef]
7. Scicchitano, G.; Berlinghieri, E.F.C.; Antonioli, F.; Spampinato, C.R.; Monaco, C. Sacred landscapes and changing sea levels: New interdisciplinary data from the early neolithic to the present in South-Eastern Sicily. In *Under the Sea: Archaeology and Palaeolandscapes of the Continental Shelf*; Bailey, G.N., Harff, J., Sakellariou, D., Eds.; Coastal Research Library; Springer International Publishing: Cham, Switzerland, 2016; pp. 233–253. ISBN 978-3-319-53160-1.
8. Anzidei, M.; Antonioli, F.; Benini, A.; Lambeck, K.; Sivan, D.; Serpelloni, E.; Stocchi, P. Sea level change and vertical land movements since the last two millennia along the coasts of Southwestern Turkey and Israel. *Quat. Int.* **2011**, *232*, 13–20. [CrossRef]
9. Lo Presti, V.; Antonioli, F.; Auriemma, R.; Ronchitelli, A.; Scicchitano, G.; Spampinato, C.R.; Anzidei, M.; Agizza, S.; Benini, A.; Ferranti, L.; et al. millstone coastal quarries of the Mediterranean: A new class of sea level indicator. *Quat. Int.* **2014**, *332*, 126–142. [CrossRef]
10. Orrù, P.E.; Mastronuzzi, G.; Deiana, G.; Pignatelli, C.; Piscitelli, A.; Solinas, E.; Spanu, P.G.; Zucca, R. Sea level changes and geoarchaeology between the Bay of Capo Malfatano and Piscinnì Bay (SW Sardinia) in the last 4 kys. *Quat. Int.* **2014**, *336*, 180–189. [CrossRef]
11. Mastronuzzi, G.; Antonioli, F.; Anzidei, M.; Auriemma, R.; Alfonso, C.; Scarano, T. Evidence of relative sea level rise along the coasts of Central Apulia (Italy) during the late holocene via maritime archaeological indicators. *Quat. Int.* **2017**, *439*, 65–78. [CrossRef]

12. Mattei, G.; Rizzo, A.; Anfuso, G.; Aucelli, P.P.C.; Gracia, F.J. A tool for evaluating the archaeological heritage vulnerability to coastal processes: The case study of Naples Gulf (Southern Italy). *Ocean Coast. Manag.* **2019**, *179*, 104876. [CrossRef]
13. Brancaccio, L.; Cinque, A.; Romano, P.; Rosskopf, C.; Russo, F.; Santangelo, N. L'evoluzione delle pianure costiere della Campania: Geomorfologia e Neotettonica. *Mem. Soc. Geogr. Ital.* **1995**, *53*, 313–336.
14. Clark, P.U.; Dyke, A.S.; Shakun, J.D.; Carlson, A.E.; Clark, J.; Wohlfarth, B.; Mitrovica, J.X.; Hostetler, S.W.; McCabe, A.M. The last glacial maximum. *Science* **2009**, *325*, 710–714. [CrossRef] [PubMed]
15. Hughes, P.D.; Gibbard, P.L.; Ehlers, J. Timing of glaciation during the last glacial cycle: Evaluating the concept of a global 'last glacial maximum' (LGM). *Earth-Sci. Rev.* **2013**, *125*, 171–198. [CrossRef]
16. Lambeck, K.; Purcell, A. Sea-level change in the Mediterranean sea since the LGM: Model predictions for tectonically stable areas. *Quat. Sci. Rev.* **2005**, *24*, 1969–1988. [CrossRef]
17. Vacchi, M.; Marriner, N.; Morhange, C.; Spada, G.; Fontana, A.; Rovere, A. Multiproxy assessment of holocene relative sea-level changes in the Western Mediterranean: Sea-level variability and improvements in the definition of the isostatic signal. *Earth-Sci. Rev.* **2016**, *155*, 172–197. [CrossRef]
18. Lodolo, E.; Galassi, G.; Spada, G.; Zecchin, M.; Civile, D.; Bressoux, M. Post-LGM coastline evolution of the NW sicilian channel: Comparing high-resolution geophysical data with glacial isostatic adjustment modeling. *PLoS ONE* **2020**, *15*, e0228087. [CrossRef]
19. Mastronuzzi, G.; Sansò, P. Holocene coastal dune development and environmental changes in Apulia (Southern Italy). *Sediment. Geol.* **2002**, *150*, 139–152. [CrossRef]
20. Scardino, G.; Sabatier, F.; Scicchitano, G.; Piscitelli, A.; Milella, M.; Vecchio, A.; Anzidei, M.; Mastronuzzi, G. Sea-level rise and shoreline changes along an open Sandy coast: Case study of Gulf of Taranto, Italy. *Water* **2020**, *12*, 1414. [CrossRef]
21. Rovere, A.; Stocchi, P.; Vacchi, M. Eustatic and relative sea level changes. *Curr Clim. Chang. Rep.* **2016**, *2*, 221–231. [CrossRef]
22. Lambeck, K.; Woodroffe, C.; Antonioli, F.; Anzidei, M.; Gehrels, W.; Laborel, J.; Wright, A. Paleoenvironmental records, geophysical modeling, and reconstruction of sea-level trends and variability on centennial and longer timescales. *Fac. Sci.-Pap. Arch.* **2010**, *c04*, 61–121.
23. Aucelli, P.P.C.; Di Paola, G.; Incontri, P.; Rizzo, A.; Vilardo, G.; Benassai, G.; Buonocore, B.; Pappone, G. Coastal inundation risk assessment due to subsidence and sea level rise in a Mediterranean alluvial plain (volturno coastal plain—Southern Italy). *Estuar. Coast. Shelf Sci.* **2017**, *198*, 597–609. [CrossRef]
24. Aucelli, P.P.C.; Mattei, G.; Caporizzo, C.; Cinque, A.; Amato, L.; Stefanile, M.; Pappone, G. Multi-proxy analysis of relative sea-level and paleoshoreline changes during the last 2300 years in the Campi Flegrei Caldera, Southern Italy. *Quat. Int.* **2021**, *602*, 110–130. [CrossRef]
25. Mastronuzzi, G.; Antonioli, F.; Anzidei, M.; Aucelli, P.P.C.; Caporizzo, C.; Donadio, C.; Lo Presti, V.; Mattei, G.; Scardino, G.; Scicchitano, G.; et al. Dove Il mare incontra la terra. In Il Mediterraneo e la sua storia. *Catalogo Mostra Thalassa Museo Archeologico Nazionale di Napoli* **2020**, *1*, 22–31.
26. Vacchi, M.; Ermolli, E.R.; Morhange, C.; Ruello, M.R.; Donato, V.D.; Vito, M.A.D.; Giampaola, D.; Carsana, V.; Liuzza, V.; Cinque, A.; et al. Millennial variability of rates of sea-level rise in the ancient harbour of Naples (Italy, Western Mediterranean sea). *Quat. Res.* **2020**, *93*, 284–298. [CrossRef]
27. Shennan, I.; Horton, B. Holocene land- and sea-level changes in great britain. *J. Quat. Sci.* **2002**, *17*, 511–526. [CrossRef]
28. Engelhart, S.E.; Horton, B.P.; Douglas, B.C.; Peltier, W.R.; Törnqvist, T.E. Spatial variability of late holocene and 20th century sea-level rise along the Atlantic coast of the United States. *Geology* **2009**, *37*, 1115–1118. [CrossRef]
29. Lorscheid, T.; Stocchi, P.; Casella, E.; Gómez-Pujol, L.; Vacchi, M.; Mann, T.; Rovere, A. Paleo sea-level changes and relative sea-level indicators: Precise measurements, indicative meaning and glacial isostatic adjustment perspectives from Mallorca (Western Mediterranean). *Palaeogeogr. Palaeoclimatol. Palaeoecol.* **2017**, *473*, 94–107. [CrossRef]
30. Aucelli, P.P.C.; Mattei, G.; Caporizzo, C.; Cinque, A.; Troisi, S.; Peluso, F.; Stefanile, M.; Pappone, G. Ancient coastal changes due to ground movements and human interventions in the Roman Portus Julius (Pozzuoli Gulf, Italy): Results from photogrammetric and direct surveys. *Water* **2020**, *12*, 658. [CrossRef]
31. Auriemma, R.; Solinas, E. Archaeological remains as sea level change markers: A review. *Quat. Int.* **2009**, *206*, 134–146. [CrossRef]
32. Amato, V.; Aucelli, P.P.C.; Mattei, G.; Pennetta, M.; Rizzo, A.; Rosskopf, C.M.; Schiattarella, M. A geodatabase of Late Pleistocene—Holocene Palaeo sea-level markers in the Gulf of Naples. *Alp. Mediterr. Quat.* **2018**, *31*, 5–10.
33. Morhange, C.; Laborel, J.; Hesnard, A. Changes of relative sea level during the past 5000 years in the ancient harbor of Marseilles, Southern France. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* **2001**, *166*, 319–329. [CrossRef]
34. Brückner, H.; Müllenhoff, M.; Gehrels, R.; Herda, A.; Knipping, M.; Vött, A. From archipelago to floodplain—Geographical and ecological changes in miletus and its environs during the past six millennia (Western Anatolia, Turkey). *Z. Fur Geomorphol. Suppl.* **2006**, *142*, 63–83.
35. Morhange, C.; Marriner, N.; Pirazzoli, P. Evidence of Late Holocene Tsunami events in Lebanon. *Z. Für Geomorphol.* **2006**, *146*, 81–95.
36. Aucelli, P.; Caporizzo, C.; Cinque, A.; Mattei, G.; Pappone, G.; Stefanile, M. New insight on the 1st century bc paleo-sea level and related vertical ground movements along the Baia—Miseno coastal sector (Campi Flegrei, Southern Italy). In Proceedings of the IMEKO TC4 International Conference on Metrology for Archaeology and Cultural Heritage; MetroArchaeo, Florence, Italy, 4–6 December 2019; Volume 2019, pp. 474–477.

37. Mattei, G.; Troisi, S.; Aucelli, P.P.C.; Pappone, G.; Peluso, F.; Stefanile, M. Sensing the submerged landscape of nisida roman harbour in the gulf of naples from integrated measurements on a USV. *Water* **2018**, *10*, 1686. [CrossRef]
38. Vecchio, A.; Anzidei, M.; Serpelloni, E.; Florindo, F. Natural Variability and Vertical Land Motion Contributions in the Mediterranean Sea-Level Records over the Last Two Centuries and Projections for 2100. *Water* **2019**, *11*, 1480. [CrossRef]
39. Price, S.; Higham, T.; Nixon, L.; Moody, J. Relative sea-level changes in crete: Reassessment of radiocarbon dates from Sphakia and west crete1. *Annu. Br. Sch. Athens* **2002**, *97*, 171–200. [CrossRef]
40. Scheffers, A.; Scheffers, S. Tsunami deposits on the coastline of west crete (Greece). *Earth Planet. Sci. Lett.* **2007**, *259*, 613–624. [CrossRef]
41. Stiros, S.C. The 8.5+ magnitude, AD365 earthquake in crete: Coastal uplift, topography changes, archaeological and historical signature. *Quat. Int.* **2010**, *216*, 54–63. [CrossRef]
42. Evelpidou, N.; Karkani, A. Archaeology and sea-level change. In *Encyclopedia of Coastal Science*; Finkl, C.W., Makowski, C., Eds.; Springer International Publishing: Cham, Switzerland, 2018; pp. 1–7. ISBN 978-3-319-48657-4.
43. Morhange, C.; Marriner, N. Archeological and biological relative sea-level indicators. In *Handbook of Sea-Level Research*; John Wiley & Sons, Ltd.: New York, NY, USA, 2015; pp. 146–156. ISBN 978-1-118-45254-7.
44. Scarano, T. Refuge or Dwelling Place? The MBA Fortification Wall of Roca (Lecce, Italy): The Spatial and Functional Analysis of Postern C. *Rivista di Scienze Preistoriche* **2011**, *LXI-2011*, 95–122.
45. Alfonso, C.; Auriemma, R.; Scarano, T.; Mastronuzzi, G.; Calcagnile, L.; Quarta, G.; Bartolo, M.D. Ancient coastal landscape of the marine protected area of Porto Cesareo (Lecce, Italy): Recent research. *Underw. Technol.* **2012**, *30*, 207–215. [CrossRef]
46. Milella, M.; Pignatelli, C.; Donnaloia, M.; Mastronuzzi, G. Sea level during 4th–2nd century B.P. in Egnazia (Italy) from archaeological and hydrogeological data. *Alp. Mediterr. Quat.* **2006**, *19*, 253–260.
47. Gioia, D.; Bavusi, M.; Di Leo, P.; Giammatteo, T.; Schiattarella, M. Geoarchaeology and geomorphology of the Metaponto area, Ionian coastal belt, Italy. *J. Maps* **2019**, *16*, 117–125. [CrossRef]
48. Antonioli, F.; Anzidei, M.; Lambeck, K.; Auriemma, R.; Gaddi, D.; Furlani, S.; Orrù, P.E.; Solinas, E.; Gaspari, A.; Karinja, S.; et al. Sea-level change during the Holocene from Sardinia and in the northeastern Adriatic (central Mediterranean Sea) from archaeological and geomorphological data. *Quat. Sci. Rev.* **2007**, *26*, 2463–2486. [CrossRef]
49. Ferranti, L.; Antonioli, F.; Mauz, B.; Amorosi, A.; Dai Pra, G.; Mastronuzzi, G.; Monaco, C.; Orrù, P.; Pappalardo, M.; Radtke, U.; et al. Markers of the last interglacial sea-level high stand along the coast of Italy: Tectonic implications. *Quat. Int.* **2006**, *145–146*, 30–54. [CrossRef]
50. Ferranti, L.; Antonioli, F.; Anzidei, M.; Monaco, C.; Stocchi, P. The timescale and spatial extent of vertical tectonic motions in italy: Insights from relative sea-level changes studies. *J. Virtual Explor.* **2010**, *36*, 1–35. [CrossRef]
51. Mastronuzzi, G.; Milella, M.; Piscitelli, A.; Simone, O.; Quarta, G.; Scarano, T.; Calcagnile, L.; Spada, I. Landscape analysis in torre guaceto area (BRindisi) aimed at the reconstruction of the Late Holocene sea level curve. *Geogr. Fis. E Din. Quat.* **2018**, *41*, 65–79. [CrossRef]
52. De Giosa, F.; Scardino, G.; Vacchi, M.; Piscitelli, A.; Milella, M.; Ciccolella, A.; Mastronuzzi, G. Geomorphological signature of late pleistocene sea level oscillations in Torre Guaceto Marine Protected area (Adriatic Sea, SE Italy). *Water* **2019**, *11*, 2409. [CrossRef]
53. Alessio, G.; De Lucia, M.; Gaudiosi, G.; Nappi, R.; Porfido, S. Towards New Insights into Seismic Hazard of the Salento Peninsula (Apulia, Southern Italy) from the Analysis of Far and near Field Seismicity. *GNGTS* **2016**, *2016*, 107–111.
54. Mastronuzzi, G.; Pignatelli, C.; Sansò, P.; Selleri, G. Boulder accumulations produced by the 20th of February, 1743 Tsunami along the coast of southeastern Salento (Apulia region, Italy). *Mar. Geol.* **2007**, *242*, 191–205. [CrossRef]
55. Pierri, P.; Lorenzo, S.D.; Calcagnile, G. Analysis of the low-energy seismic activity in the southern Apulia (Italy). *Open J. Earthq. Res.* **2013**, *2*, 91–105. [CrossRef]
56. Rovida, A.; Locati, M.; Camassi, R.; Lolli, B.; Gasperini, P. The Italian earthquake catalogue CPTI15. *Bull. Earthq. Eng.* **2020**, *18*, 2953–2984. [CrossRef]
57. Galli, P.; Naso, G. The taranta effect of the 1743 earthquake in Salento (Apulia, Southern Italy). *Boll. Geofis. Teor. Appl.* **2008**, *49*, 177–204.
58. Nappi, R.; Gaudiosi, G.; Alessio, G.; De Lucia, M.; Porfido, S. The environmental effects of the 1743 Salento earthquake (Apulia, southern Italy): A contribution to seismic hazard assessment of the Salento Peninsula. *Nat. Hazards* **2017**, *86*, 295–324. [CrossRef]
59. Auriemma, R.; Mastronuzzi, G.; Sansò, P. Relative sea-level changes during the Holocene along the coast of southern Apulia (Italy). *Geomorphologie* **2004**, *1*, 19–34. [CrossRef]
60. Mastronuzzi, G.; Sansò, P. Large boulder accumulations by extreme waves along the adriatic coast of southern Apulia (Italy). *Quat. Int.* **2004**, *120*, 173–184. [CrossRef]
61. Cagnazzo, C.; Potente, E.; Regnauld, H.; Rosato, S.; Mastronuzzi, G. Autumnal beach litter identification by mean of using ground-based IR thermography. *Environments* **2021**, *8*, 37. [CrossRef]
62. Bonaldo, D.; Antonioli, F.; Archetti, R.; Bezzi, A.; Correggiari, A.; Davolio, S.; De Falco, G.; Fantini, M.; Fontolan, G.; Furlani, S.; et al. Integrating multidisciplinary instruments for assessing coastal vulnerability to erosion and sea level rise: Lessons and challenges from the Adriatic sea, Italy. *J. Coast. Conserv.* **2019**, *23*, 19–37. [CrossRef]
63. Bonaldo, D.; Bucchignani, E.; Pomaro, A.; Ricchi, A.; Sclavo, M.; Carniel, S. Wind waves in the Adriatic sea under a severe climate change scenario and implications for the coasts. *Int. J. Climatol.* **2020**, *40*, 5389–5406. [CrossRef]

64. Nandasena, N.A.K.; Scicchitano, G.; Scardino, G.; Milella, M.; Piscitelli, A.; Mastronuzzi, G. Boulder displacements along rocky coasts: A new deterministic and theoretical approach to improve incipient motion formulas. *Geomorphology* **2022**, *407*, 108217. [CrossRef]
65. Tropeano, M.; Sabato, L.; Pieri, P. Filling and cannibalization of a foredeep: The bradanic trough, southern Italy. *Geol. Soc. Lond. Spec. Publ.* **2002**, *191*, 55–79. [CrossRef]
66. De Santis, V.; Scardino, G.; Ortiz, J.E.; Sánchez-Palencia, Y.; Caldara, M. Pleistocene terracing phases in the metropolitan area of Bari—AAR dating and deduced uplift rates of the Apulian Foreland. *ROL* **2021**, *54*, 49–61. [CrossRef]
67. Pieri, P. Geologia della città di bari. *Mem. Della Soc. Geol. Ital.* **1975**, *14*, 379–407.
68. Ricchetti, G.; Ciaranfi, N.; Luperto Sinni, E.; Mongelli, F.; Pieri, P. Geodinamica ed evoluzione sedimentaria e tettonica dell'avampaese apulo. *Mem. Della Soc. Geol. Ital.* **1992**, *41*, 57–82.
69. Andriani, G.F.; Walsh, N. Rocky coast geomorphology and erosional processes: A case study along the Murgia coastline south of Bari, Apulia—SE Italy. *Geomorphology* **2007**, *87*, 224–238. [CrossRef]
70. Waelbroeck, C.; Labeyrie, L.; Michel, E.; Duplessy, J.C.; McManus, J.F.; Lambeck, K.; Balbon, E.; Labracherie, M. Sea-level and deep water temperature changes derived from benthic foraminifera isotopic records. *Quat. Sci. Rev.* **2002**, *21*, 295–305. [CrossRef]
71. Siddall, M.; Rohling, E.J.; Almogi-Labin, A.; Hemleben, C.; Meischner, D.; Schmelzer, I.; Smeed, D.A. Sea-level fluctuations during the last glacial cycle. *Nature* **2003**, *423*, 853–858. [CrossRef] [PubMed]
72. Grant, K.M.; Rohling, E.J.; Ramsey, C.B.; Cheng, H.; Edwards, R.L.; Florindo, F.; Heslop, D.; Marra, F.; Roberts, A.P.; Tamisiea, M.E.; et al. Sea-level variability over five glacial cycles. *Nat. Commun.* **2014**, *5*, 5076. [CrossRef]
73. Doglioni, C.; Mongelli, F.; Pieri, P. The puglia uplift (SE Italy): An anomaly in the foreland of the apenninic subduction due to buckling of a thick continental lithosphere. *Tectonics* **1994**, *13*, 1309–1321. [CrossRef]
74. Doglioni, C.; Tropeano, M.; Mongelli, F.; Pieri, P. Middle-late pleistocene uplift of puglia: An "Anomaly" in the apenninic foreland. *Mem. Soc. Geol. Ital.* **1996**, *51*, 101–117.
75. De Santis, V.; Caldara, M.; Torres, T.; Ortiz, J.E.; Sánchez-Palencia, Y. A review of MIS 7 and MIS 5 terrace deposits along the gulf of Taranto based on new stratigraphic and chronological data. *Ital. J. Geosci.* **2018**, *137*, 349–368. [CrossRef]
76. De Santis, V.; Scardino, G.; Meschis, M.; Ortiz, J.E.; Sánchez-Palencia, Y.; Caldara, M. Refining the middle-late pleistocene chronology of marine terraces and uplift history in a sector of the Apulian foreland (Southern Italy) by applying a synchronous correlation technique and amino acid racemization to Patella Spp. and Thetystrombus Latus. *IJG* **2021**, *140*, 438–463. [CrossRef]
77. Iannone, A.; Pieri, P. Considerazioni critiche sui "Tufi calcarei" delle murge. Nuovi dati litostratigrafici e paleoambientali. *Geogr. Fis. E Din. Quat.* **1979**, *2*, 173–186.
78. Azzaroli, A.; Perno, U.; Radina, B. Note illustrative della carta geologica d'italia alla scala 1:100.000, foglio 188 gravina di puglia. *Serv. Geol.* **1968**, *57*, 1–22.
79. Meletti, C.; Patacca, E.; Scandone, P. Construction of a seismotectonic model: The case of italy. *Pure Appl. Geophys.* **2000**, *157*, 11–35. [CrossRef]
80. Del Gaudio, V.; Pierri, P.; Calcagnile, G.; Venisti, N. Characteristics of the low energy seismicity of central Apulia (southern Italy) and hazard implications. *J. Seismol.* **2005**, *9*, 39–59. [CrossRef]
81. Del Gaudio, V.; Pierri, P.; Frepoli, A.; Calcagnile, G.; Venisti, N.; Cimini, G.B. A critical revision of the seismicity of northern Apulia (Adriatic microplate—Southern Italy) and implicationsfor the identification of seismogenic structures. *Tectonophysics* **2007**, *436*, 9–35. [CrossRef]
82. Ciaranfi, N.; Pieri, P.; Ricchetti, G. Note alla carta geologica delle murge e del salento (Puglia Centromeridionale). *Mem. Della Soc. Geol. Ital.* **1988**, *41*, 449–460.
83. Di Bucci, D.; Caputo, R.; Mastronuzzi, G.; Fracassi, U.; Selleri, G.; Sansò, P. Quantitative analysis of extensional joints in the southern Adriatic foreland (Italy), and the active tectonics of the Apulia region. *J. Geodyn.* **2011**, *51*, 141–155. [CrossRef]
84. Auriemma, R.; Mastronuzzi, G.; Sansò, P. Middle to Late Holocene relative sea-level changes recorded on the coast of Apulia (Italy)/Variations relatives du niveau marin pendant l'holocène moyen et supérieur le long des côtes méridionales des pouilles (Italie). *Géomorphol. Relief Processus Environ.* **2004**, *10*, 19–33. [CrossRef]
85. Auriemma, R.; Mastronuzzi, G.; Sansò, P.; Zongolo, F. The Harbour of the Mansio Ad speluncas (Brindisi, Italy): A key to sea level changes in the past 3500 years? *Adv. Archit. Ser.* **2005**, *19*, 5–14.
86. De Santis, V.; Caldara, M.; Pennetta, L. The marine and alluvial terraces of tavoliere di puglia plain (southern Italy). *J. Maps* **2014**, *10*, 114–125. [CrossRef]
87. Mastronuzzi, G.; Sansò, P. Coastal towers and historical sea level change along the Salento coast (southern Apulia, Italy). *Quat. Int.* **2014**, *332*, 61–72. [CrossRef]
88. Gabellone, F.; Giannotta, M.T.; Monte, A.; Quarta, G. Tomba delle melagrane in Egnazia (Brindisi–Italy): Integrate historical-scientific analyses. In Proceedings of the 6th International Symposium on the Conservation of Monuments in the Mediterranean Basin, Lisboa, Portugal, 7–10 April 2004.
89. Primavera, M.; Simone, O.; Fiorentino, G.; Caldara, M. The palaeoenvironmental study of the Alimini Piccolo lake enables a reconstruction of holocene sea-level changes in southeast Italy. *Holocene* **2011**, *21*, 553–563. [CrossRef]
90. Bogusz, J.; Klos, A. Wavelet analysis for investigation of precise gnss solutions' credibility. *Artif. Satell.* **2010**, *45*, 163–173. [CrossRef]

91. Cohen, M.X. A better way to define and describe morlet wavelets for time-frequency analysis. *NeuroImage* **2019**, *199*, 81–86. [CrossRef] [PubMed]
92. Spampinato, C.R.; Costa, B.; Di Stefano, A.; Monaco, C.; Scicchitano, G. The contribution of tectonics to relative sea-level change during the holocene in coastal south-eastern sicily: New data from Boreholes. *Quat. Int.* **2011**, *232*, 214–227. [CrossRef]
93. Antonioli, F.; Mourtzas, N.; Anzidei, M.; Auriemma, R.; Galili, E.; Kolaiti, E.; Lo Presti, V.; Mastronuzzi, G.; Scicchitano, G.; Spampinato, C.; et al. Millstone quarries along the Mediterranean coast: Chronology, morphological variability and relationships with past sea levels. *Quat. Int.* **2017**, *439*, 102–116. [CrossRef]
94. Lambeck, K.; Anzidei, M.; Antonioli, F.; Benini, A.; Verrubbi, V. Tyrrhenian sea level at 2000 BP: Evidence from roman age fish tanks and their geological calibration. *Rend. Fis. Acc. Lincei* **2018**, *29*, 69–80. [CrossRef]
95. Valenzano, E.; Scardino, G.; Cipriano, G.; Fago, P.; Capolongo, D.; De Giosa, F.; Lisco, S.; Mele, D.; Moretti, M.; Mastronuzzi, G. Holocene morpho-sedimentary evolution of the Mar Piccolo Basin (Taranto, Southern Italy). *Geogr. Fis. E Din. Quat.* **2018**, *41*, 119–135. [CrossRef]