Evaluation of recent vertical motions along the Island of Capri: geoarchaeological evidences and implications at the Roman villa of Palazzo a Mare

Corrado Stanislao
Italy
corrado.stanislao@unina.it

Keywords: coastal geomorphology, archaeological markers, sea-level rise, Capri, southern Italy

Abstract

This paper presents new geoarchaeological and geomorphological results along the northern and central coasts of the island of Capri where the submerged ruins of Villa Palazzo a Mare enabled the ancient position of both the sea level and the coastline to be reconstructed, as well as making it possible to evaluate the type, entity and rate of vertical ground movements. The surveys covered a maritime villa attributed in its first phase to Augustus. The sea level in Roman times, deduced from the submersion measurement of archaeological markers, has highlighted that despite the general trend of stability of the island of Capri locally many events after the Roman age occurred. Therefore, a rapid displacement due to aseismic and microseismic phenomena occurred during post-Roman age, which caused the coast to drop with consequent shoreline adjustments. An integrated approach linking the morpho-evolution of the landscape to proper management of exposed cultural heritage and the resolution of coastal hazard, is essential, particularly if we consider the population concentration in coastal zones.

Introduction

The research illustrates geomorphologic and geoarchaeological results concerning the northern coastal sector of the Island of Capri, in the Gulf of Naples, between Marina Grande and Punta Bevero, where the Roman age ruins of Palazzo a Mare have been discovered. New investigations in this coastal area have been triggered by the propensity of the island for recreational and touristic activities, combined with a millennial cultural heritage, which makes it a highly vulnerable area to climatic and morphological variations. In this sense, studying the position of the shoreline over time is crucial to understand i) the coastal system changes with its complex dynamics, ii) the coastal response to changes related to the relative variation of the mid-sea level, iii) if and what kind of actions and interventions for proper territorial planning could be useful, ecosustainable, and accepted by the society. Taking a long-term view about coastline management and coastal hazard, shoreline changing can be used to calibrate the forecast scenarios of sea-level rise, taking also into account the tectonic features of coastland margins. Actually, a proper coastal zone management should consider both the global sea-level rise and the local geological components that can modify its entity, even significantly. The interactions between global and local dynamics over the last 10,000 years, have contributed to change the morphology of coastline and to delineate its current conformation.

The IPCC (Intergovernmental Panel on Climate Change) report has shown that variations of the marine level in the Mediterranean do not follow global trends (Woodward et al., 2014), since they are largely influenced by regional and geological climatic features. IPCC scenarios consider the elevation of the sea level only, while they do not consider the negative contributions (acceleration of the submerged) or positive (stability or emersion) depending on other movements unlinked to ice melting, such as isostatic, bradyseismic and volcano-tectonic movements. Campania is an example of what had been said so far, where the effects of all the movements above mentioned create complex dynamics, quite difficult to discriminate.

Modern measurement techniques as metric tilt monitoring, IFSAR (Interferometry SAR), precision leveling and GPS can measure the relative motions with remarkable accuracy. Unfortunately, these data have very short time series which are never larger than 20 years. To reconstruct past dynamics and measures useful to understand modeling caused by vertical motion, data derived from geoarchaeology are used, which through the spatial arrangement of archaeological elements combined with geomorphologic study, gave information and measures to understand the morpho-evolution of the landscape and littoral erosion from Greek-Roman age to the present.

Geological and geomorphological framework

Morphostratigraphic and structural layout of the sea bottom in the perimeter of Capri and of the overlooking southern sector of Sorrento Peninsula, from Punta San Lorenzo (NW) to Punta Campanella (SW), is linked to its tectonic-eustatic evolution and to its control on coastal morphogenetic processes (Fig.1).

Morphobathymetric trend shows a tight relation with emerged landscape, underlining the physiographic framework. The seabed in front of the steep carbonate cliff may assume a large variety of forms, with an articulated topography reflecting there recent tectonic activity affecting this portion of the Apennine Chain during the Quaternary, when extensional subsidence and uplift resulted in a *horst* and *graben* structure (Brancaccio et al., 1991).

In the geodynamic evolution background of the Apennine Chain, the island can be considered as the unique emerging relic part of the western belt belonging to the Campano-Lucano Apennine, lowered and buried under the Tyrrhenian coastal plains during the Quaternary extensional tectonic phases (Signorini, 1950; Beneo, 1951; Sgrosso, 1986).

In particular, along the island northern side (Marina Grande) layers of debris and incoherent detritic soils, containing gravel sand mainly carbonate heterogeneous and cataclastic blocks in thin matrix, as well as reworked pyroclastic deposits lying on the clay substratum, outcrop.

History of Capri Island

The human presence on the Island of Capri has been attested since the lower Paleolithic, but the historical development of the island occurred with the colonization of the Greeks who made it a crucial point for maritime trades. Capri was part of the territory of *Neapolis* and politically depended on this city until Augustus made the island its own property, giving the Neapolitans the volcanic Island of Ischia, in the Gulf of Naples, and starting a massive building activity on the territory. Differently from Augustus, his successor, Tiberius made Capri

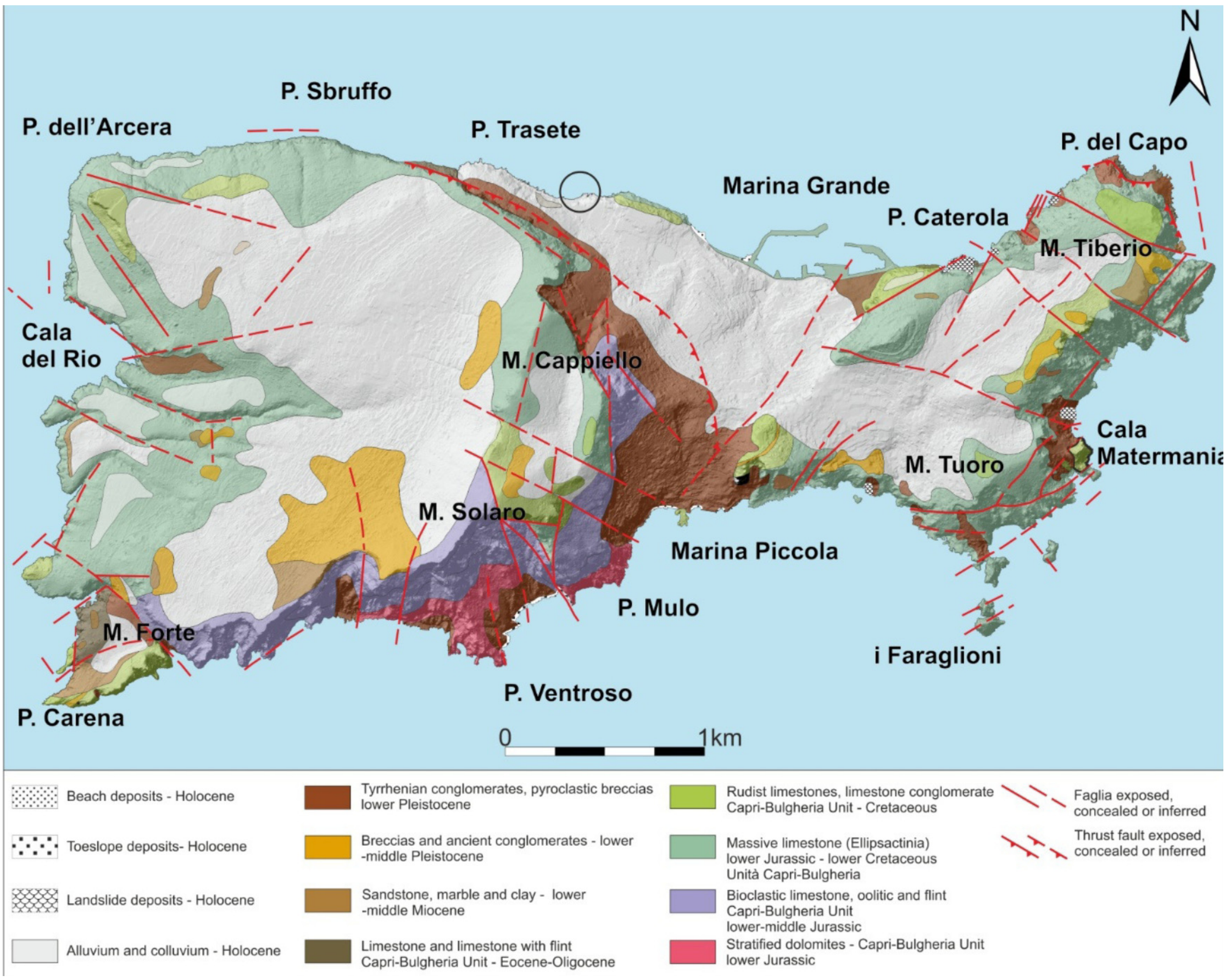

Figure1 – Schematic geological map of Capri Island (after Barattolo et al., 2016); open circle is the study area.

Island a stable location between 27 and 37 AD. The choice to retire on the island maybe coincided with the new policy of Tiberius, whom aiming for a dictatorship government form interrupted the cooperation with the senate, elevating Capri as the new capital of the empire. Tiberius, in a clear break with Roman politics, was surrounded by Greek philosophers and Babylonian astrologers, continuing the building policy inaugurated by Augustus, building twelve huge villas, also providing implantation of nymphs in various island caves.

One of the most significant Roman villas is Palazzo a Mare. The *villa* extends over a large area, from Cape Bevaro to the beach, known as "Bagni di Tiberio", with various nucleus between the sea and the promontory, reflecting the usual type of the *villa maritima*, characterized by scattered architectural elements in a panoramic position. The structure consisted essentially of a long staircase covered with barrel vaults, a private marina and a semicircular exedra-nymphaeum decorated by columns (Di Franco, 2015) (Fig.2).

The *villa*, attributed to Augustus with subsequent modifications due to Tiberius, was stripped of its pavements, capitals and marble columns in the 18th century by Hadrawa. It suffered further damages during the French occupation at the beginning of the 19th century, when a fort was built and the central part was turned into a parade ground. Modern building stock has further transformed the appearance of the areas, hence just some submerged elements of the imperial house remains, partitions of terracing walls, some cisterns and ruins of residential quarters.

Figure 2 – Reconstruction of the *villa maritima* in a painting of Michele Ogranovitsch, 19th - 20th century.

Analytical Methods

The study was focused on a critique reading of coastland geomorphologic literature, evaluating maps about geomorphological characteristics aimed to highlight coastal hazard and morphoevolution. Detailed fieldwork has been executed in order to take a census of archaeological sites and to understand the morphoevolution of the coastal zone from the Greek-Roman age to the current. On these sites, geomorphologic and geoarchaeological evaluations, both terrestrial and underwater, were carried out by repeated measurements with depth gauges, poles and measuring tapes. Moreover, meteomarine climate data have been analyzed, and historical and structural seismic catalogues were consulted (Working Group, 2004; Guidoboni, 2007).

Measurements of the depth (q), in centimeters below sea level, at which the archaeological structures lie were corrected by the formula of Leoni & Dai Pra (1997):

$$q = Q + h_i + \Delta h_p \tag{1}$$

which considers the depth of archaeological remain (Q), hydrometric level at the time of measurement (h_i) and the barometric correction (Δh_p). Hydrometric level was calculated by records of the nearest station (The National Tidegauge Network of ISPRA, mareografico.it). The barometric pressure, measured in *situ,* was mediated by the record of the Meteorological Observatory of the University of Naples Federico II. The Δh_p was calculated considering a regression coefficient of -1 cm/mbar (Palumbo & Mazzarella, 1982).

In order to use the archaeological finds as a marker of the Roman sea level, the depth measurement has been completed with the functional elevation (f_e), which is the original elevation of structure above sea level. Therefore, the formula can be developed as follows:

$$q = Q + h_i + \Delta h_p + f_e \tag{2}$$

The error on the position of the sea level is related to the type of marker. Coastal archaeological sites places in the intertidal zone, such as Roman fishpond, can provide very precise estimates of these changes, while the outer walls are unreliable (Anzidei et al., 2003).

In order to identify the directions of provenance of sea storms and improve the correction factor of the functional elevation (f_e), the calculation of geographic (Fgeo) and effective (Feff) fetches (Fig.3) was carried out at 5° angle intervals for each direction (α). The effective fetch was calculated adding ±45° to limits of the coastal sector, according to the method of Milano (1977) through the following expression:

$$F_{eff} = \frac{\Sigma F_{geoi} \cos^2 \alpha_i}{\Sigma F \cos^2 \alpha_i} \tag{3}$$

Analysis of wind direction and velocity and related frequency was carried out using 3-hour data provided by the meteorological station of Ustica Island, southern Italy, 2 m asl (38°42'28.12"N 13°10'39.23"E), between 1951 and 1998. These data were integrated with anemometric data recorded by Naples tidal station of ISPRA national tide gauge network, located in the port at 1.7 m asl (40°50’27”N, 014°16’09”E), during 1997-2007 period.

Finally, geodetic parameters used to process geo-thematic maps and the digital restitution of collected data are DATUM WGS84, UTM Zone 33, False EST: 500,000 m, False north: 0 m, Latitude of origin: 0° N, Longitude of origin: 15°E, scale factor: 0.9996.

Results

The archaeological complex is greatly deteriorated by continuous architectural changes occurred during the last three centuries. According to Maiuri (1956), the real emperor residence was in the fort area, later converted into a private

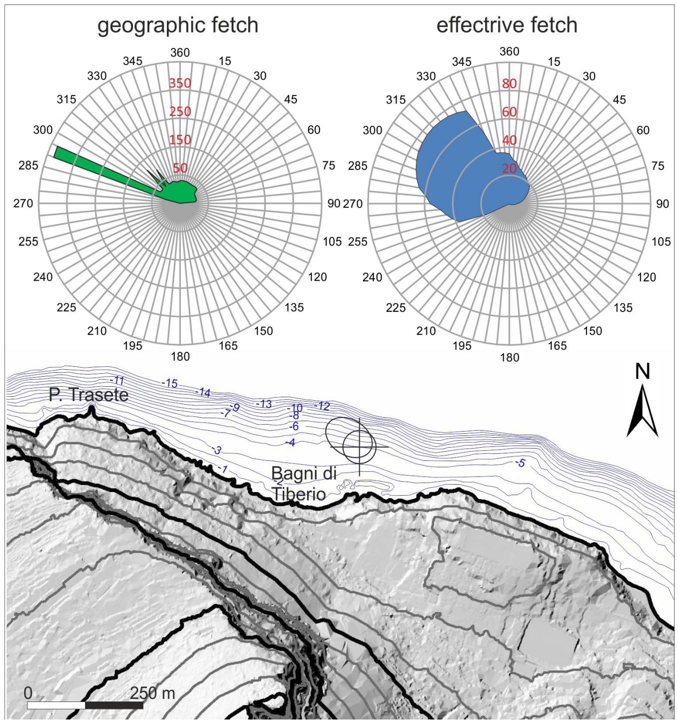

Figure 3 – Polar diagrams of geographic and effective fetches calculated in A, according to Milano (1977), considering extension of offshore, the study area; isobath (-m bsl) from Piano Stralcio di Bacino per la Difesa delle Coste – Autorità di Bacino Campania Centrale.

villa, where some areas of uncertain function, tanks and an impluvium are still recognizable. Maiuri attributes functions of fish tanks and docking to the currently submerged structures. Underwater surveys show that of the archaeological complex (Fig. 4a) remains just some parts of the nymphaeum and few submerged elements (Fig. 4b).

A ramp with marble steps, currently hidden by vegetation, led to the maritime quarter of the villa, in the middle of which the large exedra-nymphaeum is located. The latter is made of *opus reticulatum* alternating with rows of tiles. Probably, hydraulic mortar used in the structure was mixed with materials coming from nearby volcanic districts of the Phlegrean Fields and the Mt. Somma-Vesuvius (Rispoli et al., 2015; Stanislao et al., 2011). Submerged structures, useful as geoarchaeological markers, consist of a underwater arch (Fig. 4c), whose base is placed at -4.2 m depth, made of bricks and mortar. A similar submarine arch was discovered only along the coast of Naples, at about -2.2 m deep, partly cut in tuff (Donadio et al. 2015).

The tunnel (Fig. 4d), at -1.6 m deep, cuts orthogonally the structure with respect to the coastline. It is not possible to observe the docking spotted by Maiuri. Probably, the modern breakwater barrier, located on the east side of the wall, obstructed the small Roman harbour. Furthermore, the surveys show that the structure in place is not disjointed, collapsed

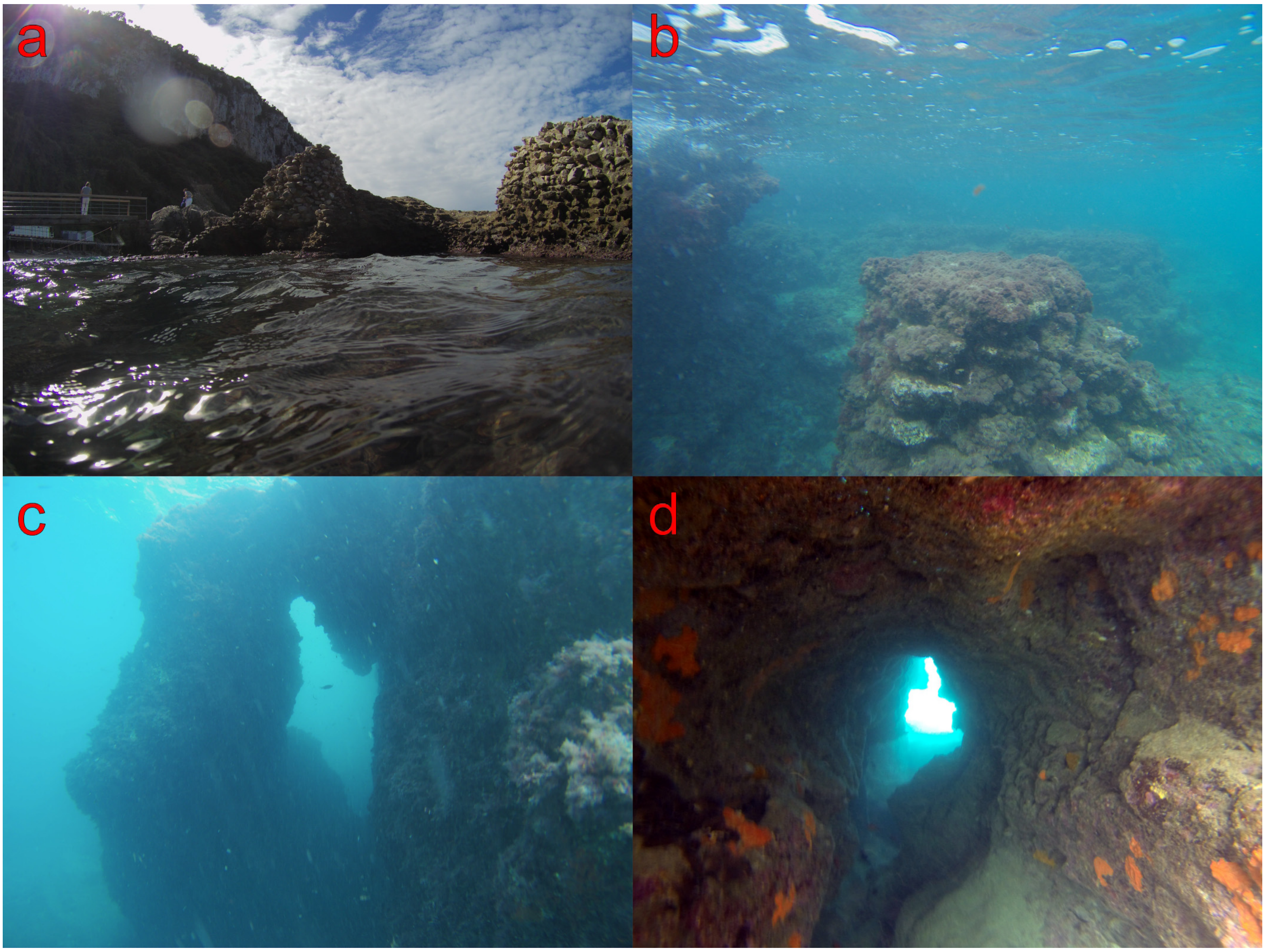

Figure 4 – Emerged (a) and submerged (b) ruins of Palazzo a Mare; c, submerged arch; d, tunnel (photos a-c by C. Stanislao, 2015; photo d by C. Donadio, 2015).

or inclined towards the sea, so its elevations and measures can be considered meaningful and reliable.

Discussion

The mutual interaction between tectonics and glacial-hydrostatic adjustment has controlled the structuring of coastline. Moreover, these factors contributed to the development of the physiographic units and to the genesis of more recent morphologies set on inherited landscapes. These last have been modeled in tectonic and climatic conditions which are very different from present ones: in fact, they manifested before and then during the Quaternary, especially in the last 10,000 years (Holocene). Therefore, in the current coastal landscapes of Campania both different tectonic styles and morphoclimatic systems no longer active are recognizable.
From the archaeological point of view, this part of coastline stimulates great interest, although it has not been the subject of systematic researches aimed to the knowledge of the territory and to the realization of an archaeological map for protection and safeguarding of the underwater heritage. Among many Roman villas of the Island of Capri, Palazzo a Mare is partially submerged with a maximum depth of-4.2 m (Fig. 5).
At this depth, 1 m for a maritime structure must be added in order to preserve the functionality of the structure itself even under severe sea storms. A total drowning of 5.2 m was evaluated. (Fig.6). This value was calculated with equation (3).
The meteomarine climate of the Capri Island shows a geographical fetch with main sector towards northwest, extending about 450 km, with winds coming from the first and fourth quadrants; the effective fetch, calculated for the maximum extension with northwest direction, is equal to 70 km.
Wind that generate significant sea storms blow mainly from the northwest, is a destructive agent to archaeological structure, which extends parallel to the shoreline with N90° direction.
This submerging can be partly attributed to the glacial-hy-

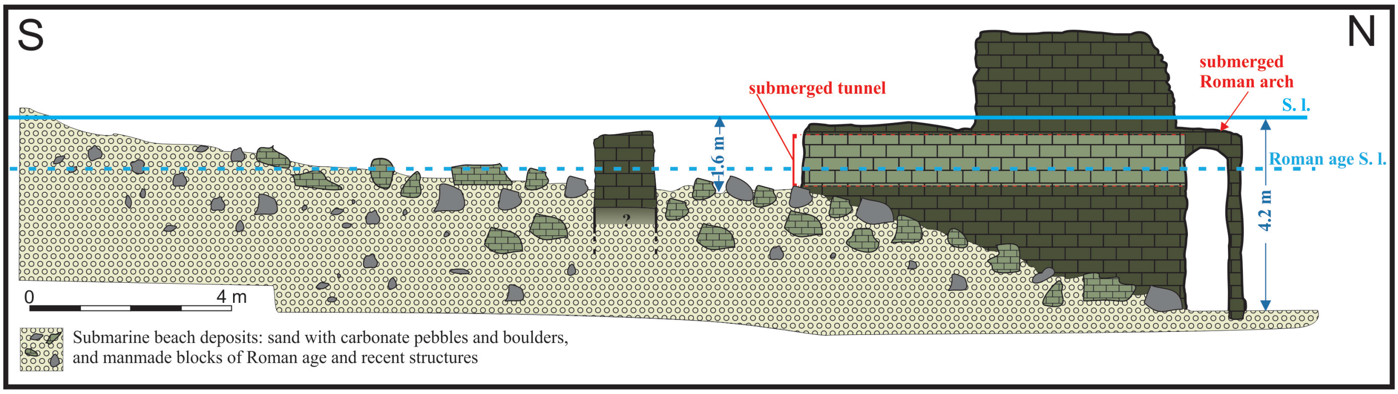

Figure 5 – South-North section of archaeological structures at Roman villa of Palazzo a Mare; depth is in meters bsl.

drostatic adjustment, whose causes can be summarized in: i) changes in the volume of water (melting glaciers, thermal expansion of ocean water masses), ii) lifting of emerging lands and lowering ocean beds as consequences of the gla-

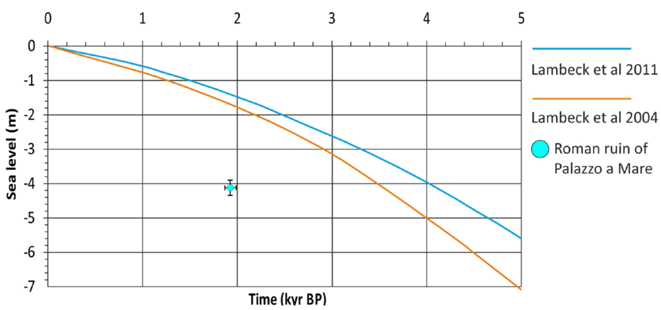

Figure 6 – Position of archaeological markers linked with predicted sea level curve for the site of Campania.

cial crusts melting, according to the rheological response of the lithosphere. This adjustment from Greek-Roman period is about 1.25 cm (Lambeck et al., 2004, 2011).

Moreover, a slight subsidence was recorded, with average rate of -0.12 cm/yr in the 2002-2011 period (Fig.7) by radar PSI technique-SAR (permanent Scatter Interferometry – Syntetic Aperture Radar) and by ERS satellites with ascending orbit (IREA, webgis.irea.cnr.it). Considering this value for the last 2000 years, since Roman age a subsidence of 2.4 m occurred.

These phenomena partially justify the drowning of submerged ruins, because other factors influenced the examined area. In the literature (Working Group, 2004; Guidoboni, 2007) there are no significant earthquakes able to dip the area, confirming the absence of seismicity linked to the Apennine chain.

A plausible mechanism is represented by aseismic and microseismic movements along the faults reticulum linked to the fault principal system, NE-SW oriented. These phenomena surely act slow ground vertical movements in a range of -0.6 and -0.8 cm/yr, which could increase coastal hazard due to sea cliff erosion and landslides (De Pippo et al., 2009). This interpretation is supported by the local displacement of the Tyrrhenian (125 kyr BP) marine terrace and sea notch (Ferranti et al., 2007).

Conclusions

Several areas along the Mediterranean coasts show submerged ruins of Greco-Roman Period few meters under the current sea level (Auriemma & Solinas, 2009). The causes of the drowning of archaeological ruins are mainly attributed to the interactions between sea-level rise and subsidence, while in volcanic areas the adjunctive effect of tectonics, seismicity and locally brady-seismic phenomena determined a higher and rapid soil down lifting such as recorded in Campania (Aiello et al., 2007; Putignano et al., 2014).

The historical evolution of the carbonate Island of Capri has been influenced by sea-level rise due to the glacio-hydro-isostatic effect (*sensu* Lambeck et al., 2011) and wave erosion, which have led to the submersion and retreat of the coast. Locally, this trend has been influenced by geological component.

The Roman ruins of Augusto's maritime villa are located at -4.2 m depth. Even considering the sea level during Roman age (-1.25 m lower than the present day), the downlift is incongruent with the general island uplift of ~1.5 m due to tectonics, marked along the cliffs by the current elevation of the palaeo-sea notch modeled at 5.5 m ~125 kyr BP (MIS 5.5 high stand, Tyrrhenian). Likely, a rapid displacement due to aseismic and microsismic movements during post-Roman age occurred.

The analysis of meteomarine conditions show that the villa is exposed to the northwest storms, which developed waves crashing sine 2000 years on the Palazzo a Mare, the last archaeological evidence of *villa maritima* on the island. Therefore, it should be protected and restored with a land-sea project following and adaptive strategy and environmental design approach.

Moreover, to estimate the coastal hazard is necessary to evaluate the recent data on the predictions of sea-level rise

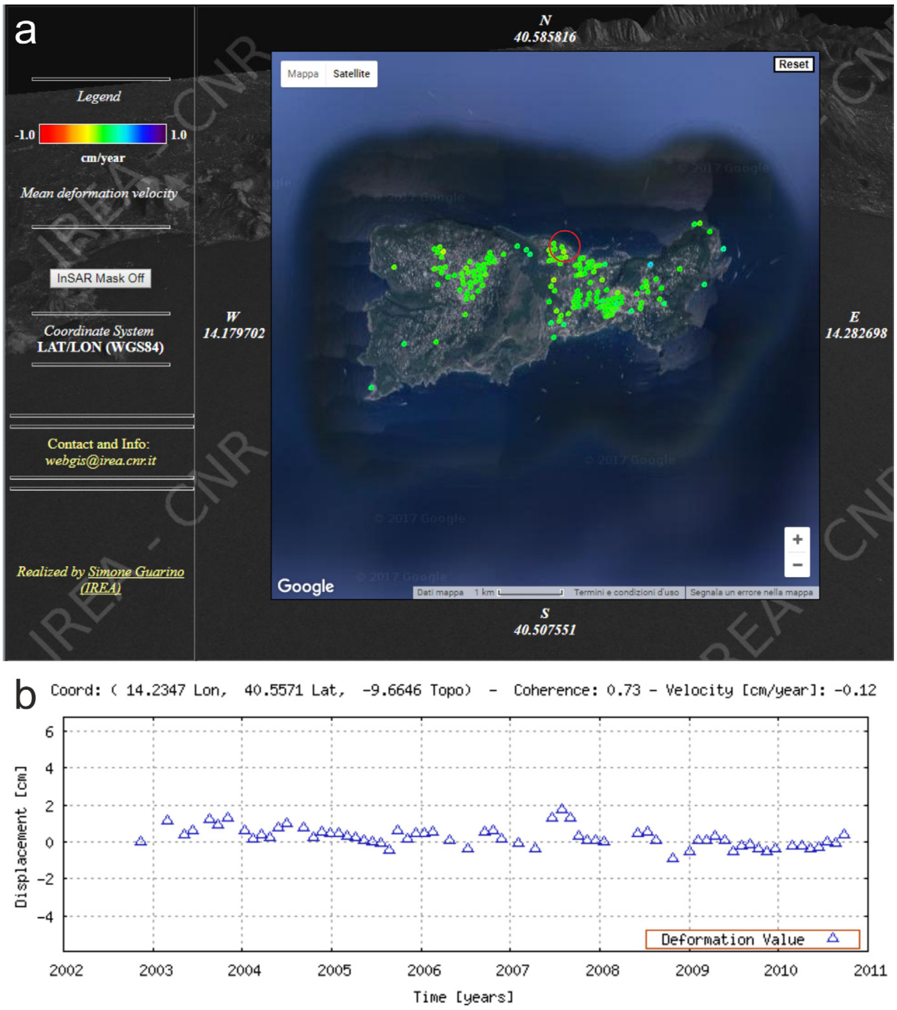

Figure 7 – a, ERS images of Capri Island, from Irea (Istituto per il rilevamento eletromagnetico dell'ambiente); red open circle is the study area; b, InSAR deformation-timeseries.

and to consider also a morpho-structural and morpho-evolutionary models derived from geoarchaeological and geomorphological evidences. Finally, these models must be set on a local scale since multiple causes simultaneously act along the territory in different ways and intensity, leading to great modification of the coastland.

Acknowledgements

This paper is an Italian contribution to the project IGCP 639-International Geological Correlation Programme "Sea-level change from minutes to millennia" by UNESCO - IUGS (Project Leaders: S. Engelhart, G. Hoffmann, F. Yu and A. Rosentau). Finally, I would like to say thank you to the reviewers for their valuable comments, which improve the manuscript.

References

Aiello G., Barra D., De Pippo T., Donadio C., Petrosino, C. 2007. *Geomorphological evolution of Phlegrean volcanic islands near Naples, southern Italy*. *Zeitschriftfür Geomorphologie*, 51(2): 165-190.

Anzidei M., Benini A., Lambeck K., Antonioli F., Esposito A., Surace L., 2003. *Siti archeologici costieri di età romana come indicatori delle variazioni del livello del mare un'applicazione al mar Tirreno (Italia centrale)*. L. De Maria and R. Turchetti Eds., *Evolución Paleoambiental de Los Puertos y Fondeaderos Antiguos en el Meditterráneo occidental*: 115-125.

Auriemma R., Solinas, E. 2009. *Archaeological remains as sea level change markers: a review. Quaternary International*, 206(1): 134-146.

Barattolo F., Donadio C., Pennetta M., Perriello Zampelli S. 2016. *Guida Geologica Regionale. Campania e Molise*, *Soc. Geol. It.*: 171-180.

Beneo E., 1951. Lo schema strutturale dell'Isola di Capri. *Servizio Geologico d'Italia*, Roma.

Brancaccio, L., Cinque, A., Romano, P., Rosskopf, C., Russo, F., Santangelo, N., Santo, A. 1991. *Geomorphology and neotectonic evolution of a sector of the Tyrrhenian flank of the Southern Apennines (Region of Naples, Italy)*. *Zeitschrift für Geomorphologie*, 82: 47-58.

De Pippo T., Donadio C., Pennetta M., Terlizzi F., & Valente A., 2009. *Application of a method to assess coastal hazard: the cliffs of Sorrento Peninsula and Capri (southern Italy)*. In: Violante C. (ed), Geohazards in rocky coastal areas, *Geological Society of London*, Spec. Publ., 322, 189-204.

Donadio C., Pennetta M., Stanislao C. 2015. *Geoarcheological and geomorphological evidences of recent ground vertical movements along the coast of Campania, southern Italy*. *International Congress GeoSUB – Underwater Geology*, Trieste, 39-40.

Di Franco, L. 2015. *Capreensia disiecta membra. Augusto a Capri e la villa di Palazzo a Mare*, *Scienza e Terra Eds*., Roma

Ferranti L., Antonioli F. 2007. *Misure del solco tirreniano (MIS 5.5) nell'isola di Capri: valutazione di attività tettonica durante il Pleistocene superiore*. *Il Quaternario*, 20(2): 125-136.

Guidoboni E., Ferrar, G., Mariotti D., Comastri A., Tarabusi G, Valensise G., 2007. CFTI4 Med, *Catalogue of Strong Earthquakes in Italy (461 B.C.-1997) and Mediterranean Area (760 B.C.-1500). INGV-SGA.*
IREA-CNR InSAR WEB GIS, Mean deformation velocity, webgis.irea.cnr.it/

Istituto Superiore per la Protezione e la Ricerca Ambientale, The National Tidegauge Network, mareografico.it.

Lambeck K., Antonioli F., Anzidei M., Ferranti L., Leoni G., Scicchitano G., Silenti S., 2011. Sea level Change along the Italian coast during the Holocene and projections for the futures. *Quaternary International*, 232: 250-257.

Lambeck K., Anzidei M., Antonioli F., Benini A., Esposito E., 2004. *Sea level in Roman time in the Central Mediterranean and implications for modern sea level rise. Earth and Planetary Science Letters,* 224: 563-575.

Leoni G., Dai Pra G., 1997. *Variazioni del livello del mare nel tardo olocene (ultimi 2500 anni) lungo la costa del Lazio in base ad indicatori geo-archeologici. Interazioni fra neotettonica, eustatismo e clima*. *ENEA, Dipartimento Ambiente, Centro Ricerche Casaccia*, Roma, RT/AMB/97/8.

Maiuri A., 1956. *Capri: Storia e monumenti*. Roma.

Palumbo A., Mazzarella A., 1982. *Mean Sea Level Variations and Their Pratical Applications*. *Journal of Geophysical Research*, 87(C6): 4249-4256.

Milano V., 1977. *Sulle lunghezze del fetch effettivo nel Mar Mediterraneo.Prog. Fin. "Conservazione del suolo", subprog. "Dinamica dei litorali"*, C.N.R., Roma, 33:239-248.

Putignano M. L., Orrù P. E., Schiattarella M. 2014. *Holocene coastline evolution of Procida island, Bay of Naples, Italy*. *Quaternary International*, 332: 115-125.

Rispoli C., Graiano S. F., De Bonis A., Cappelletti P., Esposito R., Talamo P., 2015. *Piscina Mirabilis characterization of geomaterial*. *Proceedings of the 1st Conference of Metrology for Archaeology*. Benevento, 266-270.

Sgrosso I., 1986. *Criteri ed elementi per una ricostruzione paleogeografica delle zone esterne dell'Appennino centromeridionale. Mem. Soc. Geol. It*., 35: 203-228.

Signorini R. 1950. Sulla tettonica dell'Isola di Capri. *Boll. Soc. Geol. Ital.*, 69: 516-534.

Stanislao C., Rispoli C., Vola G., Cappelletti P., Morra V., de' Gennaro M., 2011. *Contribution to the knowledge of ancient Roman seawater concretes: Phlegrean pozzolan adopted in the construction of the harbour at Soli-Pompeiopolis (Mersin, Turkey)*. *Periodico di mineralogia*, 80(3): 471-488.

Woodward A., Smith K. R., Campbell-Lendrum D., Chadee D. D., Honda Y., Liu Q., Confalonieri U., 2014. *Climate change and health: on the latest IPCC report. The Lancet*, 383(9924): 1185-1189.

Working Group CPTI, 2004. *Catalogo Parametrico dei Terremoti Italiani*, vers. 2004 (CPTI04). *INGV*, Bologna. http://emidius.mi.ingv.it/CPTI/2004.