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FIRST RESULTS ON THE COASTAL CHANGES RELATED TO LOCAL SEA LEVEL VARIATIONS ALONG THE PUTEOLI SECTOR (CAMPI FLEGREI, ITALY) DURING THE HISTORICAL TIMES

Pietro P.C. Aucelli [1], Aldo Cinque [2], Gaia Mattei [1], Gerardo Pappone[1], Michele Stefanile [3]

1 Dipartimento di Scienze e Tecnologie, Università degli Studi di Napoli Parthenope, Napoli, Italy
2 Dipartimento di Scienze della Terra, dell'Ambiente e delle Risorse, Università di Napoli Federico II, Napoli, Italy
3 Dipartimento Asia Africa e Mediterraneo, Università L'Orientale di Napoli, Napoli, Italy
Corresponding author: G. Mattei <gaia.mattei@uniparhtenope.it>

ABSTRACT: Puteoli coastal sector is located in the Campi Flegrei volcanic area, along the Mediterranean coasts. This sector is rich in archaeological remains here used as sea-level markers useful to reconstruct the vertical ground movements affecting the CF area. Marine surveys by means of an Unmanned Surface Vessel equipped with geophysical instruments were carried out along the coastal sector to reconstruct the seabed morphology and to detect the submerged remains. By analysing geomorphological stratigraphic and archaeological data, the natural and anthropogenic landscape evolution of Puteoli since the Greek-Roman period was evaluated.

KEYWORDS: Campi Flegrei volcanic area; vertical ground movements; sea level markers; coastal changes

1. INTRODUCTION

The Puteoli coast is located in the central part of Campi Flegrei caldera, an active volcanic system whose activity spans the last 50,000 years (De Vivo et al., 2010 and reference therein). The caldera formation is mainly related to the Campanian Ignimbrite (CI, 37 ky) and the Neapolitan Yellow Tuff (NYT; 15 ky) eruptions.

This area is well known for bradyseism crisis characterized by alternating phases of intense uplift and subsidence of different duration. These vertical ground movements (hereinafter VGM) have produced strong modification in the coastal landscape since the Early Holocene. La Starza marine terrace is the oldest silent witness of this volcanic behaviour. In fact, this marine terrace uplifted 30-40 m a.s.l. about 5 ky BP (Di Vito et al., 1999 and reference therein). Instead, the more recent historical coastal modifications are mainly testified by the submerged structures of Portus Julius and by the *Lythophaga* perforations on the marble columns of the *macellum*, the Roman food market so-called Serapis Temple (Morhange et al., 2006 and reference therein).

Despite the repeated modifications of the coastal landscape, this sector was extensively inhabited since the Greek time, as testified by the town of Dicearchia (531 BC) and by the neighbouring Greek colony of Kyme (the oldest in the Western Mediterranean, according to the ancient authors). However, it reached its maximum expansion during the Roman period with the settlement of the Roman colony of Puteoli (194 BC), in the same site of the Samian Dicearchia, where a *portorium* was created during the Second Punic War. During this period, several human adaptations to bradyseismic crisis that affected the Campi Flegrei area were necessary (Aucelli et al, 2017a, b and c). The studies have demonstrated that these VGMs are not distributed uniformly all over the coast and new data can improve the knowledge on the phenomenon.

In this short communication, we present the first result of a geoarchaeological study of the area located off the Puteoli coast at the footslope of La Starza marine terrace that still preserves several traces of coastal changes affecting Campi Flegrei area during the Greek-Roman period due to VGMs.

2. METHODS

The Greek-Roman sea level changes and its effects on the coasts were deduced by interpreting depositional, erosional, biological and archaeological markers (Vacchi et al., 2016 and references therein). In the first instance, the coastal sector was investigated by means of an Unmanned Surface Vessel (USV) equipped with geophysical systems and underwater cameras as well as by direct underwater surveys. The USV was engineered by our research group to carry out integrated surveys with acoustical and optical methods at the same time in very shallow waters sectors (Giordano et al., 2015; 2016).

The analysis of the morpho-acoustic data allowed reconstructing the seabed morphology and the submersion of all submerged archaeological structures (Mattei and Giordano 2014; Aucelli et al., 2016), as the *pilae* well distributed in the study area and probably dated by historical sources at Augustan period (31 BC - 14 AD). By

correcting the present submersion with respect to the indicative meaning (the elevation where the marker was built with respect to the palaeo-sea level, Vacchi et al., 2016 and references therein), a new palaeo-sea level was deduced.

Three palaeo sea-level dated at Greek-Roman period were identified by reinterpreting a stratigraphic record close to the *macellum* (Bellucci et al., 2006), taking into account the archaeological constrains provided by the restorations in this complex and by the Portus Julius construction.

The main evolutive steps of the coastal sector in the same period were deduced by analysing high-resolution morphologic (LIDAR, single beam and multibeam bathymetry) and geological data as well as by interpreting all submerged archaeological remains located in the study area.

3. RESULTS

Puteoli coastal sector has suffered short-lived subsidence phases in the historical times which greatly amplified the effects of the eustatic sea level rise (Lambeck et al., 2011), producing the submersion of wide areas.

The sea level deduced by studying the 74 submerged *pilae*, probably built not before the Augustan Age and well distributed off the Southern Puteoli coastal sector are an important evidence of a coastal retreat. As the more preserved pila has the top surface at -1 m bsl and considering an indicative range not higher than 2 m, the 1st century AD sea level was no lower than -3 m.

A previous sea level at -6 m was deduced by the present submersion of the Portus Julius entry channel (Passaro et al., 2013). In fact, this military port was hastily built in 37 BC, as a new resource for the war against the pirates, and abandoned in a few years for the rapid submersion of port facilities (Todesco et al., 2014). We can deduce a subsidence about of 3 m that also explains the construction of the *pilae* as a coastal defence during the Augustan age.

Two other relative sea level between the 1st century BC and 1st century AD were deduced by reinterpreting a stratigraphic record close to the famous *macellum* probably built in the I century AD, in a place where also a 1st mosaic floor was discovered, probably dated at mid-II century BC by several authors (i.e. Dvorak & Mastolorenz, 1991; Todesco et al., 2014). A sea level dated at the time of the construction of the first structures in this site was evaluated not higher than - 8 m by Bellucci et al. (2006), thanks to the anthropogenic deposits (with pottery fragments) on which the first floor lies. Consequently, we have calculated a subsidence phase between ca. 150 BC and 37 BC about of 2 m.

The 1st floor was totally buried by 2 m of coarse sands that can be interpreted as an antrophic intervention aimed at the construction of the 2nd marble floor.

The last relative sea level at -2 m b.s.l. was deduced from the position of the second marble floor (probably dated at Flavian age), the second in the sequence of the site, at 0.086 m a.s.l. (by supposing 2 m of indicative meaning).

4. DISCUSSION AND CONCLUSION

This study has provided new data related to Greek-Roman vertical ground movements affecting the Campi Flegrei, by means of a precise detection of four local palaeo-sea level indicators.

In the first instance, a new palaeo-sea level probably dated not before the Augustan period (Camodeca, 1994) was evaluated by sensing the underwater archaeological landscape of this sector by using a USV with geophysical instruments. The corresponding coastline position at that time was reconstructed by integrating the geophysical, geomorphological and archaeological interpretations (Figure 1).

Thanks to these interpretations, a subsidence occurred between 37 BC and the 1st century AD was evaluated for the first time, by overlaying the sea level data deriving from the submersion of the defence structures (*pilae*) here studied with that of Portus Julius (Passaro et al., 2013) built several years before the pilae. In the second instance, the reinterpretation of the stratigraphic record described by Bellucci et al. (2006) allowed us to evaluate the two other palaeo-sea level as well as the corresponding coastline positions (Figure 1). Two subsidence phases deriving from these interpretations were obtained: one between ca. 150 BC and 37 BC, and another during the of 1st century AD. Taking into account that the eustatic sea level during this time lapse was constantly at -1.1 m b.s.l. (Aucelli et al., 2017; Lambeck et al., 2011), the subsidence of about 3 m can be ascribed to a volcano tectonic ground movement.

The vertical ground movements of metric entity here tentatively proposed between 2nd century BC and 1st century AD, can be totally ascribed to a volcano-tectonic origin, taking into account that the eustatic sea level rise during this time lapse ranged between -1.38 m and 1.06 m (Aucelli et al., 2017; Lambeck et al., 2011).

Taking into account that the eustatic sea level rise during this time lapse ranged between -1.38 m and -1.06 m (Aucelli et al., 2017; Lambeck et al., 2011), these vertical ground movements of metric entity can be totally ascribed to a volcano-tectonic origin.

At that time, this study provides a first evaluation of the subsidence effects on the Campi Flegrei coastal landscape and coastal settlements during the historical times, thanks to the reconstruction of the local sea level variations between the 2nd century BC and the 1st century AD (Figure 1).

In conclusion, the historical coastal evolution of the central part of Campi Flegrei caldera has been characterized by a coastal retreating about of 150 m. The coastline positions here reconstructed between 200 BC and 14 AD have enabled us to assess this trend. This study has demonstrated as the Puteoli coastal landscape was strongly modified by volcano-tectonic movements inducing fast sea level variations. These coastal changes were reconstructed by overlaying geomorphological archaeological and stratigraphic interpretations in order to describe the interaction between landforms evolution and human adaptations. Moreover, the ongoing acquisition of new archaeological data could slightly vary some geochronological constraints related to the macellum construction phases.

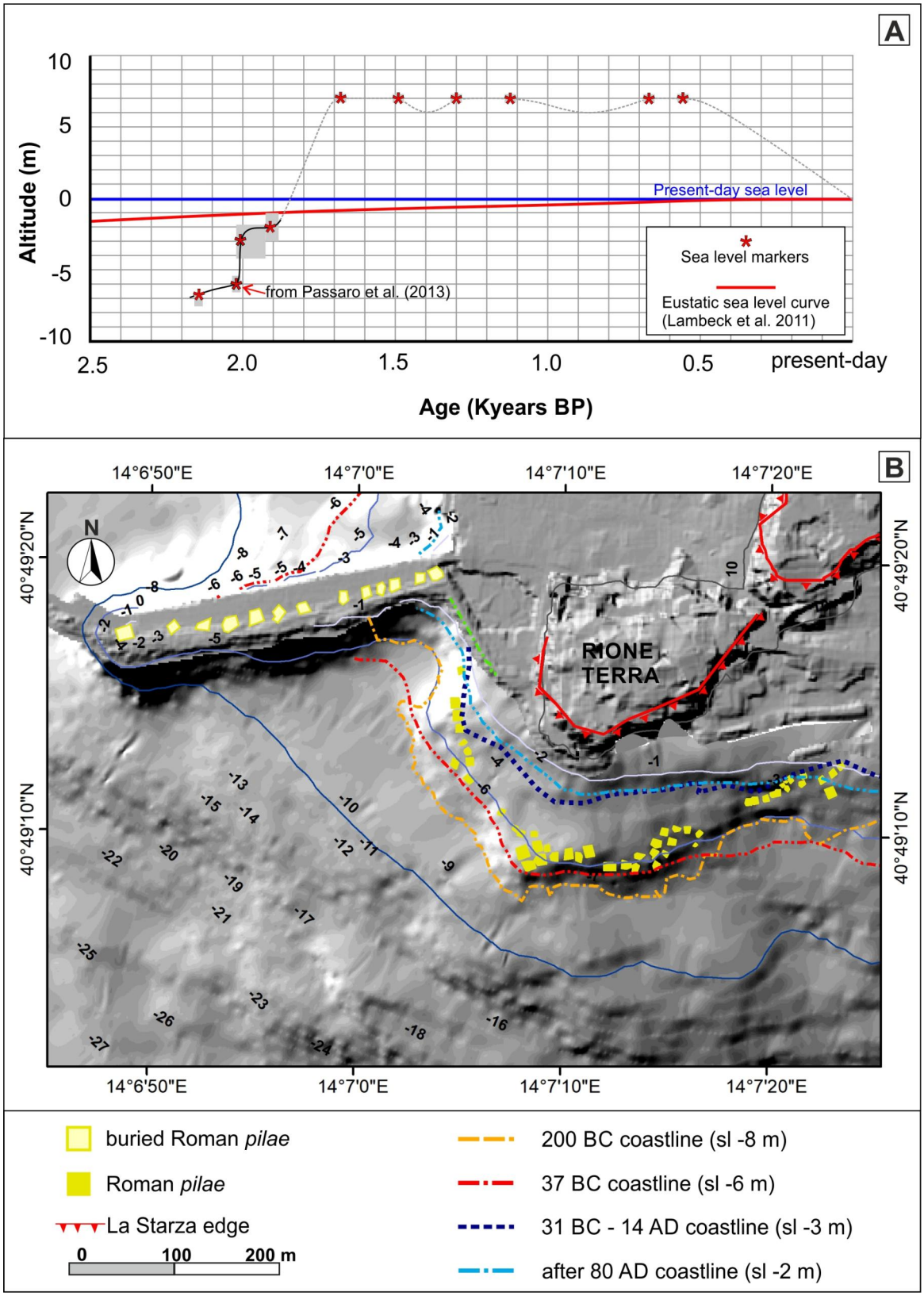

Fig. 1 - A) Relative sea level curve since the Greek-Roman times; B) 3D landscape with the Roman structures nowadays submerged and the coastline positions between the 2nd century BC and 1st century AD.

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