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A geochemical and sedimentological perspective of the life cycle of *Neapolis* harbor (Naples, southern Italy)

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ABSTRACT

Since the discovery of the ancient harbor of Naples in 2004 during construction work on an underground railway, geoarchaeological studies undertaken on the archaeological excavation have revealed the main stratigraphic and paleo-environmental levels of the harbor site near the Piazza Municipio. However, knowledge of the dynamics and paleo-environmental changes in the water column of the harbor, as well as the processes of transport and deposition of sediments that led to siltation and infilling of the harbor basin, has been lacking due to the absence of high-resolution data. To fill these gaps, we have undertaken a three-dimensional study (longitudinal, transverse and vertical) of the harbor deposits by carrying out geochemical and sedimentological analyses of four stratigraphic sections of the archaeological excavation. The results show that after a phase of relative calm during the first half of the 1st c. AD, siltation of the harbor progressed exponentially up to the 5th c. AD, when dredging operations were carried out to obtain a water level sufficient for the development of maritime and harbor activities. We attribute this acceleration of siltation to a combination of climatic, anthropic and volcanic factors. Volcanic activity was responsible for a high-energy, tsunami-type event during the eruption of Vesuvius in 79 AD. From the 5th c. AD onwards, the harbor basin of Neapolis does not appear to have been functional as evidenced by its transformation into a lagoon following coastal progradation. The last stage of infilling was the development of a flood-dominated fan delta under the combined influences of climatic cooling in the Early Medieval Cool Period and agro-pastoral activities in the catchment area of the harbor. Several generations of paleo-channels, containing flash flood deposits, as well as sheet wash from sheet floods, are indicative of high environmental instability in this period.

1. Introduction

At the beginning of the 1990s, following excavations of the ancient harbors of *Caesarea* (Israel) (Reinhardt et al., 1994, 1998; Reinhardt and Raban, 1999) and Marseille (France) (Hesnard, 1994; Morhange, 1994; Morhange et al., 2001, 2003), geo-archaeologists for the first time became interested in the sedimentary archives of ancient harbor basins. The *Caesarea* and Marseille research projects contributed to understanding the history of excavated harbors with interactions between humans and the environment at the center of interest (sea-level variations, coastline progradation, siltation rates, anthropization, etc.) (Marriner and Morhange, 2007). Ancient harbor basins are particularly worthwhile studying because they were at the heart of trade between port cities and the rest of the Mediterranean world and ensured urban development and prosperity. Thus, the conditions to which harbors were subjected during their history, especially siltation, were decisive for the survival of urban centers. At *Neapolis* (Greek for Naples), survival was even more critical as commercial links between the cities of the Bay of Naples (Fig. 1A) and Rome were essential (e.g. Balland, 1965; Domergue and Rico, 2014).

It is within this historiographic context that the

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geoarchaeological studies carried out since the 2000s at *Neapolis* have focused on changes in coastline position and sea level (Irollo, 2005; Ruello, 2008; Amato et al., 2009; Giampaola, 2009; Cinque et al., 2011), the location and extension of the harbor basin (Giampaola et al., 2006; Carsana et al., 2009), and past landscape reconstruction in the area surrounding the city (Russo Ermolli et al., 2014; Allevato et al., 2009, 2010). Although these investigations provide geomorphological and stratigraphical information useful to paleo-environmental reconstruction of the harbor zone located in the bay of Echia (Fig. 1B), identification of the dynamics and paleo-environmental changes in the water column, as well as the processes of transport and deposition of sediments that led to siltation of the harbor basin, has been out of reach due to the absence of high-resolution data (except for pollen and plant remains that have provided information on the cultural history of the urban zone of *Neapolis*; Russo Ermolli et al., 2014 and Allevato et al., 2015). In the present work, we focus on the interaction between fluvial and marine influences on the harbor water column, as well as on siltation and its human control in a sheltered bay environment, topics still poorly understood compared with deltaic environments.

While harbor geoarchaeology principally uses methods based on micropaleontology (molluscs, ostracods, foraminifera, diatoms, pollen) and sedimentology (texture, granulometry, exoscopy) (Goiran and Morhange, 2003; Marriner and Morhange, 2007; Cubizolle, 2009), geochemistry has been shown recently for Rome (Delile et al., 2014) and Ephesus (Delile et al., 2015a) to be an additional source of quantitative paleo-environmental data. Here, we apply geochemistry and statistics to the deposits of the ancient harbor basin of Naples that has been exposed since 2004 by excavation work on two new lines of the Naples underground railway. The archaeological excavation provides a unique opportunity to study the harbor deposits of Naples by means of several stratigraphic sections oriented towards the four cardinal points, and thus to examine the infilling of the harbor basin through a three-dimensional approach (longitudinal, transverse and vertical). In harbor geoarchaeology so far, only the ancient ports of Marseille (Morhange, 1994; Morhange et al., 2001, 2003) and Istanbul (Algan et al., 2009, 2011; Bony et al., 2012) have been studied by way of stratigraphic sections uncovered by archaeological excavation.

2. Study area

2.1. Geography and geology

The city of Naples is the capital of the region of Campania, which lies between Latium to the north and Calabria to the south. Its western border, in particular the coastal area, is limited by the volcanic zone of the Phlegraean Fields, while its eastern fringe reaches the slopes of Vesuvius (Fig. 1A). The region has a Mediterranean climate with mild rainy winters and hot, relatively dry summers (Allevato et al., 2012).

The Neapolitan area is part of the plain of Campania, which is situated in a graben of the same name in which both volcanism and tectonics are active. Since the Quaternary, the plain of Campania and its extension under the sea have been subject to subsidence, which is variable for different sectors and periods (Cinque et al., 2011). Brancaccio et al. (1991) have estimated a rate of subsidence during the Quaternary of 2 mm per year on average. The littoral of the plain of Campania presents a varied geomorphological framework in which steep marine cliffs alternate with narrow coastal plains (e.g., Volturno). The Bay of Naples itself is defined by the Sorrento Peninsula to the southeast and the Gulf of Puteoli to the northwest (Fig. 1A). The bay contains a succession of projecting capes (e.g., Posillipo) and coastal plains (Sebeto and Sarno) (Fig. 1A).

The principal geological structures and formations are the result of tectonic and volcanic activity in the area, which has given rise to numerous hills composed of deposits of volcanic origin. The latter derives primarily from the Phlegraean Fields and secondarily from Vesuvius (Romano et al., 2013; Russo Ermolli et al., 2014). In general, the volcanic geology of the region consists of lavas, lithified yellow tuff (>39 ka BP), Campanian ignimbrites (~39 ka BP), Neapolitan Yellow Tuff (~15 ka BP, the principal geological formation of the sector), pyroclastic deposits from the Phlegraean Fields (<15 ka BP) as well as Vesuvius, and interstratified marine and terrestrial deposits along with pyroclastic deposits (<5 ka BP) (Romano et al., 2013).

2.2. Archaeology and geoarchaeology

In the middle of the 7th c. BC, Greek colonists from Cumae founded on the hill of Monte Echia the first urban center of Naples, called *Parthenope* ("virgin" in Greek). Later, at the end of the 6th c./beginning of the 5th c. BC, the city was re-located lower down in the plain, at the foot of the terrace of Pendino, and was re-named *Neapolis* ("new city" in Greek) (Fig. 1B). Archaeological remains from the Greek period are rare on the Neapolitan coast, while those from the imperial period are more common. These latter mostly consist of Roman villas situated on the promontory of Pizzofalcone, the slopes of the hill of San Martino (Fig. 1B) and the hill of Posillipo (Fig. 1A) (Romano et al., 2013). The second category of Roman infrastructure identified in the area includes the coastal road and the aqueduct of *Aqua Augusta*. Both served the principal urban centers of the plain of Campania, from the time they were built in the Augustan period (Keenan-Jones, 2010). The course of the Roman road (*via per Cryptam*) can be identified by the presence of tombs built along it (Romano et al., 2013). It begins at *Neapolis* and runs westward along the plain of Chiaia to end at the city of Pozzuoli. Pozzuoli was considered the granary of Rome for 250 years, and hence was integrated into the Pozzuoli-Ostia-Rome harbor system at the beginning of the 2nd c. BC (Zevi, 2001a, b; Tchernia, 2011).

The archaeological excavations carried out when construction took place on the two underground railway lines in Naples led to the discovery of the ancient harbor of the city in 2004, which was situated in a bay separating the two historical centers of *Neapolis* and *Parthenope* (Fig. 1B) (Giampaola et al., 2006; Carsana et al., 2009). The discovery of this Graeco-Roman harbor between the Piazza Municipio and Piazza Bovio confirmed initial hypotheses proposed by Capasso (1895) predicting its position to be in this sector. Aside from the reconstruction of the active periods of the harbor since its foundation, determined from pottery shards, two other discoveries were of interest to archaeologists. The first was the identification of traces of dredging directly visible at the bottom of the harbor. Concave and relatively deep grooves were identified in the volcanic substratum between −7.5 and −5.6 m below local mean sea level (lmsl) near the Piazza Municipio (Giampaola et al., 2006; Carsana et al., 2009). These dredging operations occurred between the end of the 4th c. and the 2nd c. BC and were intended to increase draft in order to counter siltation of the harbor. The second significant archaeological discovery in the ancient harbor of Naples were three Roman shipwrecks perfectly preserved in the harbor silt. These ships, dated to between the 1st and the 3rd c. AD, were found between −4.1 and −3.6 below lmsl (Giampaola et al., 2006, Giampaola, 2009; Carsana et al., 2009; Allevato et al., 2009, 2010).

Since its discovery in 2004, the study of the ancient harbor of Naples has been accompanied by geoarchaeological investigations that have revealed a sedimentary infill 15 m thick (−13 below lmsl to +2 m above lmsl) above the volcanic substratum (Amato et al., 2009). The depressions formed in the