



Petro-chemical features and source areas of volcanic aggregates used in ancient Roman maritime concretes



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ABSTRACT

We present and discuss data from petrographic observation at the optical microscope, electron microprobe analyses on selected glass shards, and trace-element analyses on 14 mortar aggregates collected at the ancient harbors and other maritime structures of Latium and Campania, spanning the third century BCE through the second CE, aimed at identify the volcanic products employed in the concretes and their area of exploitation.

According to Latin author Vitruvius assertion about the ubiquitous use of Campanian pozzolan in the ancient Roman sea-water concretes, results of this study show a very selective and homogeneous choice in the material employed to produce the concretes for the different investigated maritime structures, evidencing three main pumice compositions, all corresponding to those of the products of the post-Neapolitan Yellow Tuff activity of the Phlegraean Fields, and a systematic use of the local Neapolitan Yellow Tuff to produce the coarse aggregate of these concretes. However, mixing with local products of the Colli Albani volcanic district, located 20 km east of Rome, has been evidenced at two fishponds of Latium, in Punta della Vipera and Torre Astura. Based on these petrographic and geochemical data, we conclude that the selective use of pozzolan from Campania, rather than of unproved different chemical properties, was the consequence of a series of logistic, economic, industrial and historical reasons.

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1. Introduction

The selective use of volcanic aggregates (pozzolan) exploited in the surroundings of *Puteoli* (Pozzuoli), deriving from the products of the activity of Phlegraean Fields and/or Vesuvius for building maritime structures in ancient Roman times is stated by Latin author Vitruvius in the book *De Architectura*. This assumption has been so far verified on a limited number of mortar aggregates collected in the harbors of Cosa (Jackson et al., 2010), Ostiae (Port of Claudius) and Anxur (modern Terracina) (D'Ambrosio et al., 2015) by means of trace element signature and EMP glass analyses.

Vitruvius (1999) uses the term "*pulvis*" (powder) to describe the material occurring in the region of Baiae (a village few kms southwest of *Puteoli* on the coast of the homonymous gulf, see Fig. 1) and in the area around Vesuvius, which "mixed with lime and rock fragments not only confers strength to the constructions, but is capable to solidify under water" (*De Arch.*, 2. 6. 1). By contrast, he uses the definition of

"*harena*" (sand) for the material used to produce mortar to be used in mainland constructions, despite recognizing the same volcanic origin for both: (...) And thus, just in Campania scorched earth becomes ash, so in Etruria the cocked matter becomes *carbunculus*. [*Carbunculus*, which translates as "charcoal", is indeed one type of *harena fossicia* (pit sand) that has been identified (D'Ambrosio et al., 2015) as deriving from the pyroclastic-flow deposits erupted by the Vico and Monti Sabatini volcanic districts of Latium (Fig. 1)] "*Both of these are outstanding for constructions, but one works in buildings on land, while the other works as well for sea moles. (...) (De Arch., 2.6.6) (D'Ambrosio et al., 2015, and references therein)*. This latter feature characterizes the present "hydraulic mortar", as opposite to the "aerial mortar", which cannot set underwater. However, there is no solid reason to think that the pozzolan from Latium should have a different reaction with lime when setting underwater with respect to that coming from Campania. A broad literature shows that the "hydraulic property" is due to particular chemical reactions with lime of zeolite minerals occurring in the volcanic aggregate (pozzolanic reaction), which confer to a mortar the strong binding power and the hydraulic character (e.g.: Mertens et al., 2009, and references therein). Indeed, zeolites occur in all the volcanic pozzolan of central Italy, and not only Campania.

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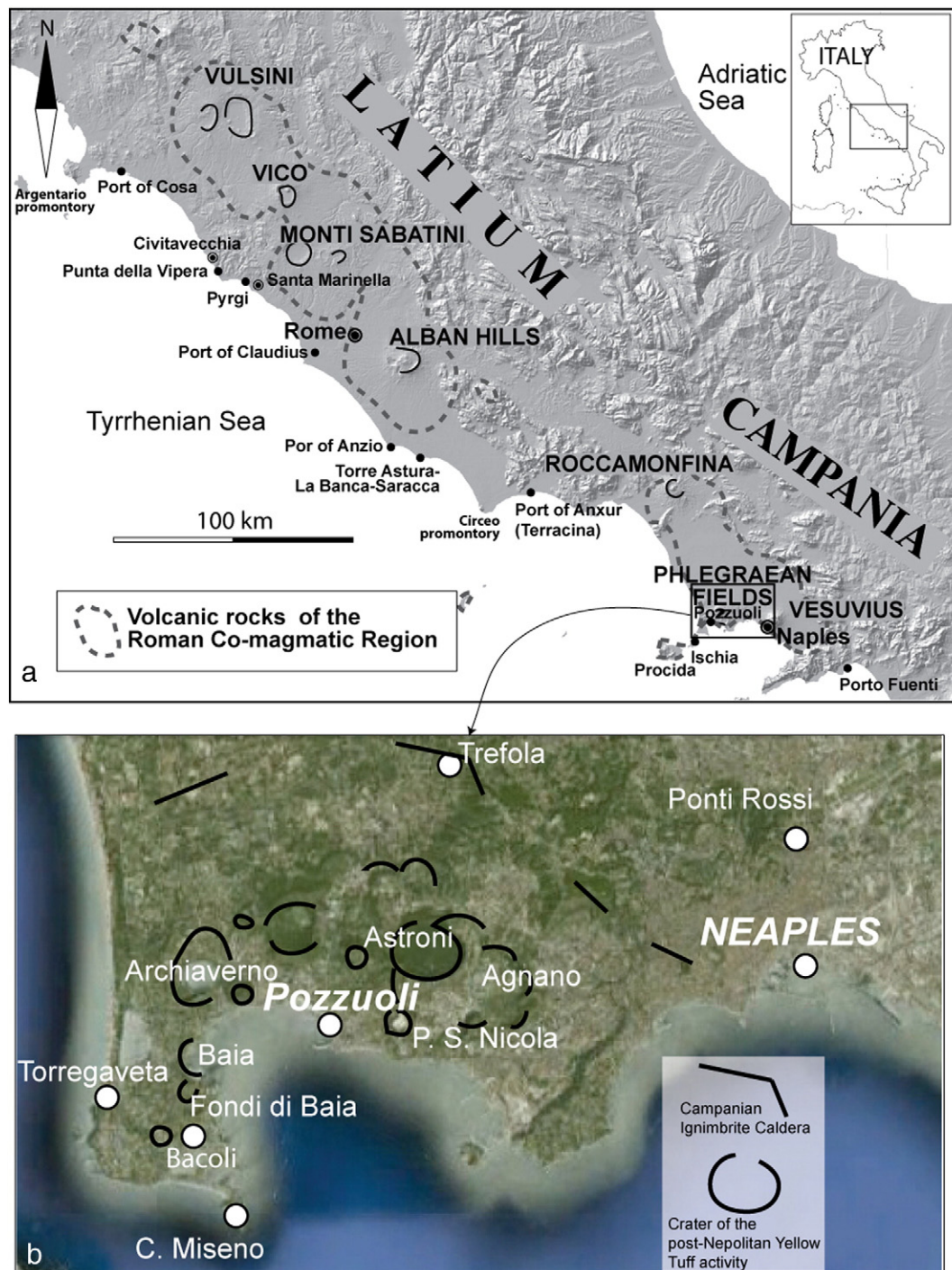


Fig. 1. a) Digital Elevation Map of central Italy showing location of the harbors and other maritime structures for which composition of the volcanic aggregate employed in the concrete has been investigated in the present study. The outcropping area of the volcanic products of the Roman co-magmatic Region (Peccerillo, 2005) is also shown. b) Detail map of the area of Pozzuoli, showing the main eruptive centers of the Phlegrean Fields volcanic activity.

D'Ambrosio et al. (2015) suggest that the selective use of pozzolan from Campania, rather than to unproved different chemical properties, may be due to a series of logistic and historical reasons. Regarding the different term used by Vitruvius for the Campanian pozzolan, *pulvis* as opposed to *harena*, after discarding the hypothesis of a finer grain size of the former, which is not supported by the study on the mortars of the Port of Claudius in Fiumicino and on the Port of Anxur (Terracina), D'Ambrosio et al. (2015) propose that the Latin author considered the whitish to light grey, high vesicular pumice clasts that make up most portion of the Campanian pyroclastic deposits as one particular, lightweight *harena fossicia*, based on

the use of the adjective "*laevis*" (light) referred to the *pulvis* (Vitr., *De Arch.*, 2.6.1.).

The present study is aimed to verify the extensive use of Campanian pozzolan to produce the maritime concretes in the Tyrrhenian Sea, which a vast literature has hypothesized to extend to the whole Mediterranean region (e.g. Oleson et al., 2004; Vola et al., 2011; Brandon et al., 2014), and to investigate the possible scientific, practical, and historical reasons. At this scope, in order to integrate previous literature data, we sampled and analyzed 14 mortar aggregates collected at the ancient harbors and other maritime structures built between the third century BCE and the first century CE in Punta della Vipera, Pyrgi, Torre

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