



At the origins of Pompeii: the plant landscape of the Sarno River floodplain from the first millennium BC to the AD 79 eruption

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Abstract

The AD 79 eruption of the Vesuvius severely affected the floodplain surrounding the ancient city of Pompeii, i.e. the Sarno River floodplain. The landscape was covered with volcanoclastic materials that destroyed the ecosystem but, at the same time, preserved the traces of former environmental conditions. This study provides—for the first time—a pollen sequence reconstructing the environmental evolution and the plant landscape of the Sarno floodplain between 900 and 750 cal BC and AD 79, i.e. before and during the foundation of the city, and during its life phases. Previous geomorphological studies revealed that the portion of the Sarno floodplain under the “Pompeii hill” was a freshwater backswamp with patchy inundated and dry areas. Palynology depicts a thin forest cover since the Early Iron Age, suggesting an open environment with a mosaic of vegetation types. The local presence of Mediterranean coastal shrubland, hygrophilous riverine forest and mesophilous plain forest is combined with the regional contribution of mountain vegetation through the sequence. Oscillations between inundated and wet ground characterized the studied area until the AD 79 eruption. Such a natural environment shows anthropogenic traits since pre-Roman times: pasturelands, cultivated fields and olive groves, which probably occupied drier soils. The most important change in the land use system was the introduction of cabbage cultivation in the fourth century BC and its intensification from the second century BC, when Roman influence grew. The presence of tree crops and of ornamental trees reveals the opulence of the Imperial age until the catastrophic eruption.

Keywords Pompeii · (pre-)Roman age · Pollen · Brassicaceae · Vesuvius

Introduction

The palynology of river floodplains is a powerful tool for the reconstruction of past vegetation and landscape evolution of these highly attractive environments for human

societies (Ejarque et al. 2015; Cremaschi et al. 2016; Pepe et al. 2016; Bosì et al. 2019). As floodplains have provided natural resources and productive lands for millennia, they can be seen as natural settings in which past societies left their clear imprint (Vitousek et al. 1997). The sedimentary records of such environments constitute pollen archives of historical events and provide a natural background to information gathered from, for example, written sources.

In the Vesuvius region (Campania, Italy) the floodplain of the Sarno River represents a crucial context for studying how human peopling left a mark on the fluvial ecosystem. This territory was occupied since prehistory thanks both to its strategic position, amidst terrestrial, fluvial and marine trading routes of the Italian Peninsula, and to the fertility of its volcanic soils (Cicirelli and Livadié 2012). In particular, it was chosen by Italic populations such as Etruscans, Greeks, and Romans throughout the first millennium BC. In AD 79 the whole floodplain was buried by pyroclastic deposits of the explosive volcanic eruption of Vesuvius, a

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circumstance that allowed for the perfect preservation of the palaeo-landscape (Luongo et al. 2003). Thanks to this exceptional process of burial, no archaeological site in the world has had a higher resonance than Pompeii and the ancient towns and villages nearby that were impacted by the catastrophic eruption. Nonetheless, even if the Sarno River plain has been studied by several authors (see Nicosia et al. 2019 and references therein) no vegetational reconstruction has yet been provided for the pre-AD 79 environment, apart from the non-systematic data from the Iron Age village of Longola di Poggiomarino, ca. 10 km NE of Pompeii (Cicirelli and Livadie 2012). In this perspective, the area between the southern scarp of the so-called ‘Pompeii Hill’, the Roman coastline, and the Sarno River palaeo-channel has a high relevance for investigating the plant landscape of the ancient floodplain.

In the past decades, a combination of ancient written sources, archaeological and archaeobotanical data and geoarchaeological investigations produced a picture of many aspects of the natural environment around and within Pompeii. While data concerning the earlier centuries are still rare, particularly for the portion of the floodplain immediately south of the city, the two last centuries of existence of Pompeii are better understood. In Roman times large parts of the arable plain seem to have been occupied by villas and farmsteads (Vogel et al. 2015; Pellegrino 2017) devoted to the cultivation and processing of cereals, grapes and, to a much lesser extent, olives (De Simone 2017). The countryside was also interspersed with trees and plants typical of the Mediterranean climate and, in the south-eastern territory of Pompeii, of wet environments (Ciarallo 2002). Eventually, within and around the urban perimeter, gardens were cultivated for both aesthetic and utilitarian reasons (horticulture) (Jashemski et al. 2002). The palynological research carried out in the Casti Amanti building complex identified for example fruit trees, such as olive and grapevine, and ornamental plants, such as rose and juniper (Ciarallo and Mariotti Lippi 1993; Mariotti Lippi 1998).

Looking specifically at the pollen studies carried out so far in the surroundings of the ancient city and in the Sarno River plain, preliminary palynological evidence has been reported by Vogel and Märker (2011). At the regional level, past vegetation data covering the Late Holocene are available from different natural and archaeological sites of the nearby areas and consist of:

- (a) The settlement of Longola di Poggiomarino in the upper part of the Sarno River plain, where marsh vegetation prevailed with deciduous oak-dominated forest and cultivated areas far from the site during the Iron Age (Di Maio et al. 2012);
- (b) A marine core (C106) in the Gulf of Salerno (Di Donato et al. 2008) with an environmental setting typi-

cal of a coastal river plain with riparian and mesophilous vegetation, Mediterranean plants with *Pinus* and synanthropic indicators;

- (c) The archaeological site of Pontecagnano (first millennium BC) in the Sele River plain, where grapevine and walnut were intensively cultivated since the sixth century BC (Russo Ermolli et al. 2011);
- (d) The *Neapolis* harbour, the pollen sequence of which (1st century BC to 5th century AD) records tree and herb crops around the Graeco-Roman city, Mediterranean plants in the rocky zones and in the narrow coastal plain, and deciduous oak forest on the surrounding slopes (Russo Ermolli et al. 2014);
- (e) The coastal lagoon of *Literna Palus* (Lago Patria) in the Volturno Plain, surrounded by a mixed deciduous and evergreen forest with local exploitation of olive, grapevine, walnut, and chestnut from the eighth century BC (Di Rita et al. 2018);
- (f) The lacustrine core of Lago d’Averno south of *Literna Palus*, where the connection of the basin with the Roman harbour in 37 BC is testified by the appearance of *Pinus*, *Platanus* and *Castanea* pollen (Grüger et al. 2002).

The present-day landscape of the Sarno River floodplain is one of the most intensely exploited and populated of Italy, a circumstance that left no place for the natural vegetation. For this reason, our natural knowledge of the millennium preceding the AD 79 eruption is quite scarce, and the environment at the dawn and at the rise of Pompeii is still a mystery. The present study relies on new pollen data collected from two cores studied by Nicosia et al. (2019). New radiocarbon dates have been obtained in order to build a more robust chronological framework for the environmental changes highlighted by palynology, such as modifications induced by both land use and natural processes. The aims of our research are:

- (1) Build a vegetation proxy of the lower Sarno River plain, before and after the foundation of Pompeii;
- (2) Provide a landscape reconstruction that combines palaeoenvironmental, geomorphological, and archaeological data in order to evidence the impact of human occupation in the floodplain from the first millennium BC to AD 79.

The geomorphological setting

The Sarno River floodplain occupies the southern portion of the ‘Piana Campana’ coastal graben (Fig. 1). The ancient city of Pompeii overlooks the western, terminal, portion of this floodplain as it is set higher up, on the remains of a volcanic relief referred to as the ‘Pompeii Hill’. Its scarps

were modelled into steep cliffs during the maximum flooding stages of the postglacial transgression (Cinque and Russo 1986; Cinque 1991; Pescatore et al. 2001). The gradual coastal progradation from ca. 5,600 cal BP (Barra et al. 1989), marked by three relict dune ridges, is summarized in Nicosia et al. (2019). Still, there is no consensus on the exact morphology of the coast and the position of the Sarno River mouth at that moment (see Fig. 6 in Pescatore et al. 1999; Stefani and Di Maio 2003; Fig. 2 in Vogel and Märker 2010; Vogel et al. 2011 and references therein). A tentative reconstruction of the progradation of the coastline from the mid-Holocene maximum flooding stage to the present day is provided in Fig. 1. During the Roman period, the Sarno River followed a meandering pattern similar to that which existed up to the point of artificial straightening in 1858 (Pesce 1996; Stefani and Di Maio 2003; Visone 2004).

Recently, an investigation by Nicosia et al. (2019; see also Furlan et al. 2019) has accurately depicted the southern portion of the ancient *suburbium* of Pompeii (Fig. 10 in Nicosia et al. 2019). The area that was investigated by means of mechanical cores is delimited by the ‘Pompeii Hill’ to the north and east, by the Bottaro-Pioppaino ridge (already in place before 900–750 cal BC, Nicosia et al. 2019) towards the sea, and by the Sarno River to the south. Based on these cores, drilled along a N-S transect, it was possible to rule out the hypothesis of an old Sarno River branch flowing at

the base of the ‘Pompeii Hill’. Also, the idea of an artificial basin that could host a harbour found no sedimentological evidence. Nicosia et al. (2019) put in evidence, through combined sediment and microfossil analysis, that this area was a freshwater backswamp with a mosaic of inundated and dry areas at least from 900 to 750 cal BC, and that these conditions persisted until the AD 79 eruption (in line with the reconstructions of Fig. 3 in Barra et al. 1989; Fig. 10 and Table 4 in Furnari 1994; Pescatore et al. 2001; Stefani and Di Maio 2003). Prior to this interval, the diatom study in Nicosia et al. (2019) showed the evolution from a brackish (i.e. planktonic) to a paralic environment in response to the late Holocene progradational trend, but these facies are not yet dated with precision. This scenario places the study area well in line with the marginal portions of a meandering river floodplain (see also Barra et al. 1989; Furnari 1994; Pescatore et al. 2001; Vogel and Märker 2011).

Furthermore, the micromorphological study of sediments in Nicosia et al. (2019) highlighted the periodic input of fall-out volcanic products in the 900–750 cal BC to AD 79 interval (i.e. presence of armoured pyroclasts and pisoliths). This is possibly correlated with the four inter-Plinian eruptions of Vesuvius (named AP 3, 4, 5, 6—with ‘AP’ standing for ‘Avellino-Pompeii’) that occurred within the studied interval (see Table 1 in Santacroce et al. 2008; Di Vito et al. 2013; Fig. 2 in Senatore et al. 2014).

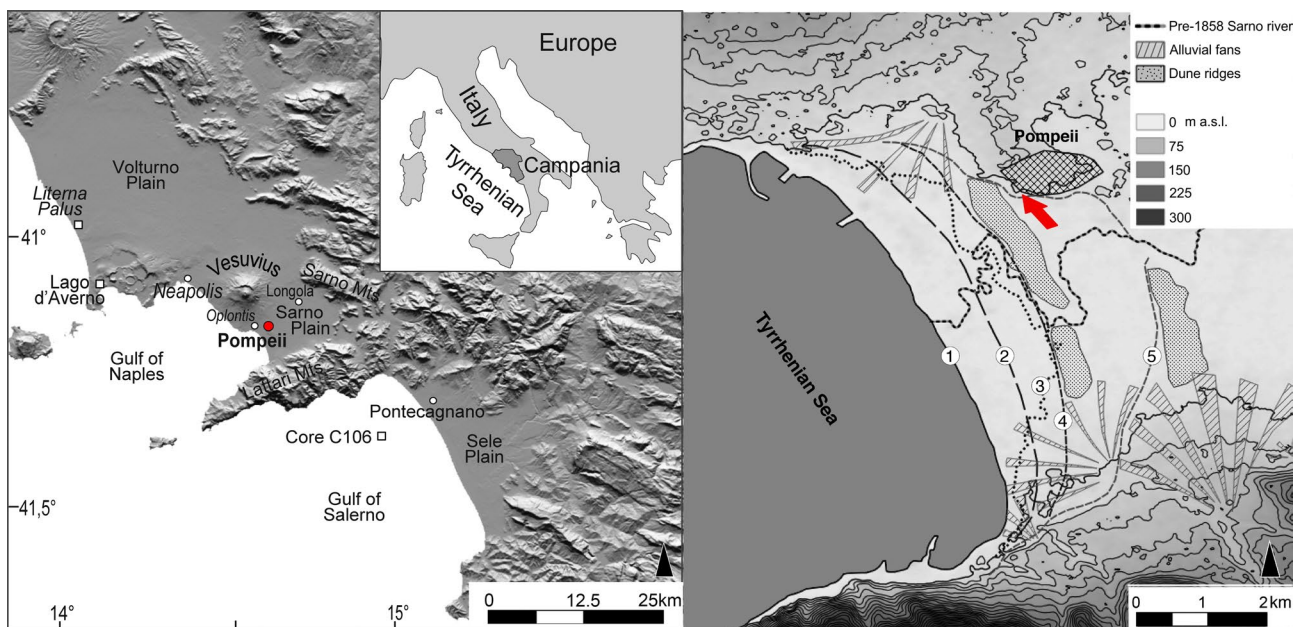


Fig. 1 Left: DEM of the Campania region with position of archaeological sites (circles) and natural sequences (squares) with pollen data discussed in the text. Right: Geomorphology of the distal part of the Sarno River plain: (1) Present-day coastline; (2) 1st century AD coastline according to Cinque and Russo (1986); (3) 1st century AD coastline according to Vogel et al. (2011), Stefani and Di Maio (2003), and Senatore et al. (2014); (4) 3,600–2,500 cal BC coastline

(Cinque 1991); (5) Coastline around 4,500 cal BC (Cinque 1991). Sandy dune ridges and alluvial fans based on: Carta Geomorfologica d’Italia 1:50.000 sheets n° 466–485 ‘Sorrento-Termini’ and on Vogel and Märker (2010). The course of the Sarno River before its artificial diversion in 1858 is based on Pesce (1996). The arrow indicates the position of coring site (see Fig. 2). Modified from Nicosia et al. (2019)

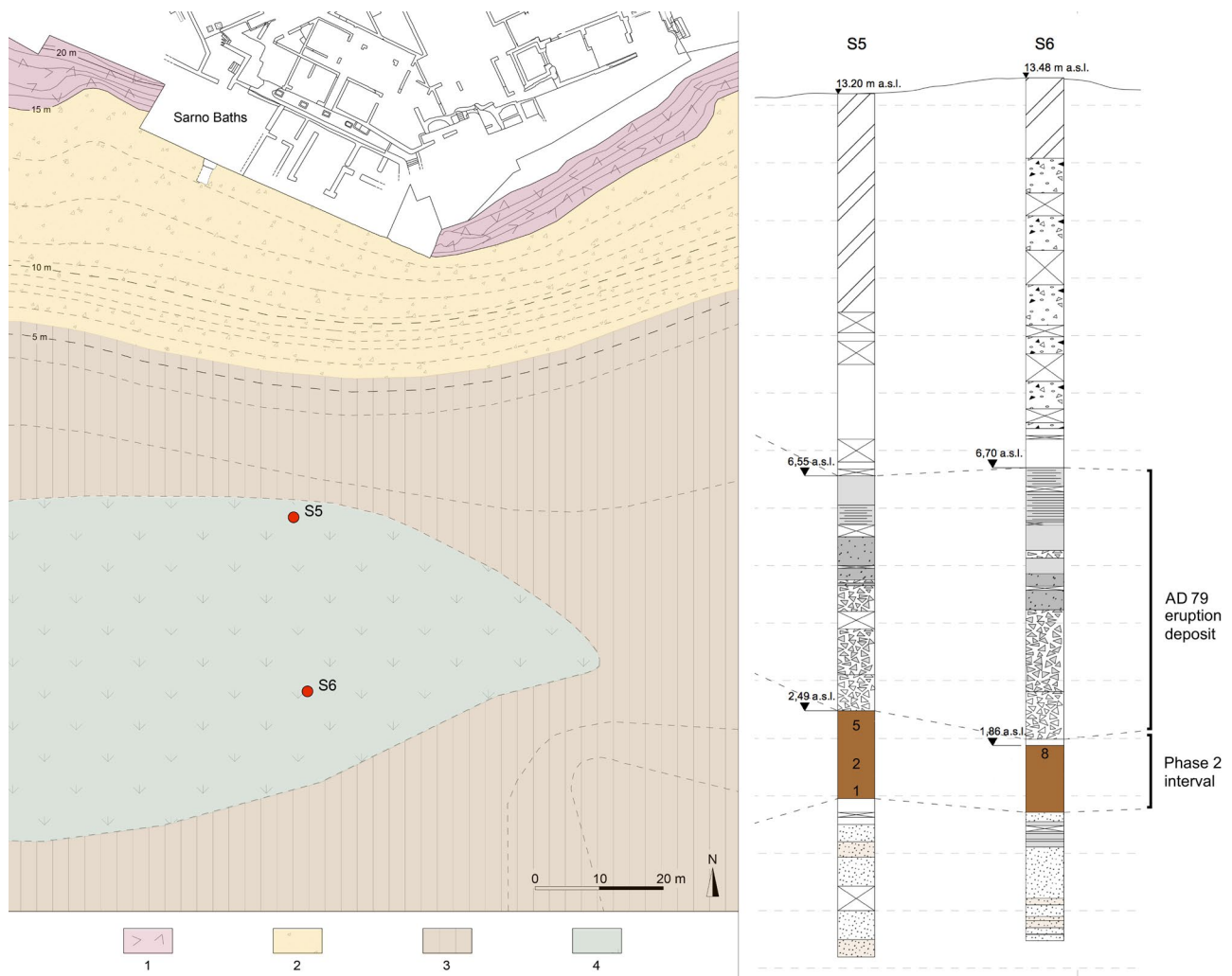


Fig. 2 Left: location of cores S5 and S6 in the southern *suburbium* of Pompeii and reconstruction of the surface characteristics of the area. 1—“Pompeii Hill” cliff, 2—refuse area, 3—soil, 4—area with stagnating shallow waters. Right: simplified stratigraphic logs of cores S5

and S6. Numbers 1, 2, 5, 8 within the Phase 2 interval refer to the dated samples considered in this paper (see Table 1). Modified from Nicosia et al. (2019)

The archaeological setting

The reconstruction of the human presence and activities in proto-historical and historical times within the study area and, more broadly, in the distal trait of the Sarno River floodplain is hampered by the thick AD 79 volcanic sediment cover. Given the great depth at which archaeological sites are buried and the present-day high urban density preventing widespread archaeological surveys, the occupation pattern evolution cannot be reconstructed with full accuracy.

The investigation of the site of Longola di Poggiomarino, carried out from the early 2000s, showed how the wet environment of the upper Sarno River valley was exploited from the Early Iron Age to the Archaic period (Cicirelli and Livadie 2012). At the same time, the scarce archaeological

evidence recorded on the Pompeii plateau seems to suggest that the area was then still poorly settled.

The 6th century BC represents a turning point in the occupation of the whole region. While the site of Longola is being definitely abandoned, the Pompeii plateau is shaped as an urban centre. Although the presence of an earlier *Altstadt* and the ethnicity of the groups contributing to the first development of the site (Etruscans, Greeks, Oscans) are still matter of debate, in-depth excavations demonstrated that the entire plateau had been settled and spatially organized since then (Fulford et al. 1999). Notably, the whole area was surrounded by city walls and two major sanctuaries were erected in its south-western sector. In the fifth century BC a period of crisis seems to affect the development of the city. This is when literary sources indicate the arrival of Samnite peoples, who steadily occupied

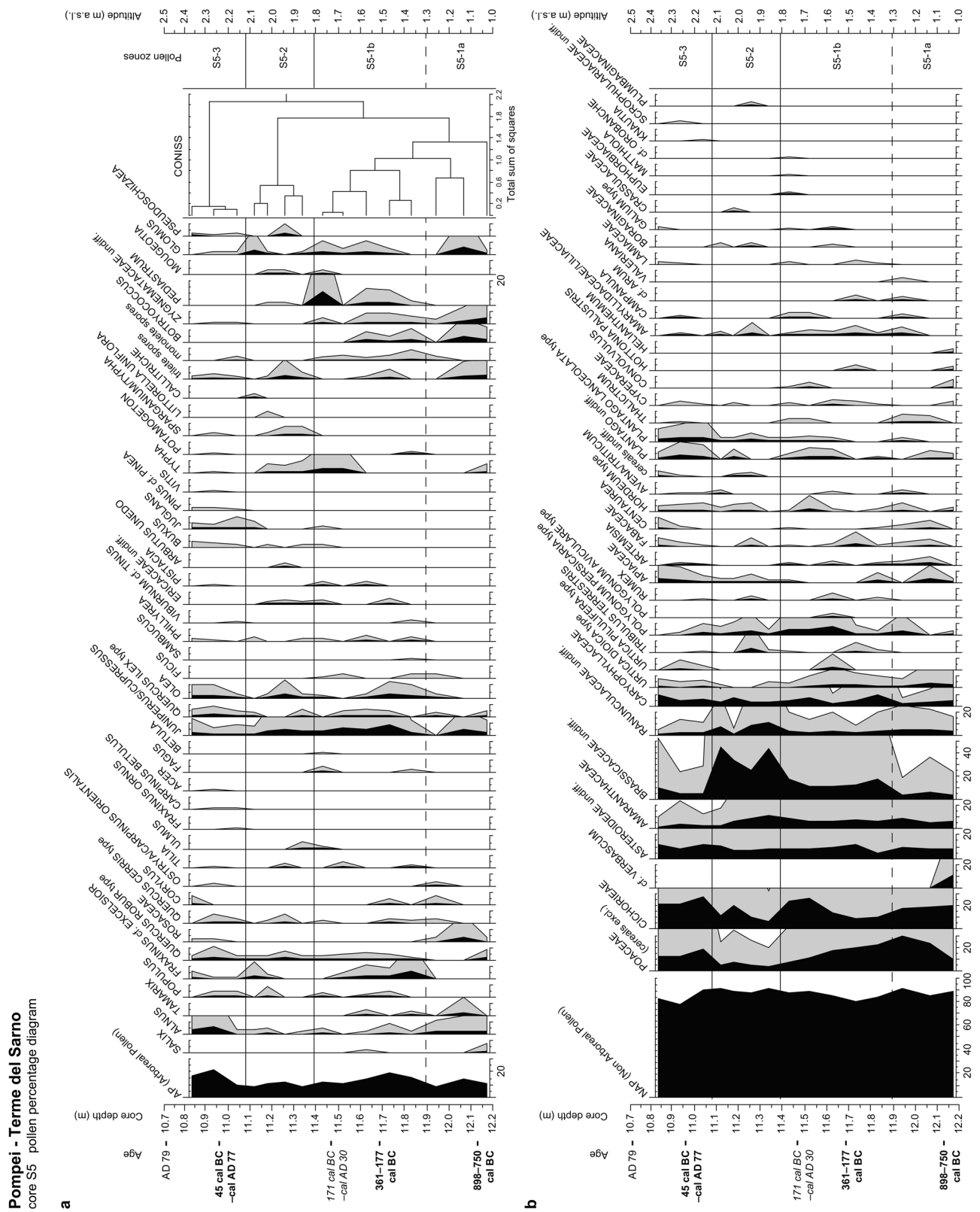


Fig. 3 Pompei—Terme del Sarno, core S5. Pollen percentage diagram with CONISS. Curve magnification 5X. Selected radiocarbon dates (the most probable interval within 95% confidence level is shown) and the bottom of AD 79 eruption deposits are reported on the left

Table 1 Radiocarbon dates from cores S5 and S6 obtained in 2019 (see Nicosia et al. 2019) and 2021

Core	Sample ID	Lab code	Year	Core depth (m)	Altitude (m a.s.l.)	¹⁴ C-date (BP)	Δ ¹³ C (‰)	Cal. age (BC)	
								1σ-range	2σ-range
S5	1	LTL17482A	2019	ca. – 12.13	ca. 1.07	2614 ± 45	– 24.1 ± 0.5	826–774	898–750 (88.8%) 684–668 (2.1%) 638–590 (4.5%)
S5	2	Beta-564502	2021	– 11.68	1.52	2190 ± 30	– 24.0	356–286 234–198	361–177
S5 ^a	3	Beta-564501	2021	– 11.48	1.72	2210 ± 30	– 26.0	260–206 320–275 359–347	371–199
S5 ^a	4	LTL17481A	2019	– 11.28	1.92	2199 ± 45	– 22 ± 0.5	358–280 (40.5%) 257–202 (27.7%)	387–164 (95%) 127–123 (0.4%)
S5	5	Beta-564500	2021	– 10.95	2.25	1980 ± 30	– 26.1	2 BC–AD 6021–11	45 BC–AD 77
S5 ^a	6	LTL17480A	2019	– 10.91	2.29	2209 ± 45	– 24.2 ± 0.1	360–343 (8.7%) 325–271 (28.6%) 263–205 (30.9%)	387–173
S6 ^a	7	LTL17485A	2019	– 12.50	0.98	2314 ± 45	– 25.1 ± 0.5	412–357 (55.9%) 282–257 (9.9%) 244–236 (2.4%)	511–350 (71.5%) 311–209 (23.9%)
S6 ^a	8	LTL17484A	2019	– 12.21	1.27	2229 ± 45	– 28.9 ± 0.6	370–350 (10.9%) 310–209 (57.3%)	394–197
S6	8	LTL17483A	2019	– 11.74	1.74	2045 ± 40	– 23.6 ± 0.5	111 BC–AD 5	171 BC–AD 30 (93.1%) AD 37–51 (2.3%)

OxCal v. 4.3.2, curve IntCal 13; Bronk Ramsey 2017, Reimer et al. 2013

^aRedundant dates or dates probably affected by issues such as old wood effect, residuality and mixing, discarded from analysis

the city and its territory. During the following decades Pompeii gradually recovers from the crisis and enters the political sphere of influence of Rome. Still, only after the Hannibalic war (i.e. the Second Punic War, 218–201 BC) the city witnesses a substantial demographic, economic, and monumental development, also heavily shaping the surrounding landscape.

The Social war (91–87 BC) and the later foundation of the Sullan colony seem to have affected the composition of the local elite. Still the latter is thought to have invested most of its resources in estates in the countryside and in commercial and craft activities (Savino 1998). Major public buildings are also erected in this period and the most important second century BC *domus* are substantially refurbished.

The early Imperial age involved a further adaptation of the monumental aspect of the city, namely with the construction of buildings devoted to the imperial cult. This phase of development underwent a sudden interruption due the AD 62–63 earthquake. Eventually, most of the necessary repairs had already been carried out in AD 79, when the city was impacted by the eruption of Vesuvius.

Materials and methods

Ten sediment cores were described by Nicosia et al. (2019) and Furlan et al. (2019) just outside the southern city walls, in correspondence with the façade of the Sarno Baths complex. Cores S5 and S6, ca. 23 m and 50 m away from the façade (Fig. 2), are 15 m deep and intercept the interval (termed Phase 2 in Nicosia et al. 2019) that represents the style of the sedimentation in this portion of the Sarno River floodplain before the burial by the AD 79 eruption. This interval has been selected for palaeoenvironmental investigations with pollen analyses and new radiocarbon dates (this paper) integrating the sedimentological, micromorphological, and diatom analyses published in Nicosia et al. (2019).

Pollen analysis was carried out on 16 sediment samples taken from core S5 (Phase 2 interval, 10.84–12.38 m relative depth = 2.36–0.82 m a.s.l.) and 13 samples from core S6 (Phase 2 interval, 11.59–12.08 m relative depth = 1.89–1.40 m a.s.l.).

Samples of ca. 2–3 g of dry sediment were processed with cold HCl (37%), cold HF (40%) and hot NaOH (10%) (Fægri and Iversen 1989, modified) in order to remove calcium carbonate, silica and humic acids respectively. An additional physical treatment was applied to the residues by using an Ultrasonic Bath equipped with a 10 μm sieve in order to remove supplementary hydrothermal minerals and organic

materials. *Lycopodium* spores were added in order to estimate pollen, NPPs (non-pollen palynomorphs) and micro-charcoal concentration (Stockmarr 1971). The pollen identification is based on atlases (Reille 1992, 1995) and reference collections. Following Smit (1973), pollen of *Quercus* species has been morphologically divided into three groups: *Q. robur*-type, the deciduous oaks; *Q. cerris*-type, the semi-deciduous oaks including also the evergreen *Q. suber* (cork oak); *Q. ilex*-type, the evergreen oaks (cork oak excluded). Rosaceae refers only to the tree species belonging to this family (i.e. *Crataegus*, *Prunus*, *Sorbus*). Among Cupressaceae, *Juniperus* and *Cupressus* are not distinguished. As to *Pinus*, the identified pollen is tentatively ascribed, based on size and morphology of the grains, to *Pinus* cf. *pinea* (Roure 1985). Following Andersen et al. (1979), the identified cereals are *Avena/Triticum* and *Hordeum*-type; Cereals undiff. group includes all those pollen grains whose measurements were not feasible due to collapse and deformation. Among Brassicaceae, the crop species can be identified on the basis of pollen morphology as reported by Russo Ermolli et al. (2014). Cichorieae represents the only European tribe of the Asteraceae family with fenestrate pollen grains (Florenzano et al. 2015).

The pollen percentage diagrams have been drawn using different pollen and spore basis sums (i.e. terrestrial spermatophytes, aquatic angiosperms, ferns, algae, fungi; Berglund and Ralska-Jasiewiczowa 1986) by means of the TILIA program (Grimm 1992). All arboreal and non-arboreal pollen taxa with values higher than 2% of the pollen based sum were used for the CONISS cluster analysis (Grimm 1992). A significant number of charcoal particles were also counted from pollen slides in order to evaluate the fire impact on past landscapes (Sadori and Giardini 2008). Data are also presented as concentration values, together with synthetic records for total terrestrial and aquatic plants, ferns, algae, fungi and *Pseudoschizaea*.

Chronology

The chronology of the Phase 2 interval was established in 2019 with AMS radiocarbon dates from handpicked charcoals. This allowed us to ascribe the studied sequence to a period ranging from the Early Iron Age to AD 79, the latter date clearly marked by the onset of pyroclastic deposits.

With respect to the radiocarbon dates originally employed in Nicosia et al. (2019), performed at the University of Lecce (Italy), three additional dates were obtained from core S5. These additional samples were sent to Beta Analytics (USA). Dates were calibrated using the software OxCal v. 4.3.2 (Bronk Ramsey 2017) with IntCal 13 atmospheric data (Reimer et al. 2013).

Table 1 incorporates the results of each radiocarbon analysis performed, together with sample depth.

As a whole, the redundancy of some dates and factors such as old wood effect, residuality, mixing and erosional processes in fluvio-palustrine environments (Morin et al. 2014; Sadori et al. 2016) seem to have affected the results.

This led us to reject redundant dates and to incorporate in the S5 pollen diagram one date from core S6, relying on stratigraphic and topographic correlations between the Phase 2 interval in the two adjacent cores (Nicosia et al. 2019, Fig. 3). Bayesian statistical processing proved of little help, given the quality and quantity of available data (Bronk Ramsey 2009). The results suggested a cautious approach and the main zones highlighted by pollen analysis (see paragraph 5.2) were therefore labelled with rather generic chronological periods:

- Zone S5-1a: first half of the first millennium BC;
- Zone S5-1b: Hellenistic Age;
- Zones S5-2, 3: Roman Age.

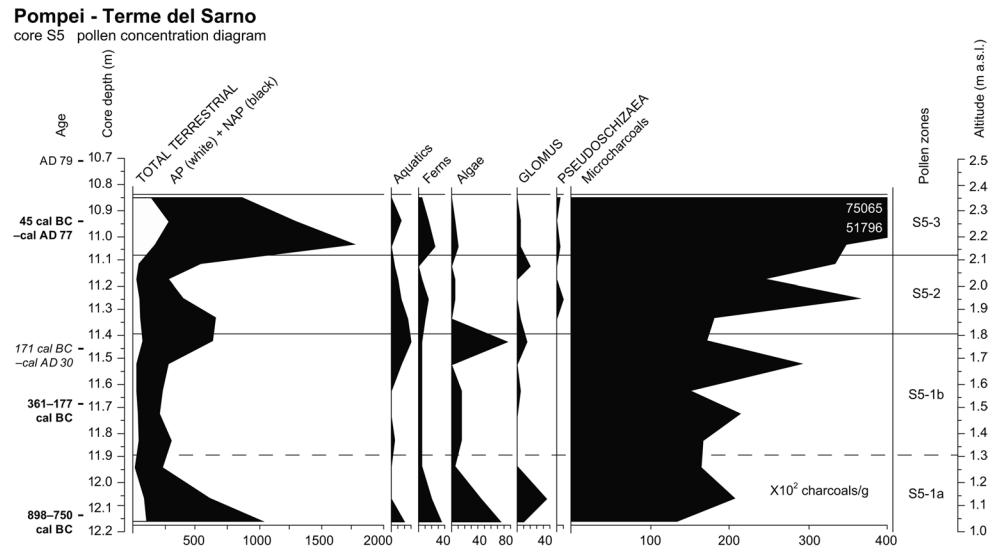
Since it was not possible to establish a reliable age-depth model, the pollen diagrams were drawn against depth and the accepted calendar dates indicated on the side. The correlation between the two pollen records is based on radiocarbon dates and plant assemblages (i.e. pollen zones) but each core is presented and discussed separately.

Results

In core S5 the pollen grain preservation is rather variable among samples; the number of indeterminate (degraded and broken) grains spans between 5 and 15% of the pollen basis sum. The pollen concentration is very low and spans between ca. 200 and 1,700 pollen grains/g. The mean count of terrestrial spermatophyte pollen is 207 grains/sample. A total of 77 taxa (including 31 arboreal, 40 herbaceous and 6 aquatic taxa) has been identified. NAP (non-arboreal pollen) is significantly dominant over arboreal pollen (AP). The most abundant taxa are Brassicaceae, Cichorieae and wild Poaceae among herbs and *Juniperus*, *Alnus*, *Olea* and *Fraxinus* cf. *excelsior* among trees. Pollen data, plotted as percentage and total concentration values, are shown in Figs. 3 and 4. To facilitate the description of the core, three pollen zones (S5-1 to 3) have been distinguished with the support of statistical analysis. In Fig. 5, pollen taxa have been tentatively grouped on the basis of their ecological and economic values. *Pinus* cf. *pinea*, *Buxus* and *Olea* curves are presented separately. Amaranthaceae, Fabaceae and Rosaceae families have been excluded from grouping due to the presence of both cultivated and wild species.

In core S6, most samples were barren or very poor in pollen. The low number of identified pollen grains prevented

Fig. 4 Pompei—Terme del Sarno, core S5. Pollen and charcoal concentration diagram. Selected radiocarbon dates (the most probable interval within 95% confidence level is shown) and the bottom of AD 79 eruption deposits are reported on the left



Pompei - Terme del Sarno
core S5 pollen percentage diagram of plant groups

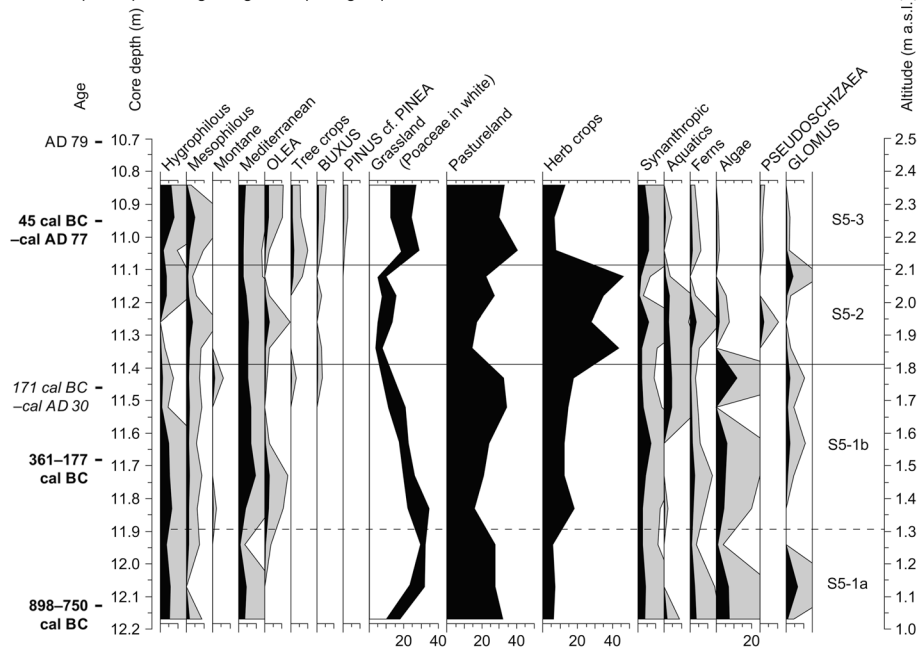


Fig. 5 Pompei—Terme del Sarno, core S5. Pollen percentage diagram of plant groups and NPPs. Hygrophilous: *Alnus*, *Corylus*, *Fraxinus* cf. *excelsior*, *Populus*, *Salix*, *Tamarix*; Mesophilous: *Acer*, *Carpinus betulus*, *Fraxinus ornus*, *Ostrya/Carpinus orientalis*, *Quercus cerris*-type, *Q. robur*-type, *Tilia*, *Ulmus*; Montane: *Betula*, *Fagus*; Mediterranean: *Arbutus unedo*, Ericaceae undiff., *Juniperus/Cupressus*, *Phillyrea*, *Pistacia*, *Quercus ilex*-type, *Viburnum* cf. *tinus*; Tree crops: *Juglans*, *Vitis*; Grassland: Amaryllidaceae/Liliaceae, Api-

aceae, *Artemisia*, Boraginaceae, Caryophyllaceae, *Helianthemum*, *Knautia*, Lamiaceae, *Plantago* undiff., Poaceae; Pastureland: Asterioideae undiff., Cichorieae, *Rumex*; Herb crops: *Avena/Triticum*, cereals undiff., Brassicaceae, *Hordeum*-type; Synanthropic: *Polygonum aviculare*-type, *Plantago lanceolata*-type, *Tribulus terrestris*, *Urtica dioica*-type, *U. pilulifera*-type. Selected radiocarbon dates (the most probable interval within 95% confidence level is shown) and the bottom of AD 79 eruption deposits are reported on the left

the application of the CONISS analysis and the distinction of robust pollen zones. Although the results have weak statistical value, they show a general agreement with those of S5 for both the pollen assemblages and the landscape setting they suggest. Concentration values in core S6 range between

ca. 100 and 1,600 pollen grains/g. Only percentage values have been plotted (Fig. 6). The number of indeterminate pollen grains exceeds 20% of the pollen basis sum. The list of pollen taxa amounts to 22, including eight arboreal and 14 herbaceous ones.

Zone S5-1 (12.17–11.39 m) covers half the record and is characterized by herbs (NAP: 80.7–91.9%), low pollen concentration (219–916 pollen grains/g) and a high number of taxa (63). The zone is divided in two sub-zones.

Sub-zone S5-1a (12.17–11.88 m; first half of the first millennium BC) is mainly dominated by Poaceae and Cichorieae (max. 28.9 and 23.2% respectively), whereas Rosaceae (max. 4.3%), *Alnus* (max. 3.6%), *Tamarix* (2.9%) and *Juniperus* (max. 4.3%) prevail among trees and shrubs. Ferns are represented mainly by trilete spores (max. 3.4%), whereas the algae refer to *Botryococcus* (max. 4.1%) and Zygnemataceae undiff. (max. 5%). *Glomus* (max. 6.7%) has also been identified among fungal remains.

Sub-zone S5-1b (11.88–11.39 m; Hellenistic age) is characterized by the decrease of *Alnus* (max. 1.8%) and the appearance of *Fraxinus* cf. *excelsior* (max. 5.5%), and is also noteworthy for the presence of *Populus* (max. 0.9%); sparse grains of *Fagus* (0.9%) and *Betula* (0.3%) are recorded only in this subzone, *Buxus* (0.6%) and *Juglans* (0.6%) start their curve in the top sample. *Juniperus* (max. 7.9%) and *Olea* (max. 2.6%) are present through the sequence. Poaceae constantly decrease to a minimum of 7.7%, while Brassicaceae (17.8%) show an increase from the bottom of the zone. Ferns (trilete and monolete spores: max. 1.7%) and *Glomus* (2.2%) are always present and a significant increase of water plants (see *Typha*, max. 4.3%) is recorded. Among algae, *Pediatrum* (max. 10.3%) prevails.

In zone S5-2 (11.39–11.08 m; Roman age) herbs are always dominant (NAP: 87.5–91.7%), pollen concentration

is still low (289–656 pollen grains/g) and the total number of taxa decreases (38).

The most important taxon is Brassicaceae, whose percentage reaches 45.1%, whereas *Olea* slightly increases to 2.9%. Apart from the abundance of trilete spores (max. 3.5%), the increasing variability of water herbs is noteworthy: *Typha* (max. 2.1%), *Sparganium/Typha* (max. 1.6%), *Littorella uniflora* (1.1%), and *Callitriche* (0.7%) have been identified. *Pseudoschizaea* (2.2%) appears and is still present in the following zone.

Finally, in zone S5-3 (11.08–10.84 m; pre-AD 79 Roman age) herbs reach the lowest value of the whole sequence (NAP: 78.4–90.1%), pollen concentration has the highest value (866–1,753 pollen grains/g), and the total number of taxa is 52.

Poaceae and Cichorieae increase again (max. 18.8 and 28% respectively), together with the rapid decrease of *Fraxinus* cf. *excelsior* (min. 0.2%) and the increase of *Alnus* (max. 6.7%). *Pinus* cf. *pineae* (max. 0.5%) and *Vitis* (0.2%) appear for the first time, while *Juglans* (max. 1.9%) and *Buxus* (max. 1.1%) are present from the end of zone S5-1. *Olea* reaches 2.1%. Among NPP remains, ferns (trilete and monolete spores: max. 0.9%), *Glomus* (max. 0.5%), and *Pseudoschizaea* (max. 0.5%) are poorly represented. Microcharcoals reach the highest concentration values at the top of the core: more the 75,000 micro-fragments were calculated (Fig. 4).

Core S6, despite a lower variability of taxa (max. total number: 21), shows the presence of significant plants such as *Juglans*, *Pinus* cf. *pineae* and *Vitis*. While the first two

Pompei - Terme del Sarno
core S6 pollen percentage diagram

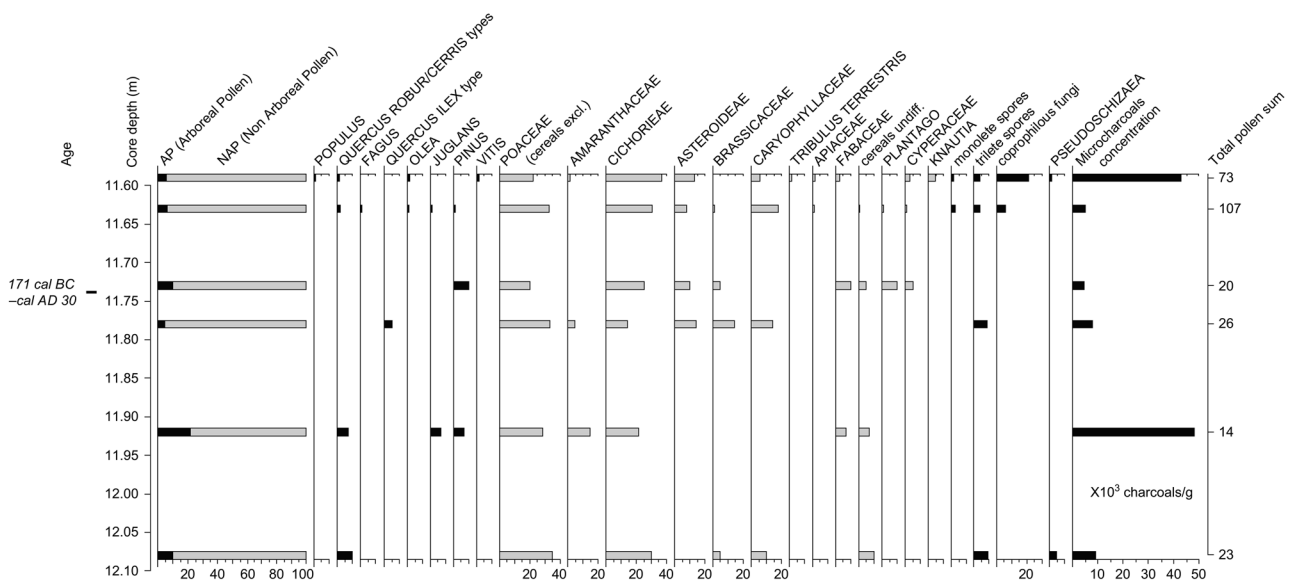


Fig. 6 Pompei—Terme del Sarno, core S6. Pollen percentage diagram

taxa are present before the suggested age of 171 cal BC-cal AD 51, the latter appears in the most recent sample below the AD 79 volcanic deposit. Such an occurrence, in addition to the percentage values of Brassicaceae, suggests a strong resemblance to zones S5-1b to 3 of the main core. The identification of many coprophilous fungi at the very top of the core is also remarkable (max. 21.2%, Fig. 6).

Discussion

The pollen sequence begins in the Iron Age and records the plant landscape evolution in the floodplain between the Pompeii plateau, the river and the sea for ca. eight centuries. The low forest cover depicts a local, open environment, highly impacted by human activities. This environment shows features of relict wet woodland which is a typical natural vegetation of Tyrrhenian coastal plains (Di Rita and Magri 2012; Pepe et al. 2013; Bellotti et al. 2016; Russo Ermolli et al. 2018). The maxima AP values are found in S5-1b and S5-3 (Fig. 3: 21.6 and 19.3% respectively), indicating the local presence of Mediterranean coastal scrubland and hygrophilous riverine forest. A regional contribution, even if minor, to the pollen rain from nearby mountains cannot be ruled out. Major palynological differences through the sequence are due to hydrological changes, land use and cultural developments, although no clear evidence of the establishment of the ancient city could be identified. Accordingly, NAP values show the relevant presence of Brassicaceae, Cichorieae and Poaceae. Hygro- and hydrophilous herbs, ferns and algae are always present, even if showing a decreasing trend towards the top of the core. The alternate role (both in time and space) of riparian forest, wet meadows, vegetable gardens and pastures might have been influenced by river dynamics or by economic choices of the inhabitants of the area, either Roman Pompeians or their predecessors.

Environmental changes in the Sarno River floodplain

Pollen data are giving some insight into the environmental changes that occurred in the Sarno River floodplain in interaction with erosional phases, groundwater fluctuations and river flow variations. All these factors can account for the very low pollen preservation recorded all through the analysed sequences. The mobilization of sediments from the catchment of the Sarno River is testified by the occurrence of mycorrhizal fungi (*Glomus*) and *Pseudoschizaea*, a microfossil derived from a green alga (Scott 1992). These are mobilized with soil deposits after intense rainfall events (De Vita and Piscopo 2002; Zanchetta et al. 2004). The periodic input of sediments in the floodplain could be a contributing cause to the low concentration of pollen.

In the first half of the first millennium BC (zone S5-1a), a humid environment characterized the floodplain (Fig. 5). In particular, the first sample is characterized by hygro- and hydrophilous taxa, trees such as *Alnus* and *Salix* and herbs such as *Hottonia palustris*, Cyperaceae, and *Typha*, ferns and algae. Worthy of mention in this sample is the peak of *Verbascum* (12.5%), only recorded here. The grains could belong to *V. blattaria* L., a typical herb of uncultivated land and of riverbanks and ditches. As to oaks, *Q. robur* L. is the most probable deciduous oak species (*Q. robur*-type, 1.8%) in the first sample since it is tolerant of wet soils and flooding. It is then replaced, for a short time, by the pioneers Rosaceae. A change of the water table could also be indicated by the presence of *Tamarix*. Tamarisks are salt-tolerating plants and might even have been present along the seacoast, which was ca. 1.5 km away from the study area during the Early Iron Age (Nicosia et al. 2019), or also inland in patchy wet areas. Then *Q. cerris*-type, including pollen of both *Q. cerris* and *Q. suber* begins (0.7%). Both oaks give indication of less water availability. The high amount of Poaceae and the contemporary presence of green algae, like *Botryococcus* and Zygnemataceae, confirms that the area was a freshwater environment with wet meadows, as previously suggested by Ciarallo (2002). Nonetheless, the patchy scenario depicted by the geomorphological reconstruction of Nicosia et al. (2019) is testified by the co-occurrence of grassland and pastureland taxa (Fig. 5). Halophytic plants of the Amaranthaceae family might have also populated the strip of land between the sea and the floodplain. The Mediterranean environments were especially dominated by Cupressaceae, in particular “Mediterranean” juniper species (*Juniperus oxycedrus* and *J. phoenicia*) and/or *Cupressus sempervirens*, whose indigenous status and diffusion is debated (Pignatti 1982; Bagnoli et al. 2009), which is at present found in the coastal scrubland (Fig. 5). Juniper plants probably populated the Bottaro/Pioppaino dune ridge, which delimited the wetland towards the sea. Trunks of juniper were found in the positions where they had lived on a beach at *Neapolis*, dated to the sixth century AD (Vacchi et al. 2020). Evergreen oak (*Q. ilex*-type) forest was also present (max. 0.9%), probably mixed with deciduous specimens as recorded in the lowland of Volturino Plain (Grüger et al. 2002; Di Rita et al. 2018).

Mesophilous taxa (Fig. 5) were probably growing in the floodplain and/or in the Sarno, Lattari, and Somma mountains (Di Donato et al. 2008; Di Maio et al. 2012; Russo Ermolli et al. 2014). Synanthropic taxa are mostly represented by *Urtica*-types (max. 4.3%), which include nitrophilous species growing in footpath and ruderal communities (Behre 1981).

During the Hellenistic age (zone S5-1b), hygrophilous and Mediterranean taxa still prevail among trees, but a change occurs in the local wet environment, the *Fraxinus*

cf. *excelsior* curve begins and soon after also that of *Populus* (Fig. 3).

The appearance of common ash and poplar, combined with the decrease of alder suggests an enrichment in the hygrophilous trees. Moreover, a change in the groundwater level could also be hypothesized, since the ash root system does not withstand waterlogged conditions as alders do. Grassland is reduced and pastures expanded due to the availability of new soils for pastoral activities (Fig. 5). Synanthropic taxa slightly increase thanks to weeds and ruderal plants (Fig. 5). Environmental dynamics encompassing the strong influence of groundwater fluctuations south of Pompeii have already been hypothesized by the geomorphological reconstruction of Vogel and Märker (2011). At the same time, the presence of humid areas is still revealed by pollen of *Polygonum persicaria*-type (sensu Reille 1992; Fig. 3: max. 7.9%), fern spores and algae. Halophytes (*Typha*) and hydrophytes (*Potamogeton*) especially indicate ponds with more stagnant and salty water (Fig. 3).

In addition to deciduous forest, pollen rain from altitudinal vegetation is represented by montane taxa such as *Fagus* and *Betula* (Fig. 5). This vegetation type is well attested for the Tyrrhenian region during the first millennium BC, even at lower elevation than at present (Grüger et al. 2002; Russo Ermolli et al. 2011, 2014; Di Rita et al. 2018). Interestingly, nowadays birch is only present in the Lattari Mountains south of Pompeii, as a relict taxon of the glacial vegetation, but archaeobotanical data from Pompeii reveal that beech wood was exploited as fuel since pre-Roman times (Ciarallo 2002; Veal and Thompson 2008).

In the Roman age (zone S5-2), the wetland shrunk to the advantage of crop production: cabbage fields, and perhaps olive groves, were favoured by a low water table, and synanthropic plants developed. Increased erosion, due to enhanced land use, is suggested by *Pseudoschizaea*, whose occurrence under desiccation events has been highlighted by different authors (Pantaléon-Cano et al. 2003; Sadori 2018). The river flow receded, and green algae decreased until almost disappearing. Aquatic plants living in shallow or stagnant water (Pignatti 1982), such as *Callitriche* and *Littorella uniflora*, grew. Wet meadows of wild grass also shrank. On the other hand, deciduous oaks expanded in the floodplain (Fig. 5). This coincidence suggests that the English oak was probably the bulk of deciduous vegetation in the wetland as depicted for the upper Sarno River valley (Di Maio et al. 2012). Despite local hydrological changes, independent palaeoclimatic factors cannot be ruled out as concurrent causes in decreasing wet conditions across the floodplain. Unfortunately, pollen data from these environments have a limited potential for the detection of climatic interference, as they are strongly influenced by the local vegetation.

Finally, before AD 79 (zone S5-3) the level of the water table increased again as suggested by the maximum of

hygrophilous plants, and wet areas again reoccupied part of the floodplain. Poaceae pollen follows this trend (Fig. 5). Mesophilous vegetation continued to expand over the region as already testified by pollen records north of Pompeii (Grüger et al. 2002; Russo Ermolli et al. 2014), but in contrast with the palynological evidence from the south (e.g. the Sele River plain, Russo Ermolli et al. 2011). At this point, the economic exploitation of the floodplain by Romans was well developed, and tree crops and pastures characterized the landscape around Pompeii.

Land use around Pompeii

The Campania cabbage economy is well displayed by the pollen sequence. Brassicaceae are entomophilous plants and high values are not expected in pollen records. For this reason, the high percentages found in our pollen data are a strong indication of the local presence of vegetable gardens. Most grains can in fact be ascribed to *Brassica oleracea* L.; cabbages and broccoli are the cultivated varieties of a unique species (Russo Ermolli et al. 2014). It has already been demonstrated that cabbage cultivation was the core of horticultural practices in classical times (Cilliers and Retief 2009). Pliny the Elder (NH 19, 139–141) and Columella (RR 10, 135) state that these plants were especially appreciated by Romans and consumed in this region. As a matter of fact, the role of cabbages in Roman vegetable production since the first century BC is extensively testified by pollen data from Campania (Mariotti Lippi 1993; Grüger et al. 2002; Mariotti Lippi and Bellini 2006; Russo Ermolli and Messenger 2013; Russo Ermolli et al. 2014) and from other regions during the Imperial age (Montecchi and Mercuri 2018; for other cultivated species of *Brassica* refer to seed analysis in Bosi et al. 2017). Our data seem to suggest an earlier cultivation (fourth-third centuries BC?) but the chronology of our cores is not robust enough to pre-date with any certainty the cultivation of cabbages in Campania and to ascribe this practice to Samnites.

Amaranthaceae (max. 11.5%), Apiaceae (max. 3.2%) and Fabaceae (max. 2.6%) might have also been cultivated since they include vegetable-garden, aromatic and legume species. In addition, the latter two are exclusively entomophilous plants. Some plants of the legume family also grow in pastures and fallows, whereas the wild species of beet and carrot families are common in Mediterranean drylands (Mulder 1999; Bowes et al. 2015).

The local olive economy is not clearly evidenced by pollen data. The *Olea* record starts at the end of the first millennium BC (end of zone S5-1a) and increases alternatively in the following periods with intermediate values tending to zero (Fig. 3). Since olive trees are naturally present in the Mediterranean woodlands, a continuous curve was expected as recorded in the *Literna Palus* lagoon (Di Rita et al. 2018).

Nevertheless, similar oscillations in *Olea* occurrence are shown by other pollen sequences of the Tyrrhenian coast during (pre-)classical periods (Di Donato et al. 2008; Russo Ermolli et al. 2014) and suggest periods of enhanced exploitation. In our record the peaks of olive seem to alternate with the Brassicaceae ones. This might refer either to economic phases during which the tree crops advanced at the expense of herb crops following the cultural developments of the city after the Samnite occupation, or to local environmental changes which modified the relationship between cultivated land and Mediterranean vegetation.

Other important tree crops are *Juglans* and *Vitis*. These appear in the most recent samples and, together with the presence of *Pinus* cf. *pinea* (the stone-pine), can be easily considered as chronological markers of the Roman occupation of the city. A quite similar pollen assemblage is recorded by the upper samples of core S6 dated after 171 cal BC–cal AD 51 (Fig. 6). In Campania, the onset of *Vitis* cultivation is certainly attested since the Iron Age (see archaeobotanical data from Longola di Poggiomarino: Celant 2012; Delle Donne 2012), and its full exploitation as an economic plant is reported in the Etruscan town of Pontecagnano and close to the *Literna Palus* lagoon since the sixth century BC (Russo Ermolli et al. 2011; Di Rita et al. 2018). On the other hand, grapevine was cultivated across the *ager pompeianus* to a lesser extent, as referred to by Pliny the Elder and testified by scattered archaeological evidence (Di Pasquale 2010; De Carolis et al. 2012). It is noteworthy that grapevine is described as growing together with poplars and cypresses in the area between the city and the sea (De Simone 2017). In addition to *Vitis*, also *Juglans* and *Castanea* were cultivated along the shores of Lago d'Averno from at least the first century BC (Grüger et al. 2002). Walnut showed continuous pollen curves starting from ca. 1000 BC in central and southern Italy (Di Rita et al. 2018; Sadori 2018), but it was mostly favoured by Romans together with chestnut (*Castanea*) spreading throughout the peninsula (Mercuri et al. 2013). At Pontecagnano, walnut was intensively cultivated since the third century BC (Russo Ermolli et al. 2011). Another anthropogenic indicator is *Buxus*, whose pollen has been recognized starting from the Roman age (zone S5-2) and expanding before AD 79 (zone S5-3, Fig. 3). *Buxus sempervirens* (box) was cultivated by Romans for ornamental purposes according to the *ars topiaria* (Ciarallo 2002; Jashemski et al. 2018). An ambiguous pollen taxon is *Juniperus/Cupressus*, to which cypress belongs. About one hundred regularly spaced cypresses were discovered right along the Sarno River (Jashemski et al. 2002), therefore suggesting their plantation at Pompeii (Ciarallo 2002). Eventually, within and around the urban perimeter, gardens were cultivated for both aesthetic and utilitarian

reasons (horticulture), including several fruit trees and ornamental plants (Jashemski et al. 2002; Ciarallo 2009).

The past agricultural and pastoral system in the floodplain is also evident since the earliest samples. Agrarian activities are testified by the presence of cereals, i.e. *Hordeum*-type and *Avena/Triticum*, even if barley shows a greater importance than wheats as testified by charred cereal remains from Longola di Poggiomarino during the Iron Age (Celant 2012; Delle Donne 2012). Especially in the Hellenistic age (zone S5-1b) barley reaches 2.7%, suggesting the expansion of cereal fields in this period (see also the presence of weedy taxa such as *Polygonum aviculare*; Fig. 3). Interestingly, Pliny the Elder states that barley was usually cultivated by Romans together with turnips (Brassicaceae) in Campania (NH 18, 191; Buonopane 2015). Albeit favourable volcanic soils characterized the area, a high-water table due to the proximity of the Sarno River could have been a limiting factor for crop growth. In this respect, it is not surprising that the expansion of crop fields and vegetable gardens corresponds with phases of lower groundwater level or minor fluvial activity. On the other hand, most of the floodplain landscape should have been managed as pasturelands due to the high values of herbs typical of open environments and pastures. In particular, the abundance of Cichorieae suggests the presence of plants recurring in weakly developed soils and grazed fields or, at least, fields cultivated for fodder (Florenzano 2019). Nevertheless, a taphonomic overrepresentation of Cichorieae cannot be excluded due to their resistance to corrosion in oxidizing conditions, such as those hypothesized for our sequences. Other important anthropogenic indicators of pastures are *Rumex* (max. 1.1%) and *Plantago lanceolata*-type (max. 3.7%), which are trampling-resistant and nitrophilous plants favoured by soil compaction and livestock manuring (Brun 2011). The most important periods of pastoral activities are recorded in the Roman age (zones S5-1b) and, above all, in the period preceding AD 79 (zone S5-3), when microcharcoals are abundant. These suggest the intense use of fire, probably to renew the pastures, or even the occurrence of domestic fireplaces and other combustion activities from the nearby settlement. Significantly, the upper part of core S6 is also characterized by high values of Cichorieae pollen and coprophilous fungal spores, which are considered as pastoral indicators being present in animal dung (Figs. 3 and 4). In general, most component of the pollen assemblages are herb plants (*Artemisia*, Asteroideae undiff., Caryophyllaceae, *Centaurea*, Poaceae, Ranunculaceae) that are common in open habitats, such as those of riverbed vegetation, wet meadows, temperate pastures and Mediterranean dry grasslands (Florenzano et al. 2015).

Our pollen data do not completely reflect plants cultivated in orchards and/or depicted in the gardens of the Vesuvian area (Jashemski et al. 2002). For example, myrtle and different species of *Citrus* decorated the first century BC garden

of the Villa di Poppea at *Oplontis* (Barone Lumaga et al. 2020), where also a stock of pomegranate fruits was found (Borgoncino 2006). Still, no trace of these plants was found in our pollen records; however, being low pollen-producers, their pollen signal is expected to be strictly local. *Platanus*, absent in our diagrams, was also planted in Pompeii as an ornamental tree (Ciarallo and Mariotti Lippi 1993; Mariotti Lippi 1998; see also the identification of root casts in Ciarallo 2009) and its pollen record is available at Lago d'Averno (Grüger et al. 2002).

Conclusions

Our data reveal the main traits of the local and regional vegetation in the Sarno River floodplain during the first millennium BC, before and during the birth, rise, and destruction of Pompeii.

The analysed sediments represent an unstable area subject to important natural hydrological changes and strongly influenced by human activities from the Iron Age onwards. Climate influence cannot be easily recognized in pollen records from such an environment. The relict natural vegetation mainly consisted of a mosaic of different vegetation types, typical of the coastal plains of Mediterranean rivers: hygrophilous, mesophilous and Mediterranean vegetation form the different tesserae of the mosaic. The dominant vegetation is the result of strong human activities, which shaped the landscape with cultivated fields and pasturelands.

Riparian and aquatic vegetation changes suggest important changes in the river activity and in the water table level. Even if a general trend from inundated to wet soils is found from the bottom to the top of the core, many minor fluctuations are visible. Alders, poplars, willows, common ashes and tamarisks, growing along the river and its channels and ditches, concurred to shape different hydro- and hygrophilous arboreal assemblages. They were generally accompanied by aquatic herbs, algae and ferns. Sparse elements of the floodplain deciduous forest grew on wet soils, with deciduous and semi-deciduous oaks, manna ashes, and hornbeams. Evergreen trees and shrubs such as evergreen oaks, heathers, junipers and olives probably grew on the better drained soils and on sunny slopes.

Such a natural environment also contains the traces of strong human impact. In particular, the landscape shows marked anthropogenic traits beginning since the base of the studied cores, in pre-Roman times (first half of the first millennium BC). Pasture, crop, and weed taxa are markers of an intensive land exploitation undergoing land use changes. Parallel to natural environmental changes of the Sarno River floodplain, changes in the land management system in the area, based on agricultural and pastoral activities, were found. During the Hellenistic age (fourth-second

centuries BC), cabbage cultivation was possibly introduced. It is noteworthy that the pollen data discussed here represent the earliest evidence of the presence of cabbages in the Campania region, dating back to the fourth century BC. It is likely that the cultivation of cabbages was not only a sort of preference for this vegetable, but a conscious choice of the best naturally wet fields for a crop planted during summer and generally harvested in late autumn/winter. Cabbages are water-demanding in the dry season in the Mediterranean basin, when precipitation alone cannot sustain growth. Cereals and legumes seem to have represented minor crops in the area due to the high water availability of the soils. With the Roman presence (1st century BC to 1st century AD), both tree crops (*Juglans*, *Olea*, *Vitis*) and ornamental plants (clipped *Buxus*, *Cupressus*) were grown, and cabbage production even increased, suggesting economic and cultural continuity by the inhabitants of Pompeii.

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