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Coastal landscape evolution of Naples (Southern Italy) since the Roman period from archaeological and geomorphological data at Palazzo degli Spiriti site

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ABSTRACT

The Posillipo promontory is an elongated tufaceous ridge located on the southern periphery of the Campi Flegrei active volcanic complex that hosts several underwater archaeological structures dated mostly in the 1st century BC and the Imperial age. The so-called Palazzo degli Spiriti, built in the 1st century BC along the coast of the Posillipo hill (Naples, Italy), is one of the most preserved Roman maritime villas on the Gulf of Naples, with clear evidence of the interaction of both human and natural events. At this site, a relative sea level rise due to a sudden subsidence occurred between the 1st century BC and 1st century AD, probably of volcano-tectonic origin, produced a significant amount of adaptation, as the partial closure of the ground floor windows of the villa still visible. Integrated surveys by means of a marine drone and several direct archaeological measurements were carried out both on the coastline and in the underwater portion of this site.

A GIS analysis of geophysical, LIDAR, multibeam and archaeological data has returned a 3D reconstruction of the Roman landscape, useful to understand both the natural events occurred in the area since the Roman Period (vertical ground movements, wave erosion, etc.) and the correlative steps of human occupation and adaptation.

1. Introduction

A multidisciplinary approach addressed to palaeo-landscape reconstruction is the best method to understand the relationship between the natural and anthropic environments, as well as to discover the human adaptions to sudden modifications of the landscape (Westley et al., 2014; Ermolli et al., 2013; Burg, 2013; Amato et al., 2012, 2013; Pescarin, 2009).

Although the coastal environments are very dynamic, being mainly modified by climatic and endogenous factors, they have been densely inhabited throughout the Mediterranean since the Greek-Roman times.

The presence of numerous underwater archaeological finds provide evidences of this anthropization. These finds have been largely used as indicators of ancient sea levels markers in many recent geoarchaeological studies (Lambeck et al., 2004; Galili et al., 2005; Morhange et al., 2006; Scicchitano et al., 2008; Antonioli et al., 2011, 2007; Aucelli et al., 2016a, b).

One of the most populated Tyrrhenian coastal sectors during the Greek-Roman times indeed was the Gulf of Naples. The most important Greek colonies which have populated its coasts were Pithekoussai (on the island of Ischia), Kymae, Dicearchia and Neapolis. Instead, during the Roman period, the Gulf hosted several cities and towns as Aenaria, Cumae, Puteoli (with its large harbour, of a capital importance for the city of Rome), Neapolis, Herculaneum, Pompeii, Stabiae and Surrentum. In fact, the Greek geographer Strabo (Geogr., V, 242–243) described it as an uninterrupted sequence of luxurious villas and gardens.

During the same period, this area was modified by extreme events like the 79 AD eruption of Vesuvius (Santacroce et al., 2008) but also by volcano-tectonic land movements related to the activity of Campi Flegrei volcanic area (Di Vito et al., 2016; Aucelli et al., 2017a,b). Significant landscape modifications were also induced by the subsiding trend characterising the whole Gulf of Naples

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since the emplacement of the Campanian Ignimbrite deposits (Milia and Torrente, 2007; Cinque et al., 2011; Mattei, 2016).

The effects of these phenomena are well recorded in the urban area of Naples, where the interaction between exogenous, endogenous and anthropogenic factors is preserved in ancient relicts of the Greek-Roman landscape (Romano et al., 2013).

Alternating small coastal plains and cliffed promontories such as that of Posillipo (Cinque et al., 2011) characterise the present Neapolitan coastal landscape, where small sized coastal plains occur (as Chiaia and Municipio).

During the maximum expansion of the Greek-Roman town of *Neapolis*, the Chiaia and Municipio coastal plains were strongly urbanized. This urbanisation, together with endogenous and exogenous forcing, influenced the Late Holocene evolution of the coastal sector, as reconstructed by Romano et al. (2013) during geoarchaeological excavations associated with public transport works. This coastal area was subsiding over the last 6000 years with a rate about of 1 mm/y. However, pyroclastic emplacements and fluvial reworked deposits have compensated the subsidence and the eustatic sea level rise, inducing a coastal progradation.

During the Roman period, the effects of human pressure have prevailed over climate as the land mismanagement exacerbated the soil erosion, producing high sediment accumulation rate in the coastal areas. After that period, the shoreline has progressively prograded of about 300 m (Cinque et al., 2011; Romano et al., 2013).

The near high-coastal sector of Posillipo was inhabited only after the 2nd century BC when this suburban territory of *Neapolis* hosted several patrician villas. The interaction between anthropogenic forcing and wave erosion has produced a retreating of this sector in the last 2000 years (Aucelli et al., 2017a, 2017b).

One of most luxurious patrician villa still recognisable along the coast of Posillipo is the Pausilypon villa (built by Publius Vedius Pollio), a typical example of *villa maritima* of the Roman Late Republican and Imperial Ages with private harbours and fishponds (Gunther, 1913). The submersion measuring of the sluice gate in the fishpond has allowed the evaluation of a relative sea-level coeval with the villa at −3 m (Simeone and Masucci, 2009), deducing a subsiding trend comparable with those one affecting the Chiaia coastal plain.

A geoarchaeological study (Aucelli et al., 2017b) of several Roman ruins along the coastal sector of Posillipo, including Palazzo degli Spiriti archaeological site, has demonstrated the presence of two different relative paleo-sea levels during the Roman period: one dated at 1st century BC found at −5 m b.s.l. and another one dated at 1st century AD located at −3 m bsl.

Considering that the eustatic sea level rise during this time interval totalled only 17 cm (Lambeck et al., 2011), the authors hypothesised an accelerated subsidence occurred in less than 200 years about of 2 ± 0.5 m.

According to Aucelli et al. (2017b), this subsidence can be related to the Campi Flegrei (CF) volcanic activity, as the Posillipo promontory is located on the southeast limit of this volcanic area. Furthermore, it is coeval with the volcano-tectonic subsidence that induced the submersion of the Portus Julius in the adjacent Gulf of Pozzuoli (Passaro et al., 2013).

The precise evaluation of this vertical ground movement probably of volcano-tectonic origin has suggested a complex evolution of this coastal sector, due to the subsidence-induced rise of sea level, but also due to the human adaptions to this quick submersion of several coastal structures.

The study area is the Palazzo degli Spiriti, an archaeo-site nowadays partially submerged. It records the more unequivocal evidence of the abovementioned submersion and it is one of the most preserved Roman building in the Gulf of Naples.

The aim of this study is a detailed reconstruction of the archaeological landscape and its evolution by integrating archaeological and geomorphological data with marine investigations in a key site of the coasts of Naples (Italy), to understand the effects of vertical ground movements on the coastal changes.

2. Geological and geomorphological setting

The study area is the Posillipo coastal stretch including Palazzo degli Spiriti archeo-site, located on the western coast of Naples city.

The city of Naples, located along the southern Tyrrhenian coast, falls in a region of active volcanism and tectonics. It is bordered to the west by the Campi Flegrei volcanic zone (CF) and to the east by the footslopes of Mt. Vesuvius (Cinque et al., 2011; Aucelli et al., 2017c).

This coastal city overlooks the Gulf of Naples, a half-graben related to the last stages of the opening of the Tyrrhenian Sea (Iannace et al., 2015) and controlled by numerous Quaternary fault systems (Milia and Torrente, 1999; Giordano et al., 2013).

Almost everywhere in Naples, the dominant bedrock is the Neapolitan Yellow Tuff (NYT, Deino et al., 2004) deposits over 10 m thick.

The NYT formation outcrops only along steep slopes such as the Posillipo coast. This formation is usually mantled by pyroclastic fall deposits (Cinque et al., 2011; Romano et al., 2013) belonging to eruptions of many monogenic craters (tuff cone and ring) activated within the CF caldera between 10 and 3.8 ky BP (Di Vito et al., 1999; Cinque et al., 2011; Ermolli et al., 2013).

The eastern sector of the Naples coast corresponds with the Sebeto plain, which is bounded to the east by the northern slopes of Mt. Vesuvius and that is directly connected with the coastal plain of Municipio-Port of Naples, were several paleo-environmental levels confirmed the presence of a commercial harbour since the Greek times (Delile et al., 2016).

On the sub-horizontal terraces behind Municipio-Port coastal plain arose the Greek town of Neapolis (6th − 5th century BC). Instead, the town of Parthenope, founded in 7th century BC (Wanderlingh, 2015) arose on the Pizzofalcone hill, which is the horst that separates the Chiaia and the Municipio coastal plains.

The near Posillipo coastal sector, densely inhabited during the Imperial Roman period, is a high coast mainly constituted by the lithified facies of the NYT (Fedele et al., 2015, Fig. 1B). The surrounding seabed is characterised by NYT substrate covered by a thin layer of sediments (Fedele et al., 2015; Putignano and Schiattarella, 2010).

The tufa sea cliff of Posillipo is the southern limit of the homonym hill characterised by variable heights and slopes and interrupted by small bays hosting pocket beaches.

Posillipo hill borders to the south the Fuorigrotta plain by an NE-SW trending fault scarp mainly 200 m height. The fault scarp matches with the rim of NYT caldera collapse. The NYT eruption (15 ky BP, Deino et al., 2004) with relative calderization was the second more recent cataclysmic event after the Campanian Ignimbrite eruption (CI; 37 ky; Fedele et al., 2011 and references therein). It represents the most massive known trachytic phreatoplinian eruption (Orsi et al., 1992), emitting at least 40 km^3 (Deino et al., 2004) of latitic-to-trachytic magma emplaced as pyroclastic fall and flow deposits (Orsi et al., 1992, 2004). The resulting caldera covered an area of about 90 km^2 and was nested within the CI caldera (Orsi et al., 2009).

During the Quaternary period, the coastal landscape of Naples was influenced by a tectonic subsidence affecting the half graben morpho-structure of the Bay of Naples (Milia and Torrente, 1999). An important fault bounds the West coastal sector of Naples including Posillipo promontory (the offshore Magnaghi Sebeto

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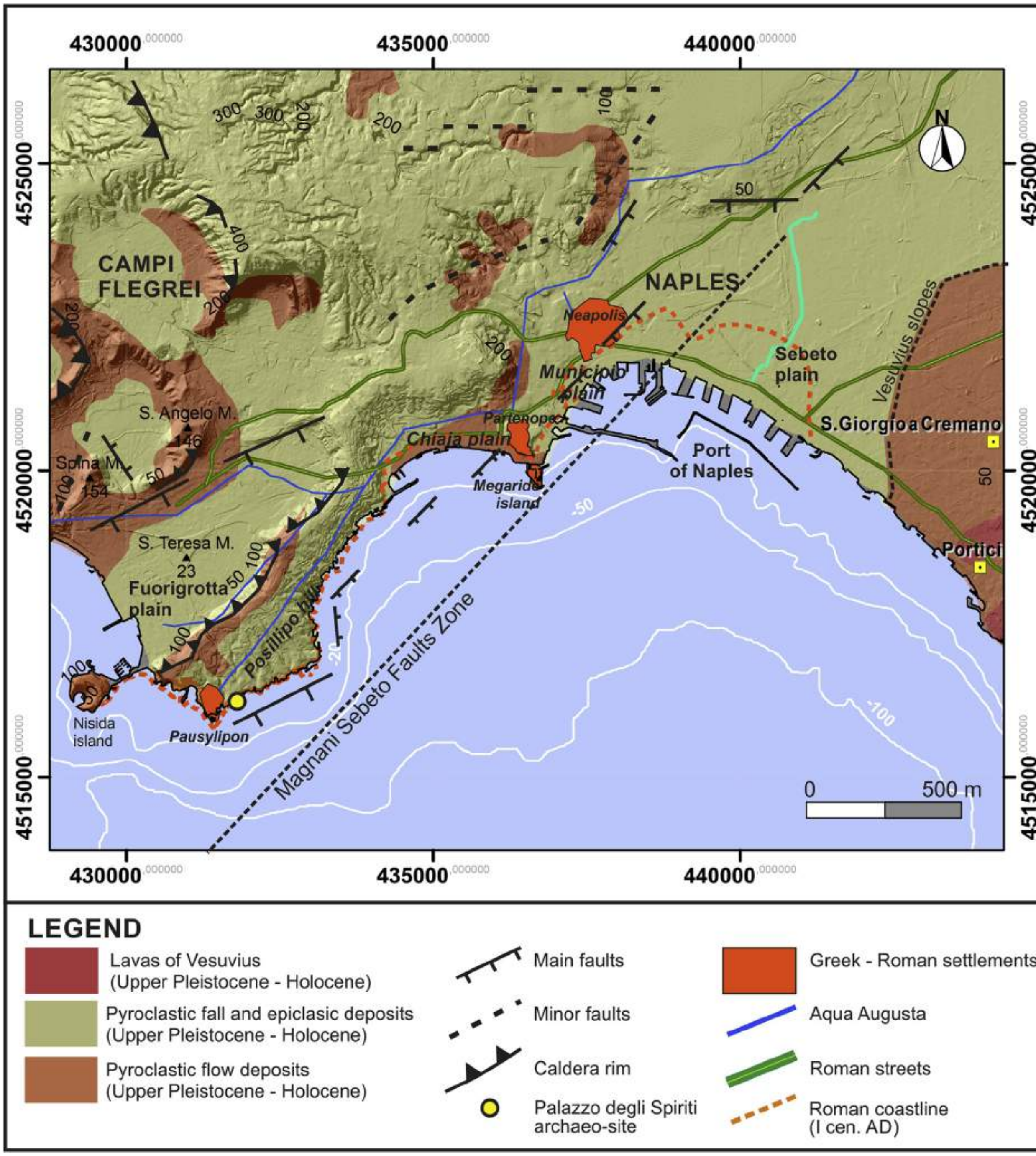

Fig. 1. Geoarchaeological sketch of the city of Naples (Italy), with the Roman coastline (orange dotted line) from Aucelli et al. (2017a). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Fault Zone, Bruno et al., 2003, Fig. 1). The onland portion of this fault zone alternates NE-SW and E-W trending segments producing fault scarps and subsequent valleys (Fig. 1).

Moreover, this landscape was controlled by the Late Quaternary volcanism of CF and Vesuvius strato-volcano (1250 m high). The volcano-tectonic ground movements related to both volcanos have controlled the shape of the coast and enhanced the submersion due to historical sea level rise. It disclosed a typical structurally controlled high coast such as Posillipo hill alternating with narrow coastal plains (Cinque et al., 2011; Aucelli et al., 2017a, Fig. 1A).

The oldest coastline recognisable in the Gulf is related to the last glacial maximum (LGM) lowstand (26-19 Ky BP, Clark et al., 2009). This landform is nowadays testified by a broad submerged terrace having its outer edge at 140–180 m of depth (Passaro et al., 2016; Aucelli et al., 2017a).

At the beginning of the next interglacial period (MIS1), the landscape was drastically changed when the NYT eruption created hills high up to 300 m above the present sea level, only peripherally aggressed by wave erosion.

During this period the postglacial sea level rise was too fast (up to 10 mm/y) to create terraces until the rate of sea level rise slowed

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down below 1 mm/y (5.0 ky BP, Lambeck et al., 2011).

In this study, all submerged terraces of Posillipo were detected to understand the late Holocene evolution of this coastal sector after the slowdown of sea level rise.

During the late Holocene in particular, chrono-altimetric sea level markers deduced by means of geoarchaeological studies at Chiaia and Municipio coastal plains show a subsiding trend about of 1 mm/y (Cinque et al., 2011; Romano et al., 2013; Aucelli et al., 2017a). Nevertheless, this sector prograded mostly because of sedimentary inputs coming from the hillslopes, probably favoured by anthropogenic impacts (Romano et al., 2013; Aucelli et al., 2017a).

This subsiding trend during the Late Holocene was confirmed along the Posillipo coastal sector. Moreover, the evolution of this sector was controlled not only by the subsiding trend but also by the NYT mining activity during Greek-Roman times as well as by the erosive action of the sea.

In addition, Aucelli et al. (2017a, b) measured 2 m of subsidence, probably of volcano-tectonic origin and related to CF volcanic activity, between the 1st century BC and the 1st century AD that accelerated the pure retreat of the sector. The presence of submerged abrasion platforms along vast stretches of the cliff studied here is a clear evidence of this subsiding trend.

3. Historical context

Many coastal archaeological structures along the shores of the Naples Gulf, nowadays partially or entirely submerged, are related to the phenomenon of the *villae maritimae* of the Roman Late Republican and Imperial Ages. The Gulf - known as Crater by the ancient authors - was inhabited permanently already from ancient time and it was involved in the first Greek colonisation in the Western Mediterranean (with settlements of capital importance like Pithekoussai, Cumae, Dicearchia and Neapolis). However, a dense population of the coasts, with an almost uninterrupted sequence of luxurious villas, precisely as described in a famous quotation by Strabo (Geogr., V, 242–243), was set only in the Roman era.

The *villae maritimae* are important testimonies of the Roman architecture during the Late Republican and Imperial Ages: their analysis allows to understand how the Romans were able to build directly on rocky coasts and jagged promontories, often inducing strong modification of the natural landscape. Their study from the perspective of the sea (Pesando and Stefanile, 2015b; 2016) can offer huge amounts of data related to the relative sea-level change, thanks to the presence of significant markers in the middle of structures. Furthermore, these markers can often be dated with a high accuracy, by crossing the ancient literary sources with the archaeological evidence and the architectural context.

The Gulf of Naples was, together with the Gulf of Gaeta (Lafon, 2001; Pesando and Stefanile, 2015a, 2016), one of the departure points of the *villae maritimae* diffusion along the Tyrrhenian coasts of Italy. The basis of the quick and early proliferation of these structures around the city of Neapolis was mainly related to several factors: the presence of a beautiful landscape with mythical tradition, the proximity to Rome and the abundance of thermal springs due to the volcanism of the region.

The most famous Roman villae in Neapolis (Fig. 2) were located on the promontory of Pizzofalcone (a large complex probably belonging to Licinius Lucullus), the slopes of the hill of San Martino (of which nothing remains) and the hill of Posillipo (Gunther, 1913). The so-called Palazzo degli Spiriti is considered as an annexe to the majestic Pausilypon, the villa of Publius Vedius Pollio, an evil and powerful man of equestrian rank that left his properties to Emperor Augustus.

4. Methods

The coastal sector including the Palazzo degli Spriti archaeological site was investigated by using a multi-techniques approach using direct and indirect methods. The data acquisition and elaboration phases were planned on two scaling level: a small-scale

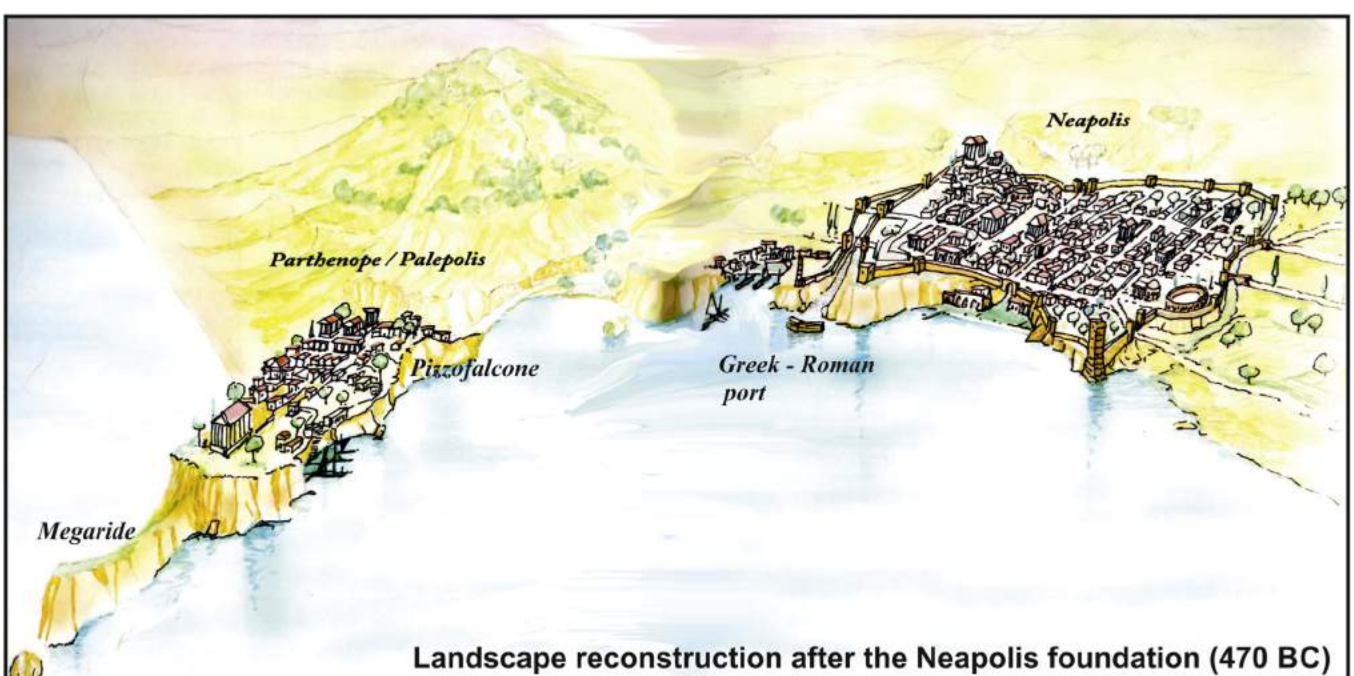

Fig. 2. Pictorial reconstruction of the Greek-Roman landscape (Wanderlingh, 2015).

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level including Posillipo coastal sector and a large scale level focused on the archeo-site.

A geoarchaeological marine survey carried out by means of a marine drone was integrated with several on-site investigations to detect all submerged archaeological remains and to precisely reconstruct the Roman landscape morphology.

4.1. Marine surveys

The indirect data acquisition along the coastal sector including Palazzo degli Spiriti was carried out by using a marine drone explicitly optimised to obtain full-coverage navigation in coastal areas. In the archaeo-site here studied, a traditional boat could not navigate because of the very shallow bathymetry and the presence of several submerged archaeological structures. Also, the coastal sector is part of a underwater protected area forbidden to navigation. The drone used (MicroVeGA, Giordano et al., 2015a) is powered by non-polluting electric motors optimised for protected marine areas, and its draught does not exceed a few centimeters, in order to navigate into the submerged part of archaeo-sites as Palazzo degli Spiriti (Fig. 3).

The marine drone has been developed by our research group to carry out measurement until the shoreline (Giordano et al., 2015b), and equipped purposely for this study with a side scan sonar system, coupled with a single beam echosounder bathymetric system.

The side scan sonar system is a Tritech Starfish 450 F, a portable instrument optimised for shallow water (450 kHz), performing the acoustic mapping of the seabed. This system was used to detect the archaeological remains lying on the seabed and to define the seabed landforms (Giordano, 1995), by discriminating the sandy bottom from the rocky one.

The bathymetric system used is an Ohmex Sonar Lite Single Beam Echo Sounder (SBES) optimised for shallow water that measures the depth with a centimetres' precision. This system was used to measure the depth of archaeological remains and to reconstruct the detailed seabed bathymetry (Mattei and Giordano, 2015).

The direct surveys were carried out by a team consisting of an underwater archaeologist and two geomorphologists to perform direct measurements. They inspected all the rooms of the Palace still intact and interpreted the archaeological remains now submerged as indicators of palaeo-sea levels (Pirazzoli, 2005; Evelpidou and Pirazzoli, 2015).

4.2. Geomorphological and GIS analysis

Palazzo degli Spiriti coastal stretch is a part of a very complex sector, where anthropogenic and natural forcing factors induced a landscape evolution that is challenging to interpret.

A classic geomorphological analysis had to be flanked by archaeological interpretations to distinguish between natural landform and anthropic shapes. However, the interpretation of the coastal structures adaptations was possible only after identifying the main evolutive steps of the coastal sector during the last millennia.

Geomorphological and geoarchaeological interpretations were obtained using GIS elaboration of a multi-scale dataset (Fig. 4), to evaluate the modification of the coastal landscape not only during the Roman time but also before the construction of Palazzo degli Spiriti.

The small-scale analysis allowed deducing how the sea level rise and the vertical ground movements affecting the Posillipo coastal sector in the last 6.0 ky (Fig. 4A) modified the coasts.

The large-scale analysis of all archaeological, geophysical and geomorphological data allowed not only the reconstruction of the Roman landscape but also the simulation of the effects of the relative sea level rise, affecting this site during the period of use (Fig. 4B).

The small-scale 3D analysis of coastal sector has been implemented in three steps (Fig. 4A).

In the first step an onshore-offshore DTM was calculated by interpolating the LIDAR (Ministry of Environment, 0–200 m asl) and bathymetric data (CARG project, 0–20 m bsl), with a Topo to Raster interpolator (1×1 m grid).

In the second step, a slope analysis was applied to the DTM. The so obtained sub-horizontal surfaces (0–5% slope) were interpreted as ancient marine terraces, while the high-sloping surfaces were interpreted as older cliffs.

Finally, the sub-horizontal surfaces were reclassified depending on the depth in four marine terraces.

The large-scale GIS analysis (Fig. 4B) of both the LIDAR cloud points and the bathymetric data derived from the marine surveys produced a high-resolution 3D reconstruction of the emerged-submerged landscape, which resulted to be very useful to detect traces of former sea levels and to positioning the archaeological structures nowadays submerged.

The bathymetric measurements (M) were corrected with respect to tidal level at each time of measurement taken from the tide gauge in the Port of Naples (hi) and the sea level barometric correction (Δhp), using LEONI and DAIPRA's formula (1997):

$$D = M + hi + \Delta hp \quad (1)$$

The interpretation of the SSS data, using a signal analysis, allowed discerning all important targets, defining their nature and

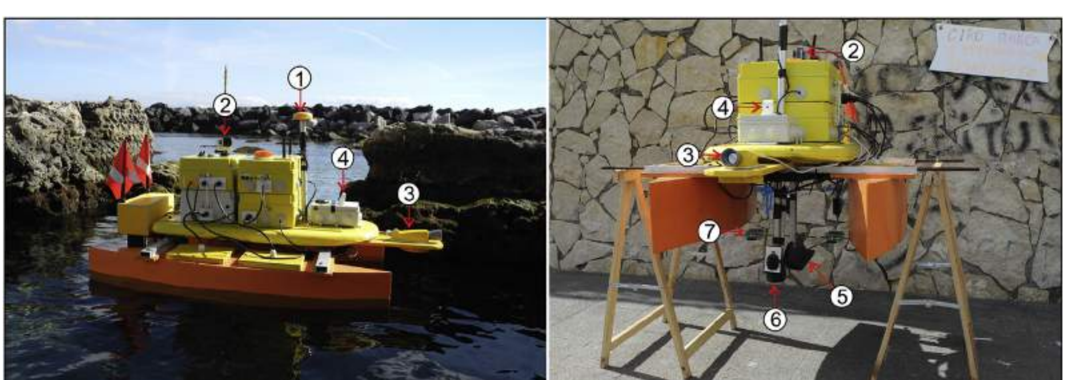

Fig. 3. Marine drone MicroVeGA: 1) GPS receiver; 2)TP-Link 5 GHz; 3) Obstacle detection system Siros 1; 4) emerged camera; 5) Side scan sonar transducer; 6) Single beam echosounder transducer; 7) underwater camera.

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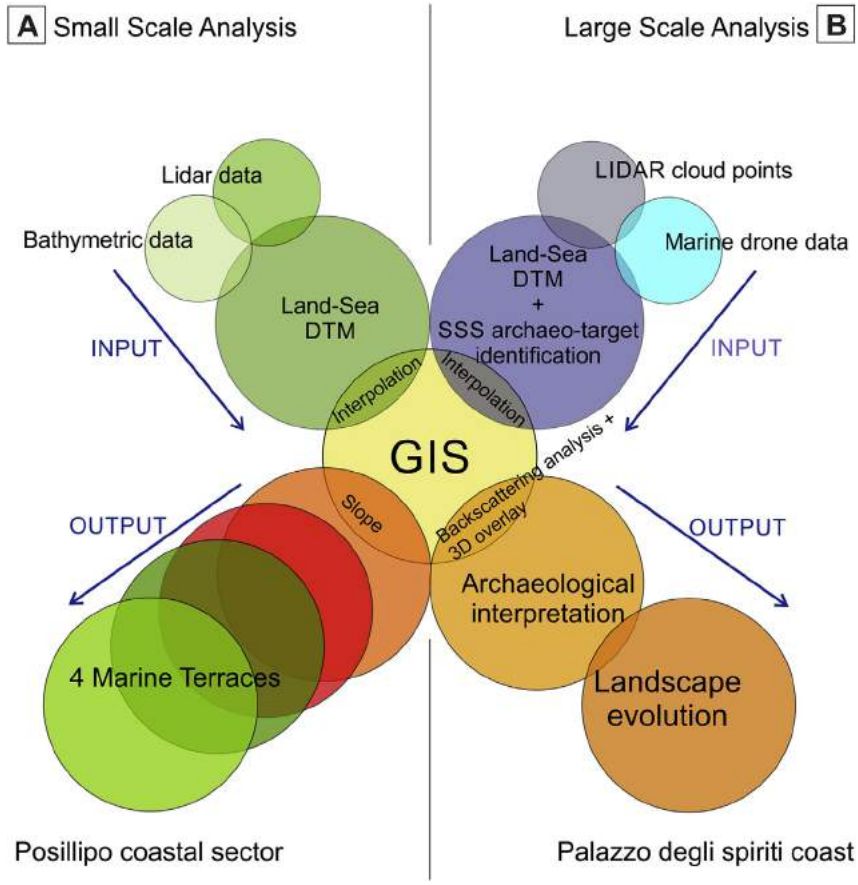

Fig. 4. Data and methods used to reconstruct A) the late Holocene landscape evolution of the Posillipo coastal sector (small-scale analysis on the left side) and, in particular of B) the Palazzo degli Spiriti coastal stretch (large-scale analysis on the right side).

dimensions (Quinn et al., 2005; Aucelli et al., 2016a). The sonograph files were imported into a GIS project to define the precise position of the acoustical targets identified (Mattei and Giordano, 2015).

5. Results

5.1. Long-term evolution of Posillipo coastal sector

The present 3D emerged-submerged landscape (Fig. 5A) obtained from high-resolution data, records the complex evolution of this sector since the last glacial period (MIS2), controlled by both natural events and anthropic activity.

The slope analysis of bathymetric data has allowed the identification of four marine terraces interpreted as polycyclic abrasion platform formed after the slowdown of the Holocene sea level rise (6 ky BP, Fig. 5B).

Four marine terraces between 1 and 35 m of depth were identified (Fig. 6), two older than the archaeo-site between −35 and −8 m of depth, and two coeval with it between −6 and −1 m of depth (Table 1).

The first terrace is the widest one. Its inner edge rests at −15 m, while its outer edge rests at −35 m, although most of it ranges between 18 and 25 m of depth. It locally extends up to the coastline, such as at the footslope of Mt. Coroglio. (Fig. 6). We propose an age younger than the 4th millennium BP considering that this abrasion platform cuts the stratified tuff of Nisida (3.9 ky BP Fedele et al., 2015).

The second terrace has an average depth of −10 m and is most visible between Punta del Cavallo and Posillipo Cape (Fig. 6). This landform is probably coeval with the near abrasion platform in the Genito Gulf (Procida island) found at the same depth. The Genito Gulf platform abrasion was precisely dated at the beginning of the Middle Italian Bronze Age, thanks to the pottery fragments, broken bones of mammals and small obsidian blocks found under a thin layer of sediments (Putignano et al., 2009).

The Gaiola Island seems to be an ancient hogback on resistant volcanic beds NW-SE oriented.

The much-reduced extension of the third terrace can be interpreted as a brief sea level stand at −5 m bsl. These marine terrace strips are relicts of an abrasion platform active during the 1st century BC, as demonstrated by the presence of several pilae close to Palazzo degli Spiriti with the base at a depth of −5.5 m bsl (Fig. 6).

Finally, the fourth terrace is well distributed along the studied coastal sector (Fig. 6) and has its inner edge at a depth about of −1 m bsl, and its outer edge at a depth of −3 m bsl. This terrace is probably of anthropic origin and related to mining activities widespread along the coastal sector during the Roman period. The primary evidence of its emersion until the 1st century AD is the presence of a small villa (so-called Pollio villa) close to the Palazzo degli Spiriti whose foundation (at a depth of −1.2 m bsl) laid on a stretch of this terrace. This villa was built between the 1st century BC and the 1st century AD as described by historical sources (Gunther, 1913). We must presume that during this period the palaeo-sea level was lower than the submersion measurement (−1.2 m bsl) of the villa foundation. An indicative range (minimum height of the archaeo-marker respect to the former sea level, Vacchi et al., 2016) of 2 m was added to the submersion measurement obtaining a palaeo-sea level at −3.2 m bsl.

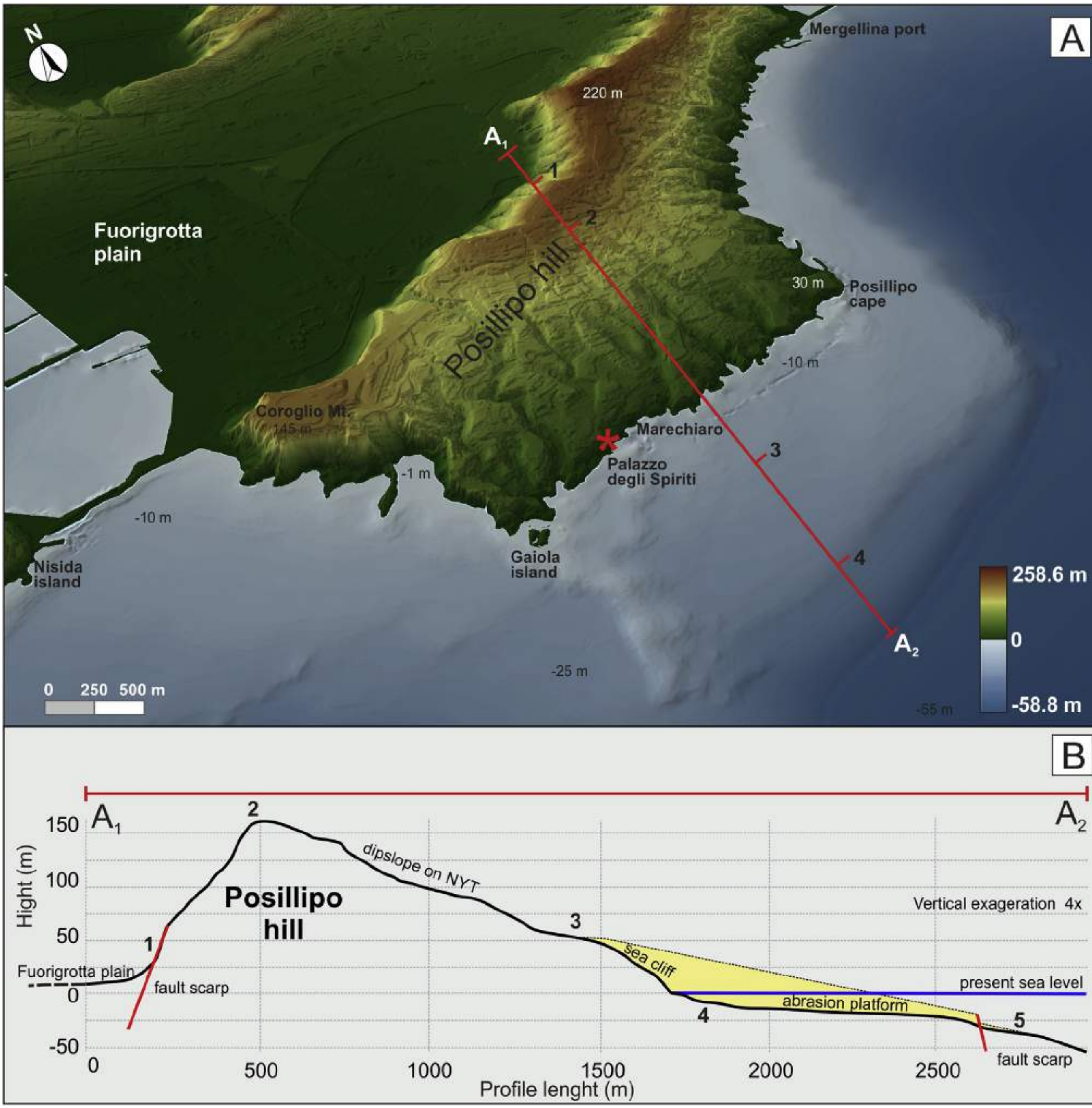

Fig. 5. A) 3D reconstruction of the emerged – submerged present-day landscape of Posillipo coastal sector; B) Topographic profile A_1A_2: 1–2 fault scarp created by the collapse of Fuorigrotta depression (Cinque et al., 2011); 2–3 dipslope on top of the NYT formation (15 ky BP); 3–4 polycyclic Holocene sea cliff; 4–5 polycyclic abrasion platform locally duplicated by a fault, according to Milia et al., 2006. The yellow area is the NYT rock volume dismantled during the shaping of the abrasion platform and its sea cliff. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Another evidence of its emersion is the submersion measurement of Palazzo degli Spiriti foundation at − 2.4 m bsl (Fig. 6). Also, this building lays on a strip of this terrace, and then we can presume that this landform was probably levelled before the building construction.

In conclusion, the fourth terrace (−1/-3 m of depth) hosting the foundation Pollio villa and Palazzo degli Spiriti indeed emerged until the 1st century AD.

According to Aucelli et al. (2017a,b), a fast subsidence, related to the CF volcanic activity, during the 1st century AD induced a sea level rise at −3 m bsl. This palaeo-sea level led to a partial submersion of both the coastal buildings and the anthropic platform, described above. In conclusion, we can presume that the fourth terrace submerged entirely after the 1st century AD.

In the case of Palazzo degli Spiriti, this sea-level stand at −3 m induced a partial closure of the ground level windows and the construction of the second level of pilae off the structure. These restructuring can be interpreted as a human adaption to a relative sea level rise, as described in the following section.

Both the third and the fourth terraces can be precisely dated

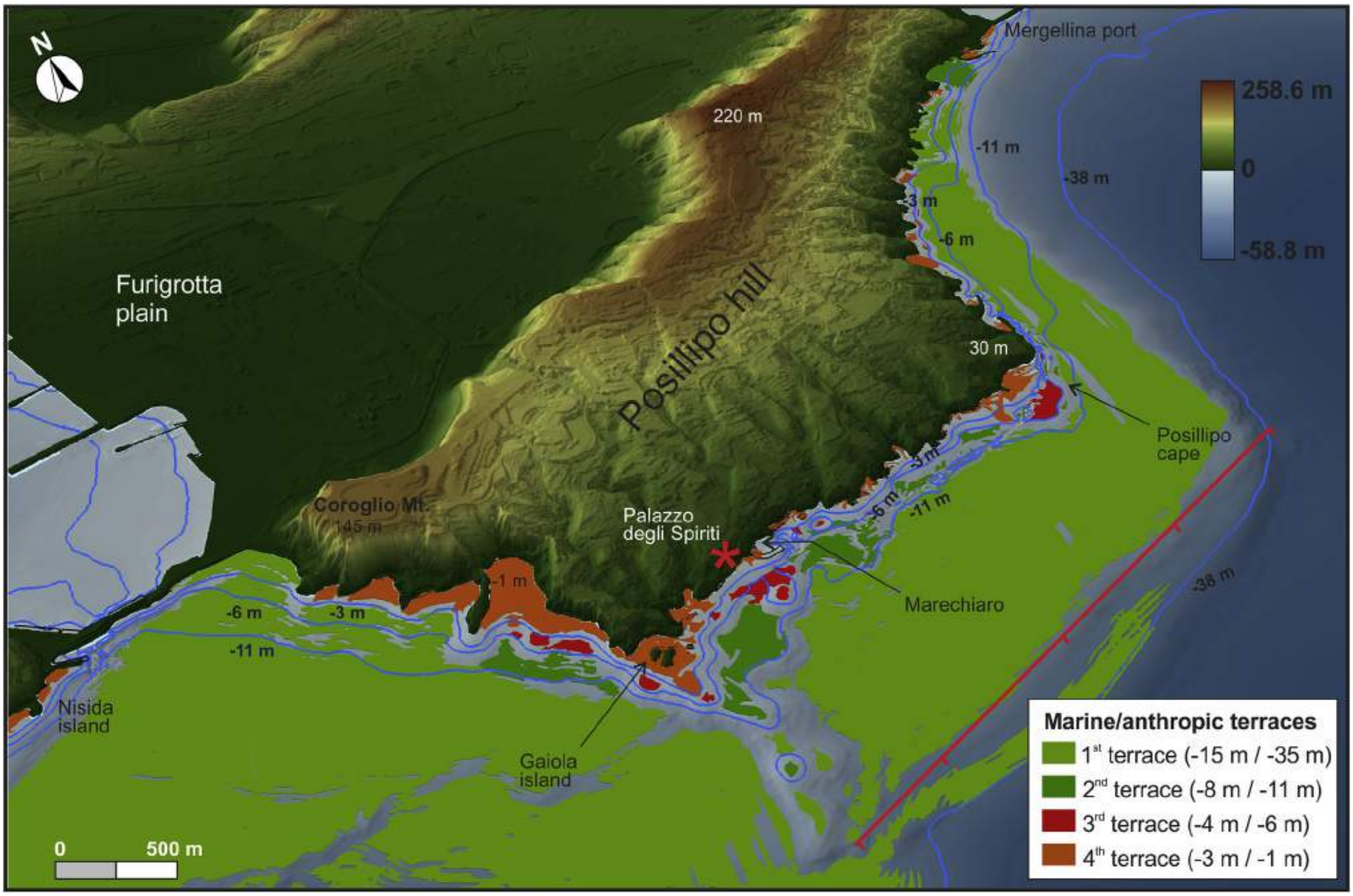

Fig. 6. Map of the marine terraces detected using a slope analysis.

Table 1
Underwater terraces and cliffs with corresponding depth range.

Terraces (0–5% of slope)	
Terraces	Depth range
1st Terrace	15–35 m
2nd Terrace	8–11 m
3rd Terrace	4–6 m
4th Terrace	1–3 m
Cliffs (10–20% of slope)	
Related to 1st Terrace	11–15 m
Related 2nd Terrace	6-7 m
Related 3rd Terrace	3-4 m

thanks to the presence of several Roman archaeological remains lying on them (Aucelli et al., 2017a).

Finally, a fault scarp NE-SW oriented off Marechiaro was identified at −33 m of depth (Fig. 6), probably belonging to the faults system described in Milia et al. (2006).

5.2. Geomorphological and archaeological interpretations

Palazzo degli Spiriti Roman villa is a three-level building built in the 1st century BC by Publius Vedius Pollio annexed to the magnificent complex of Pausylipon Villa (Gunther, 1913; Varriale, 2007).

This site is one of the well-preserved Roman site along the coasts of the Naples Gulf, with the obvious exception of Pompeii and the other sites buried by the 79 AD Vesuvius eruption.

The Palazzo lower rooms are still distinguishable as well as a part of the higher ones (Fig. 7A). The two walls protecting the villa from the waves (Fig. 7C) are laid on a narrow anthropic platform (fourth terrace abovementioned) nowadays submerged at about −2.4 m bsl (Fig. 7B).

The ground floor presents traces of restructuring as the entrances partially closed by walls (Fig. 8D), probably due to the relative sea level rise occurred during the Roman period (Aucelli et al., 2017a, b). This level is composed of five rooms. In the eastern part, the ceilings of two rooms have collapsed (Fig. 8C); in the western part, a freshwater pool is still well-preserved (Fig. 8A and B). The pool was fed by a tank (Fig. 8E) that received both rainwater and, probably, fresh water coming from a nearby source nowadays buried. The existence of the buried source demonstrated by the presence of the *Arundo donax L.* (Fig. 8E), a perennial herbaceous plant, with long and robust stem, which grows in freshwater or moderately brackish waters environments. The pool has a stair descending on the ancient shore.

The first and second floors of the villa are still preserved, as well as the external terraces connected by stairs. The third floor is almost destroyed; a perimeter wall in *opus incertum* are the only evidence still visible. The interior walls of the first and second floor are partially coated in *opus reticulatum*, probably because of a subsequent restructuring.

At about 160 m off the two external walls protecting the villa, a submerged structure is surrounded by two alignments of *pilae* at different depths (−2.4 m and −3.9 m). This structure can be interpreted as a port-like structure, due to the position off the villa, the presence of several *pilae* positioned around it as defence and the

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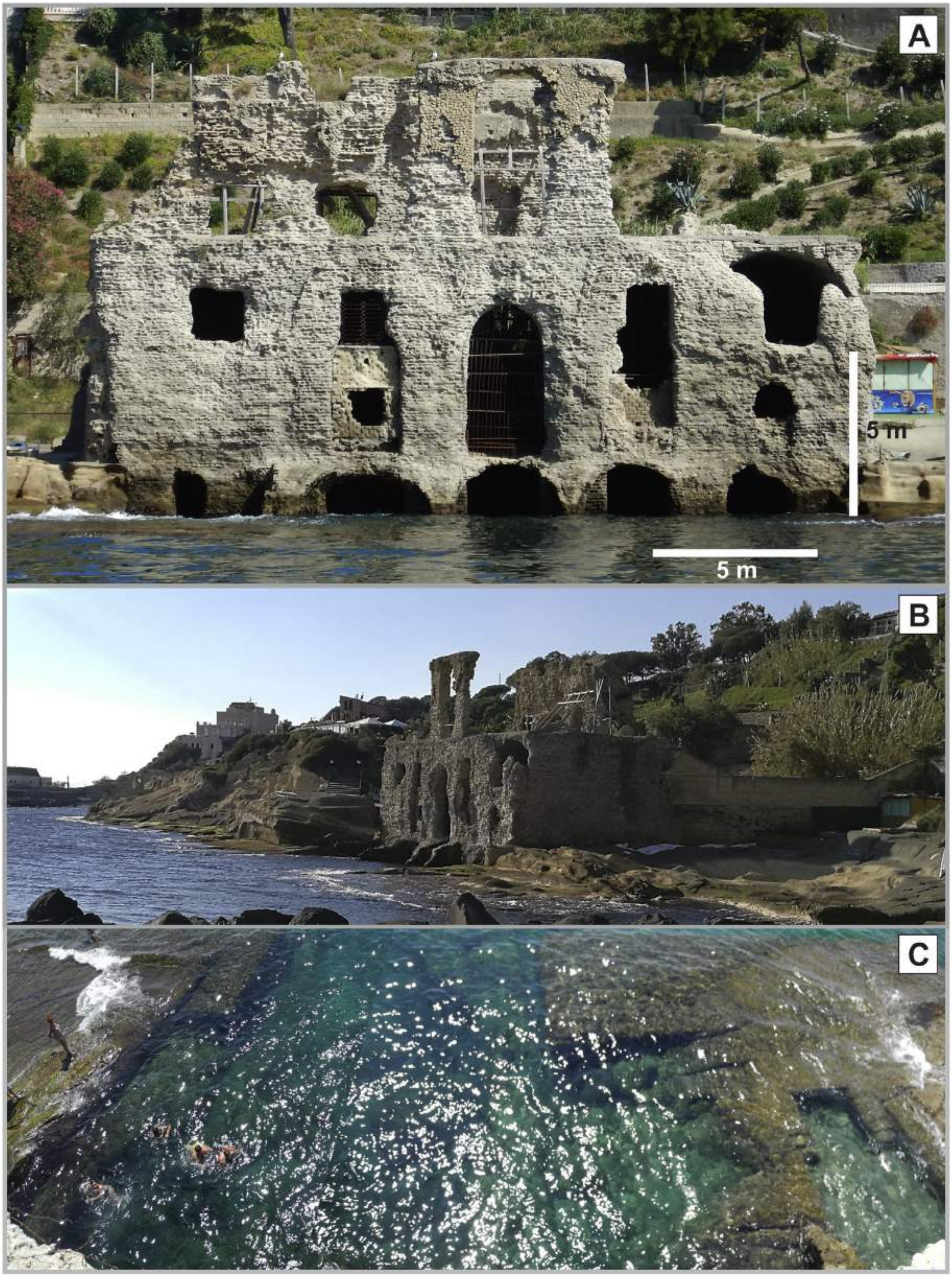

Fig. 7. A) present-day condition of the Palazzo degli Spiriti archaeological site; B) Panoramic view of the coastal sector including Palazzo degli Spiriti; C) wall protecting the villa nowadays submerged.

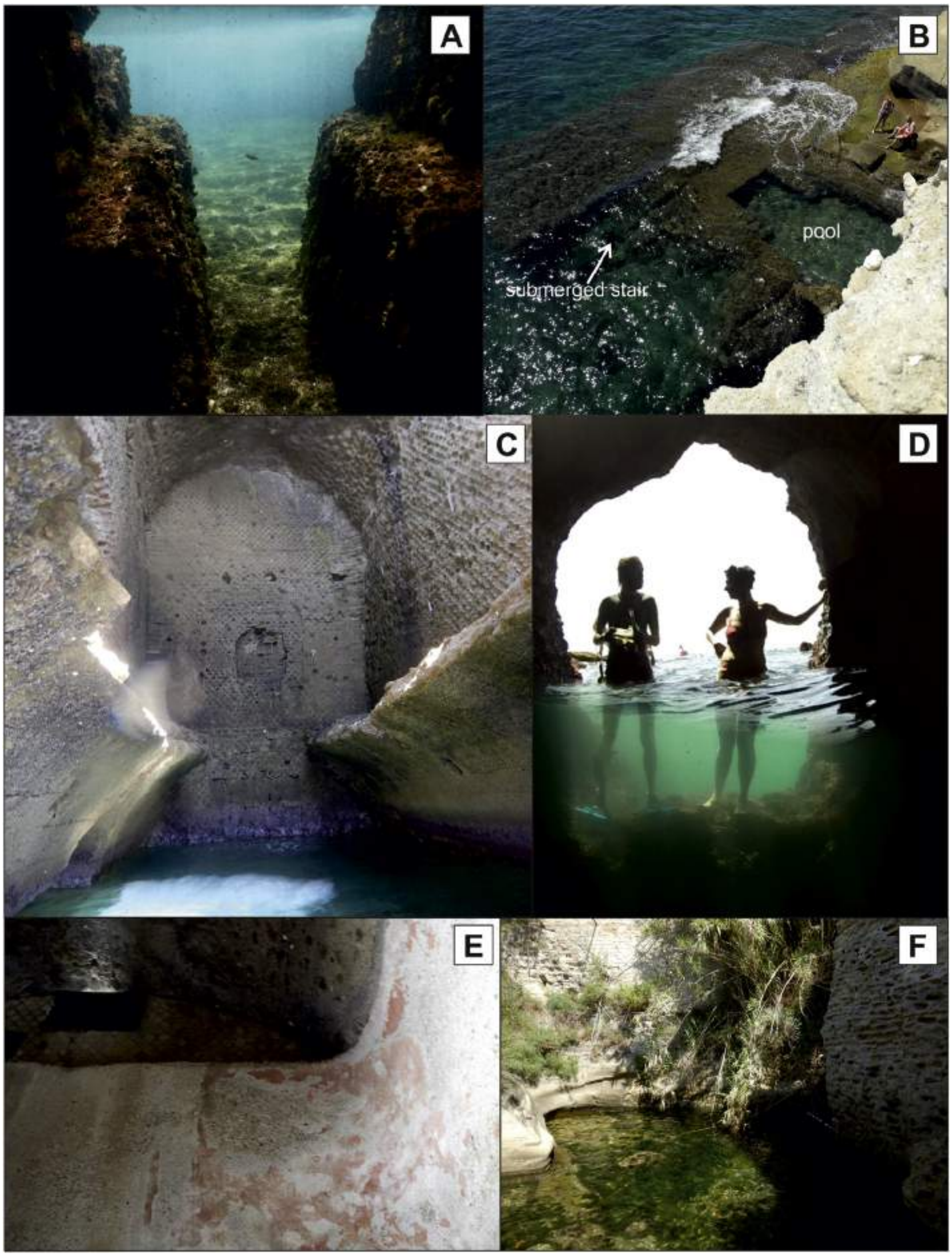

Fig. 8. A) Channel connecting the lower level of the villa to the external pool; B) external pool; C) collapsed ceiling dividing the partially submerged first level and the second level of the villa; D) entrance of a first level room, partially closed with a wall; E) wall in hydraulic mortar of the tank; F) back of the villa with the *Arundo donax L.* perennial herbaceous plant.

perfect alignment of this structure with the pier of the main harbour of Pausilypon villa, adjacent to the study area. Probably during the Roman period, this structure was connected with the villa using a wooden bridge.

Close to Palazzo degli Spiriti, a harbour and a small villa (so-called Pollio villa, Fig. 9A) annexed to the Pausylipon villa, are still recognisable. A breakwater pier protecting the port entrance (Fig. 9B, depth of −1 m) and the foundation of a small villa (Fig. 9C, depth of −1.2 m) are well preserved and nowadays submerged.

The submerged part of the study area was precisely mapped by interpreting the ss data (Fig. 10). In fact, the maximum values of the backscattering signal, typical of archaeological squared structures, have been associated with the borders both of the walls protecting the villa and the breakwater piers. By interpreting all sonographs, the shape of all archaeological targets nowadays submerged was precisely reconstructed and the presence of several ruins of destroyed structures close to the protection walls was mapped (Fig. 10).

The submerged ruins were also surveyed with the underwater camera of the drone and by scuba divers (Fig. 11A).

As shown in Fig. 11A and B, the protection walls have a multi-layer structure and are directly laid on the tufa seafloor.

The groove along one of the walls leads to the hypothesis of the presence of a sliding door (Fig. 11D). Several structures are cut into the tufa bottom, as the case of the drainage channel ending with a circular structure probably a settling pit (Fig. 11 E, F).

In Fig. 11C, an interior door partially closed with a wall is visible.

The reconstruction of the emerged-submerged 3D landscape (Fig. 12A) was obtained by elaborating LIDAR cloud points (LDSM), bathymetric data (MDTM) and by interpreting side scan sonar

Fig. 9. A) panoramic view of the Marechiaro port close to Palazzo degli Spiriti; B) Submerged breakwater of the port; C) rests of the small villa near to the port.

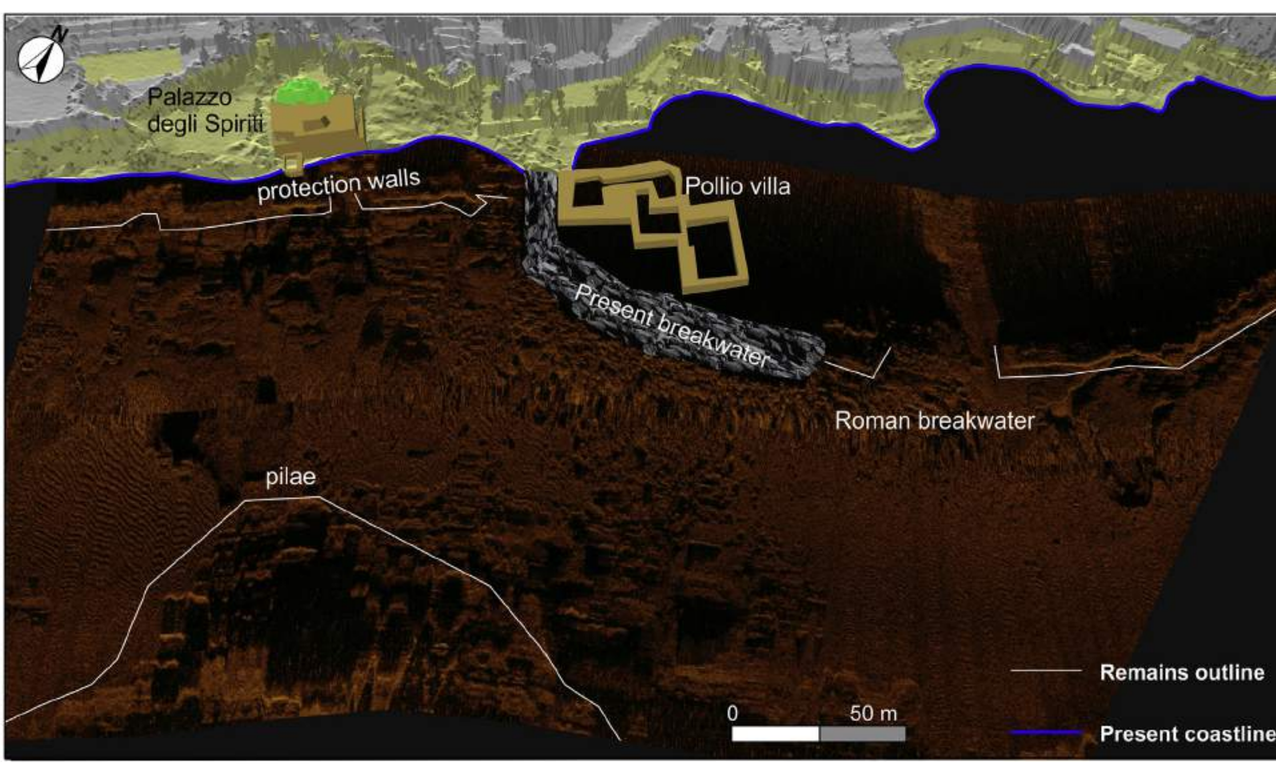

Fig. 10. SSS data mosaic of the study area, outline of the archaeological remains in white.

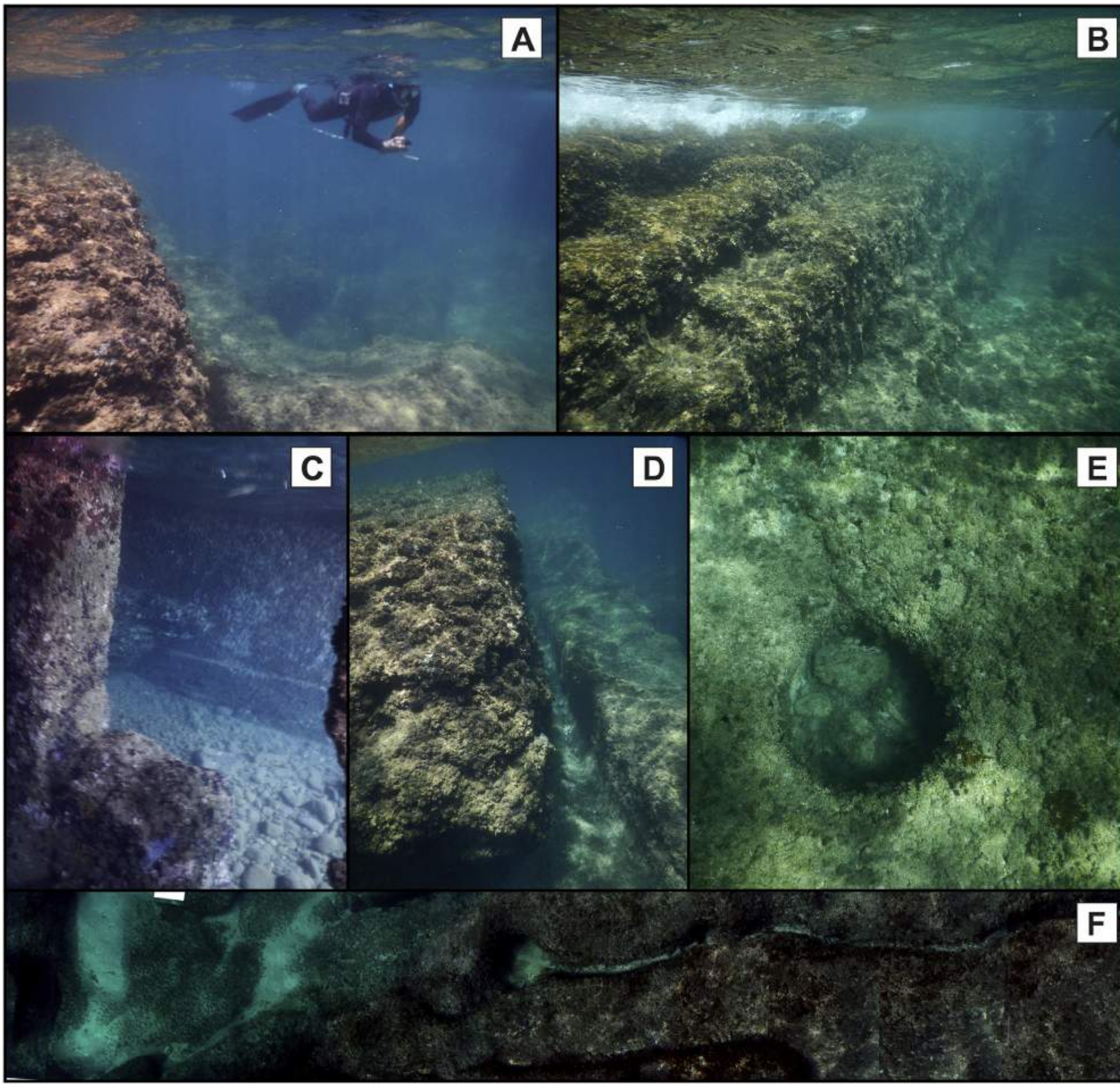

Fig. 11. Underwater photo of the study area: A) and B) protection walls; C) interior door partially closed by a wall; D) groove along a protection wall; E) and F) circular structure, probably a base of a pillar.

sonographs. In Fig. 12A, the 3D view of the present-day landscape shows a schematic reconstruction of the coastal structures nowadays partially destroyed and submerged.

By correcting the submersion measuring (S) of all archaeo-markers (Table 2) with respect to the indicative range (H, minimum height of the archaeo-marker respect to the former sea level, Vacchi et al., 2016), the depth of the two paleo-sea levels was deduced (Fig. 12B). A level not older than the 1st century BC was detected at −5 ±0.50 m and another, not younger than the 1st century AD was detected at −3 ± 0.50 m (Table 2, Fig. 12B).

6. Discussion

The GIS analysis of the high-resolution data has improved the archaeological interpretations of the emerged and submerged remains allowing several deductions related to the human occupation and adaptation.

The combination of the marine data derived from the drone surveys with the direct measuring of emerged-submerged structures and the 3D topographic view obtained by the onshore-offshore DTM of the study area allowed us to reconstruct the landscape around the Palazzo degli Spiriti archaeological site.

The slope analysis of the coastal sector, as well as the onsite surveys and the submersion measurements of all archaeological remains (Table 2), endorsed the hypothesis of two sea level during the Roman period (Aucelli et al., 2017a, b).

The presence of two marine terraces (one of natural origin and another mostly human-made) dated at the Roman period thanks to the persistence of archaeological structures demonstrated that the coastal landscape of Posillipo was significantly modified both by tufa

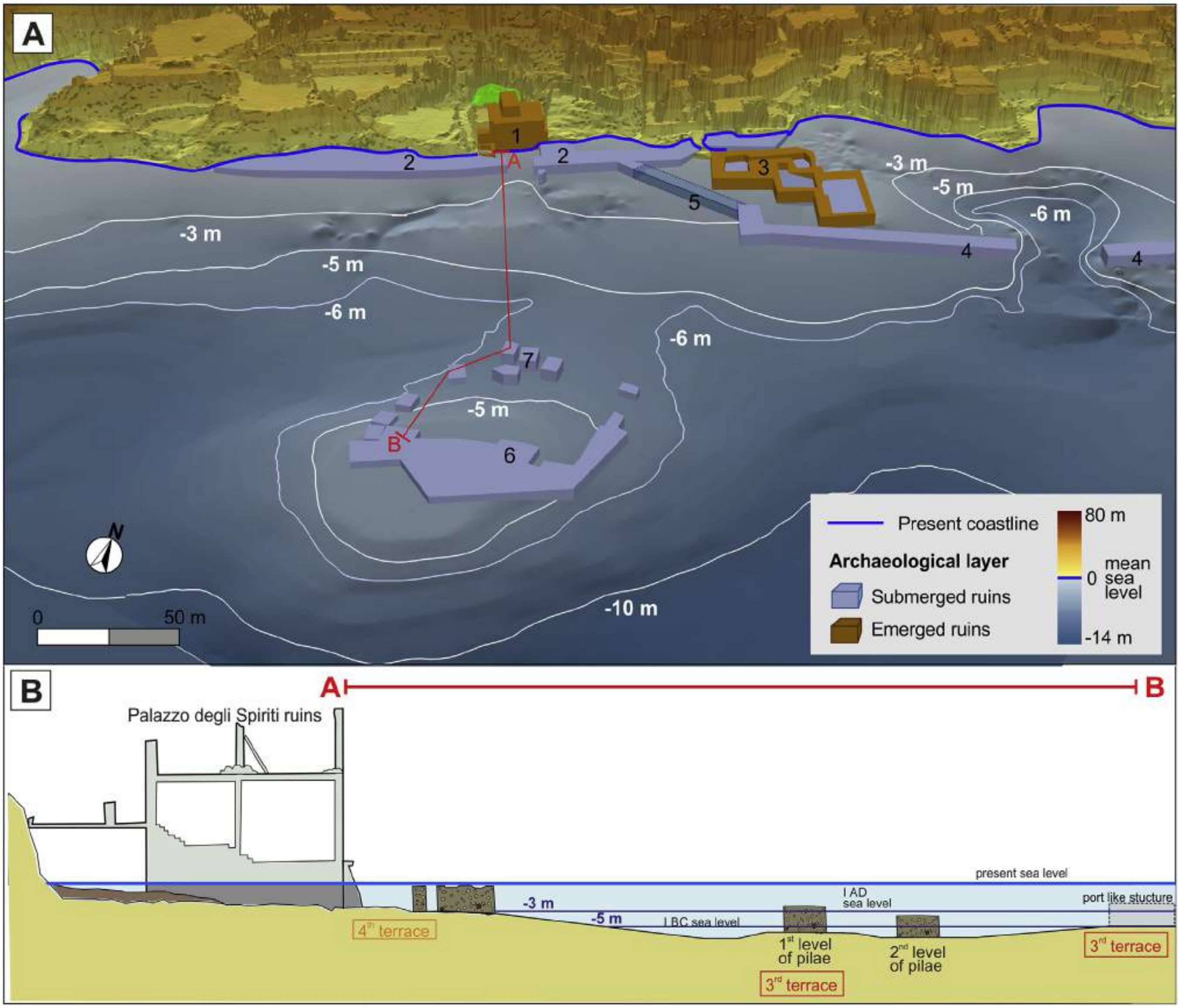

Fig. 12. A) 3D view of the present day emerged-submerged landscape and schematic reconstruction of archaeological structures (Vecchio, 1985): 1) Palazzo degli Spiriti building; 2) protection walls; 3) Pollio villa walls and foundations; 4) breakwater piers; 5) hypothesis of a wall connecting the protection walls of Palazzo degli Spiriti with the breakwater pier; 6) base of a port-like structure; 7) pilae. B) Onshore-offshore schematic cross-profile of Palazzo degli Spiriti with geoarchaeological interpretations of two palaeo-sea levels.

Table 2
Table of archaeo-markers studied, and corresponding palaeo-sea level deduced. Column 1 lists all archaeo-marker used, Column 2 gives the construction age of each marker taken from historical sources, Column 3 gives the measured submersion (S) of each marker, and Column 4 gives the indicative range (H) hypnotised for each marker (Auriemma and Solinas, 2009).

Archaeo-marker	Age	S (m)	H (m)	Palaeo-sea level (m)
Breakwater pier	I AD	−1.0	−2	−3.0
Small villa floor	I AD	−1.2	−2	−3.2
Palazzo Spiriti floor	I BC	−2.4	−2	−4.4
External pilae	I BC	−3.9	0.5	−4.4
Inner pilae	I AD	−2.4	0.5	−2.9

mining activity and by vertical ground movements that affected this area. The fast subsidence already identified by Aucelli et al. (2017b) probably had a volcano-tectonic origin. In the CF caldera centre, Portus Julius was built in 37 BC and military abandoned in 12 BC because of a rapid submersion of the piers. The case of Portus Julius is the first well-documented evidence into the CF caldera of a bradyseismic event (ancient Greek terms meaning the slow movement of the landmass). Our results prove that movements of at least metrical magnitude have also occurred outside the caldera rim.

The precise measuring of the two palaeo-sea level and the archaeological interpretations of both emerged and submerged data were used to reconstruct the landscape evolution of this coastal sector due to a fast subsidence of the area, as well as to explain the adaptation of coastal structures.

The main palaeoenvironmental changes, occurred from the 1st century BC to the present-day, are illustrated in three sketches (Fig. 13 A, B, C).

The first sketch represents the coastal landscape following the postglacial sea-level highstand and in particular during the 1st century BC when the Pausylipon villa and its annexes were built (Fig. 13A).

The second sketch shows the palaeogeographic scenario during the 1st century AD (Fig. 13B) when a fast sea level rise of 2 m

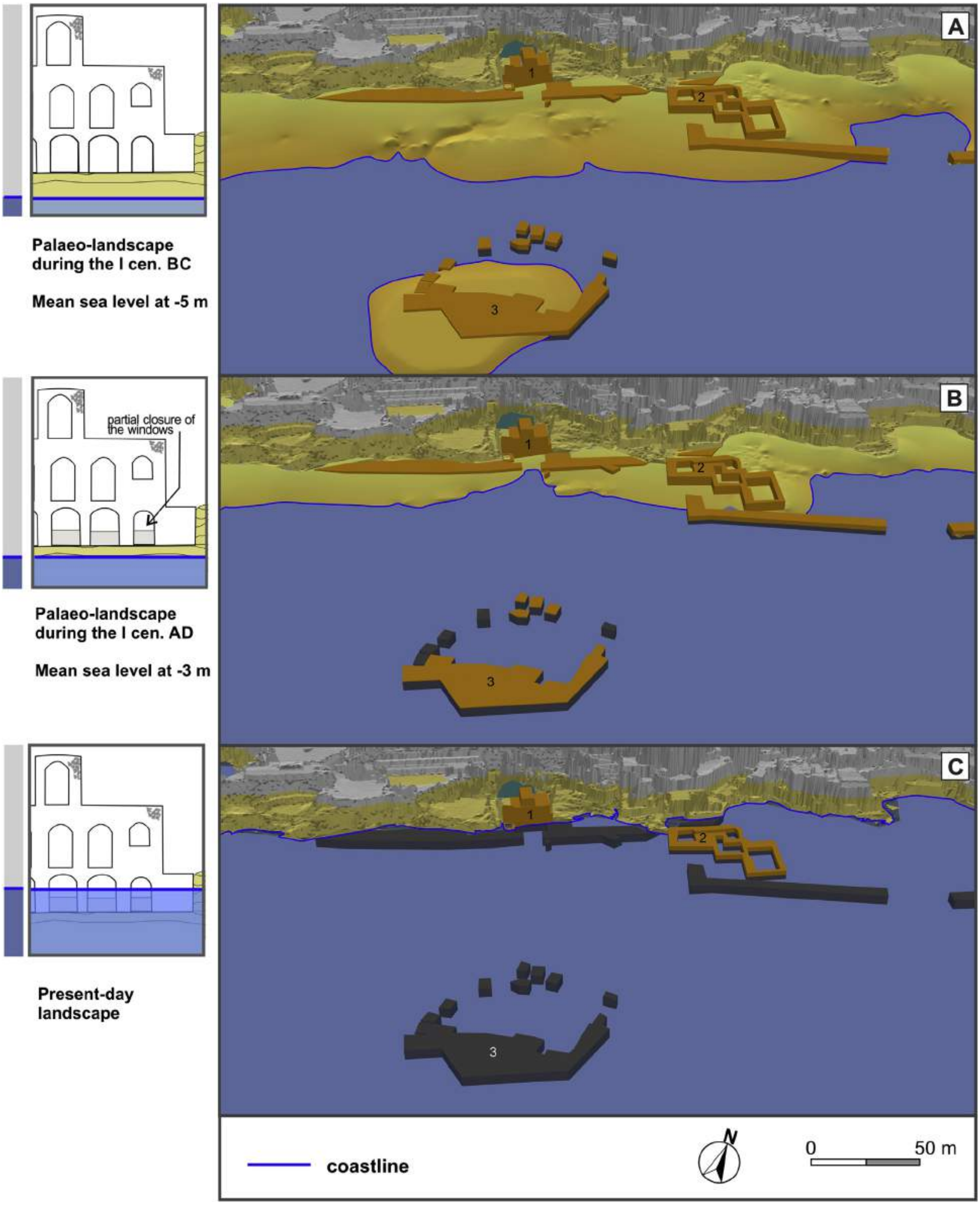

Fig. 13. Landscape reconstruction of the coastal stretch including Palazzo degli Spiriti (1), Pollio villa (2), and port structures (3) off (1). The ages of the three evolution phases are: A) the 1st century BC, when the villa was built, and the sea level was at −5 m as shown in the sketch of Palazzo degli Spiriti on the left; B) the 1st century AD, when a relative sea level rise of 2 m induced the partial closure of the 1st level entrance of the villa, as shown in the sketch of Palazzo degli Spiriti on the left; C) nowadays, with the villa ground level partially submerged.

induced the partial closure of the ground level windows of Palazzo degli Spiriti building to prevent flooding during the storm phases.

Probably also the so-called Pollio villa was abandoned at this time due to the extreme proximity of the sea level.

Moreover, we can hypothesise a readapting of the breakwater pier after the relative sea level rise. In fact, the top surface nowadays is at −1 m bsl and the basis is at −7.5 m of depth. Therefore, the breakwater seems to be a too high structure (6.5 m) considering that it was impossible to build an underwater structure to a depth more than 5 m, using the caisson technique according to Vitruvius.

Besides, this structure had to emerge at least 2 m, and no less than 1.80 m considering the draught of the Roman ships ranging from 0.5 m to 1.5 m (Auriemma and Solinas, 2009; Boetto, 2003). However, taking into account that the average depth of the harbour during the 1st century BC was about of 2.5 m, probably the breakwater initially had a height of 4.5 m, but after the rise of sea level, this structure was raised about of 2 m.

Finally, by comparing the 1st century AD palaeo-sea level with the eustatic curves (e Lambeck et al., 2011), we can conclude that this sector suffered 2 ± 0.5 m of subsidence in the last 2000 years.

The third sketch represents the present-day coastal landscape (Fig. 13C), as results of the submersion and the consequent abandonment of all coastal structures here studied.

7. Concluding remarks

The Posillipo coastal sector was strongly influenced by tectonic and volcano-tectonic effects as well as by the eustatic sea level rise after the emplacement of the NYT deposits.

The precise limiting of four ancient abrasion platforms has allowed highlighting at least three stands of the sea level in the last 5 ky, after the slowdown of the Holocene sea level rise. Furthermore, the slope analysis overlaid with archaeological interpretations has demonstrated the Roman behaviour to build coastal structures onto former coastal plains probably of anthropic origin, as in the case of Palazzo degli Spiriti and Pollio villa.

The multi-technique approach adopted to study the Palazzo degli Spiriti archaeological site allowed the geomorphological evolution of the area to be compared with the natural events of volcano-tectonic origin occurred during the Roman period and with the cultural landscape, which characterised the suburban territory of Naples at that time.

The Late Holocene landscape evolution reveals substantial coastal modification due to the interaction between endogenous, exogenous and anthropogenic forcing.

The human activity and urbanisation of this territory during the Roman period led to landscape changes. Nevertheless, the effect of a subsidence occurred between 1st century BC and 1st century AD was the primary forcing factor that induced not only landscaping changes but also human adaptations, as the partial closure of the ground level entrances of Palazzo degli Spiriti and the rise of the breakwater pier.

The subsidence trend and the concurrent eustatic sea level rise characterised this territory not only during the Roman period bat also in later centuries inducing a permanent abandonment of Roman structures nowadays almost entirely submerged.

In conclusion, the palaeoenvironmental evolution of the Posillipo coastal sector over the last 2000 years was strongly controlled by the effect of a relative sea level rise influencing the coastline modifications and the human behaviour.

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