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Past environments of Sardinian archaeological sites (Italy, West Mediterranean Sea), based on palynofacies characterization

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ABSTRACT. A study method based on characterization of palynofacies (organic matter, palynomorphs) preserved in sediments was applied to obtain information about past environments of Sardinian sites. Organic matter (OM) was classified in ten categories according to its biological source, ecological characteristics, morphology and preservation state. These categories included woody and non-woody particles (cuticles, amorphous organic matter), phytoclasts, spores and pollen grains, gelified particles, and altered phytoclasts that ranged from transparent to opaque fragments. Cluster analysis classified the samples into associations. Each cluster includes stations with a similar spatial distribution pattern. The characterization of the different types of OM was coupled with palynological analyses to produce suggested hypotheses about past vegetation, human activity and land use in Sardinia.

KEYWORDS: palynology, organic matter, past vegetation, human activity, Sardinia, multivariate analysis, Western Mediterranean

INTRODUCTION

Analysis of palynofacies (palynology and organic matter content) preserved in sediment records was developed for petroleum exploration (Combaz 1964, Cross 1964) but nowadays is used to differentiate the major constituents of the sedimentary organic matter in Holocene deposits (Sebag et al. 2006b). This valuable tool has been used in palaeoenvironmental, palaeoclimatological and palaeoceanographic reconstructions (e.g. van der Zwan 1990, Tyson 1995, Batten 1996, Gastaldo et al. 1998, Cirilli et al. 2015, Hochuli et al. 2015, García Muro et al. 2016, Kumar et al. 2016, Okeke & Umeji 2016, Koch et al. 2017) and has recently been tested in characterization of Holocene alluvial and palustrine deposits (e.g. Gastaldo & Huc 1992, Laggoun-Défarge et al. 1995, Cohen et al. 1999, Di Giovanni et al. 1999, Bourdon et al. 2000, Sebag et al. 2006a, b, Serna et al. 2015) through the identification and quantification of organic matter (OM) phytoclasts according to their origin, nature, formation or preservation in sedimentary processes. In palaeoenvironmental reconstruction studies, palynofacies analysis offers a useful tool in examining geological deposits with poorly preserved or absent fossil material, such as in non-marine, continental and high-energy depositional environments (Traverse 2007). The description and interpretation of palynofacies can also provide information on the past environment and land use in archaeological areas, especially when fossil pollen information is scarce or absent (Noël et al. 2001, Grill et al. 2007).

From the pollen composition it is possible to picture the past vegetation and to document the climatic trend in a region and/or at an archaeological site (Geib & Smith 2008, Mercuri 2008, Mariotti Lippi et al. 2009, Mercuri et al. 2010, 2015, Sadori et al. 2010, 2016, Fyfe 2012, Grill et al. 2013, Morales et al. 2013, Fiacconi & Hunt 2015, Currás et al. 2017,

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Melis et al. 2017, Novák et al. 2017, Pini et al. 2017, Pescini et al. 2018). Palynological studies in Sardinia are still rare, and applied mainly in archaeological contexts. Examples include interpretations of Early Neolithic (sixth millennium BC) coastal open-air sites (Luglié et al. 2012, Pittau et al. 2012), palaeovegetation reconstructions from some Bronze Age sites (Buosi et al. 2015, López et al. 2005) and Phoenician sites (Acquaro et al. 2001), a multidisciplinary approach (archaeological, palaeobotanical and geomorphological) to obtain information about the traditional use of seeds and fruits during Punic times and the vegetation of southern Sardinia and the ancient coastlines of the Santa Gilla Lagoon during Punic colonization (Buosi et al. 2017), and the interpretation of burning rituals, with reconstruction of the vegetation of a cremation area in the Roman Imperial Age (third century AD; Buosi et al. 2013). Changes in evergreen vegetation and the impact of human activity have been examined in central western (Di Rita & Melis 2013, Sabato et al. 2015) and northern Sardinia (Beffa et al. 2016).

To obtain information about OM sources (allochthonous and autochthonous components), the ancient environments and past vegetation of Sardinian archaeological sites, we performed a palynofacies study based on optical characterization of OM particles coupled with pollen grain analysis. The complexity of the environment and the origin and sources of OM were addressed through multivariate analyses of the phytoclasts, palynomorphs and amorphous components. An increasing number of palynological and palaeobotanical studies use different techniques of multivariate analysis to help identify environmental changes in much older epochs as well (e.g. Barbacka et al. 2014, Cleal et al. 2017). We used the results from OM characterization coupled with palynological data to interpret the past vegetation and the ancient environment. The work also yielded some insights into the environmental impact of human activities.

STUDY AREA

We investigated the palynofacies (OM, palynomorphs) of five sites in Sardinia (Italy, western Mediterranean; Fig. 1), mainly on the Campidano and the Oristano plains (southern to central western Sardinia). We chose sites differing in chronology, context, material and taphonomy. These sites are described below, in chronological order from Early Neolithic to Punic.

Site 1 – Five samples (SG1–SG5) from a drill core section (–914 to –600 cm) (Fig. 1B) from Santa Giusta (Oristano Province, western Sardinia; **SG**, Site 1 in Fig. 1A) in an area called Santa Severa. The area is rich in Nuragic to Roman archaeological evidence, the most conspicuous of which is the Phoenician town of Othoca (Pusceddu et al. 2012). The site is on the southern alluvial plain of the Tirso River and is south-east of the Santa Giusta Lagoon. The age of the deposit was established from two new AMS ^{14}C radiocarbon dates taken from shell fragments (Tab. 1). Because the production of atmospheric radiocarbon has varied through geological time, radiocarbon ages were calibrated to provide dates in calendar years before the present. All samples were calibrated using CALIB 7.1 (Stuiver et al. 2016). The radiocarbon dates available for this site are 5359–5229 2δ cal. years BC (sampled at –6.25 m) and 5558–5481 2δ cal. years BC (sampled at –7.90 m; Tab. 1). As shown in Figure 1B, the stratigraphy encompasses 100 cm of silt (600–700 m depth), 125 cm of mud (700–825 cm depth), 50 cm of muddy sand and 75 cm of sandy sediment.

Site 2 – Six samples (SAP1, SAP3, SAP5, SAP7, SAP9 and SAP10) from the open-air site at Sa Punta (**SAP**, Site 2 in Fig. 1A) in Marceddì-Terralba (western Sardinia) on the western point of a cluster of several EN sites along the coastal plain of the Oristano Gulf (Pittau et al. 2012). The site consists of a trench dug out of a limestone bank (Luglié et al. 2012, Pittau et al. 2012). Excavations at the site in 2004 revealed an undisturbed stratigraphic sequence (Fig. 1B) dating back to the last three centuries of the sixth millennium cal. BC (Early Neolithic). The radiocarbon dates available for this site are 5313–5028 2δ cal. years BC (S.U. 13 in Fig. 1B) and 5476–5067 2δ cal. years BC, respectively (Tab. 1, Luglié et al. 2012, Pittau et al. 2012). Palynological slides from this section were re-investigated for this work. As shown in Figure 1B, the stratigraphy encompasses ca 20 cm of dark grey sediment with fragments of mollusc shells (*Mytilus*, *Tapes*, *Ostraea*) (60–40 cm depth), ca 35 cm of fine pale brown sand with a few pebbles

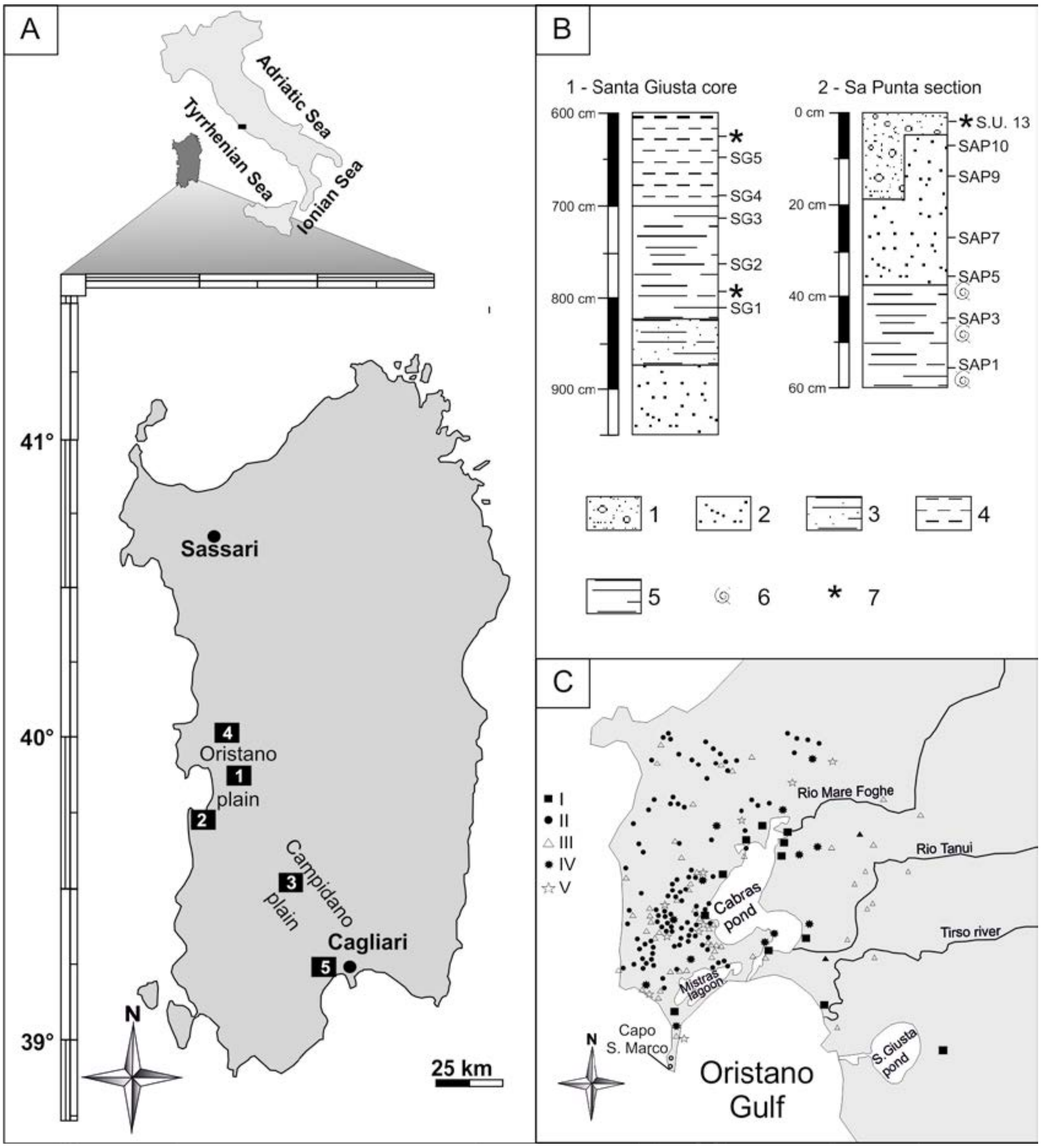


Fig. 1. Map of south-central Sardinia (Italy) showing (**A**) the location of the studied sites (**Site 1**: Santa Giusta, **SG**; **Site 2**: Sa Punta, **SAP**; Santa Giusta, **SG**; **Site 3**: Sanluri, **SL**; **Site 4**: Baratili San Pietro, **BS**; **Site 5**: Lagoon of Santa Gilla, **LSG**) and (**B**) stratigraphic sections from SG and SAP sites: **1** – sandy sediment with pebbles; **2** – sand; **3** – muddy sand; **4** – silt; **5** – mud; **6** – shell remains; **7** – samples for ^{14}C radiocarbon dating. (**C**) Distribution of archaeological sites on the Oristano Plain (modified from Depalmas & Melis 2011; Di Rita & Melis 2013): **I** – Neolithic villages; **II** – Nuraghe (Bronze Age); **III** – Nuragic villages (Bronze Age); **IV** – Punic settlements; **V** – Roman settlements

(40–5 cm depth) and ca 5 cm of Mio-Pliocene fist-sized limestone pebbles (S.U. 13; Fig. 1B).

Site 3 – Four samples (SL1–SL4) from four different collective burials in simple pits dug into the ground, situated in Sanluri (western central Sardinia; **SL)** on the central Campidano Plain (Site 3 in Fig. 1A). Based on pottery fragments, the necropolis was attributed to the Copper Age (Eneolithic) and described as pertaining to a "transitional" Monte Claro cultural phase (Martella et al. 2012, Ugas 1982). The samples are composed of sediments (gravelly sand texture) of five burials ('sacche' IV, XIII, XIV, XV and XVI) belonging to five stratigraphic units (US 35, 36, 37, 38 and 39; Martella et al. 2012) discovered in 2005 after excavations.

Site 4 – Five samples (BS1–BS5) from an artificially opened structure containing alluvial deposits, which opened between the Tirso and Rio Mare Foghe rivers in the area of Sipoi village in Baratili San Pietro (western Sardinia; northern Oristano Plain; **BS**, Site 4 in Fig. 1A). The archaeological site is a sunken sub-circular domestic structure excavated in alluvial sediment to a depth of 80 cm (Ucchesu et al. 2015). The structure probably consisted of a roof made of plant material and clay layers, as suggested by the presence of postholes and clay remains with clear impressions of branches. Faunal remains, molluscs, obsidian tools, pestles and pottery were retrieved from the well, and also charcoal and seeds (Sebis & Pau 2012, Ucchesu et al. 2015). Based on the pottery, this archaeological site was dated to the Middle Bronze Age (MBA; Sebis & Pau 2012). The infilling sediment of the sunken structure consisted of coarse and medium sand with gravel (for more archaeological details, see Sebis & Pau 2012).

Site 5 – Six sediment samples (LSG1– LSG6) from six trading amphoras of Punic manufacture discovered during underwater exploration in Santa Gilla Lagoon (southern Sardinia; **LSG**, Site 5 in Fig. 1A). The amphoras are comparable to "sacco" (bag-shaped) and "siluro" (torpedo-shaped) types, which can be dated to between the 5th and 4th centuries BC (2450 ± 40 age cal. BP 1δ; Antonioli et al. 2007, 2009). The amphoras were found in the northeast field of Santa Gilla Lagoon, ca 1.60 m below mean sea level, resting on a layer of shells under 1 m of mud that preserved the hard parts of their original content (Bernardini et al. 1993, Buosi et al. 2017, Solinas 1997, Solinas & Orrù 2006). The mud deposited inside the amphoras preserved the entire contents, with shells, oysters, mussels and pottery fragments found inside them mixed with muddy sediment, plant debris, and cattle, sheep and goat bones (Fonzo 2005).

MATERIALS AND METHODS

The samples enumerated above were subjected to palynofacies analysis (OM, palynomorphs). For organic matter characterization and palynological analyses, the samples were treated according to standard procedures: a known amount of *Lycopodium* spores was added to 15 g of dry-sieved (2 mm mesh) sediment in order to estimate the pollen concentrations. Then each sample was processed with 10% and 30% HCl (three times), HF and KOH, and subjected to heavy liquid separation (Moore et al. 1991). The residue was then ultra-filtered through 5 μm mesh so that most of the smaller debris was washed off.

After that treatment, the OM and palynomorph content of each sample contained in each slide was analysed with a Leitz Dialux 20 optical microscope.

The pollen grains were identified based on the keys of Faegri & Iversen (1989) and Moore et al. (1991), following the classification system of Erdtman (1986) and with the help of Reille's (1995, 1998, 1999) spore/pollen grain atlases and the reference collection of Sardinian pollen flora housed in the Department of Chemical and Geological Sciences of Cagliari University. The botanical nomenclature is based on Pignatti (1982).

For phytolith analysis, an aliquot of 20 g of each sediment sample was chemically treated following Piperno (2006). The sediment from each sample was shaken in 5% Calgon solution for 24 h and then wet-sieved through nested 250 mm and 53 mm sieves to separate the sand and larger particles from the silts and clays. The carbonates, organic matter and humic acids were removed respectively with 10% HCl, concentrated $HNO_3/KC1O_3$ and 10% KOH (gentle heating for 10 min). Heavy liquid ($ZnBr_2$, 2.3 specific gravity) was added. The light fraction at the top of the tube was pipetted into clean tubes, and flotation steps were repeated to ensure removal of most of the phytoliths. Distilled water was added at a ratio of 2.5:1 to lower the density of the solution to < 1 g/cc. Finally, the residue was mounted in resin.

For analysis of total OM (palynofacies) present in the samples, we used optical characterization by light microscopy. OM was subdivided into three groups: phytoclasts, palynomorphs and amorphous components. We applied ten main categories, considering the biological source of the particles, the ecological characteristics, and the morphology and preservation states attributable to several processes such as transport, the diagenetic environment and the resistance of the particles. The particles were characterized as woody and non-woody particles (cuticles, amorphous organic matter), gelified particles, and altered phytoclasts ranging from transparent to opaque fragments. Palynomorphs such as pollen grains and spores were most frequent in the studied samples.

The groups are described in detail below:

– **Amorphous organic matter** (AOM, Pl. 1)

Amorphous debris with irregular shape and a shredded appearance. Particles range from very small to large (> 5 to >100 μm) and from pale yellow to orange. They may represent organic residues of various origin, degraded by bacterial activity. In only a few cases of the Santa Giusta core (Site 1), globular particles of AOM with a puffy consistency and occurring as aggregates were present in lagoonal/deltaic facies

Table 1. ^{14}C data for the Sa Punta and Santa Giusta sites (Sardinia)

Site	Stratigraphic unit	Laboratory code	Material	^{14}C dates (BP)	$\delta^{13}C$(‰)	Calibrated age (BC)	References
Santa Giusta – SG	–6.25 m	LTL16155A	marine shells	6326 ±45	–3.6 ±0.4	5359–5229 2δ cal BC	This study
Santa Giusta – SG	–7.90 m	LTL16156A	marine shells	6572 ±50	–2.8 ±0.4	5558–5481 2δ cal BC	This study
Sa Punta – SAP	S.U. 11	AA65493	bone	6325 ±86	–20.0	5476–5067 2δ cal BC	Lugliè et al. 2012, Pittau et al. 2012
Sa Punta – SAP	S.U. 13	AA65497	*Ostrea edulis*	6652 ±55	–1.8	5313–5028 2δ cal BC	Lugliè et al. 2012, Pittau et al. 2012

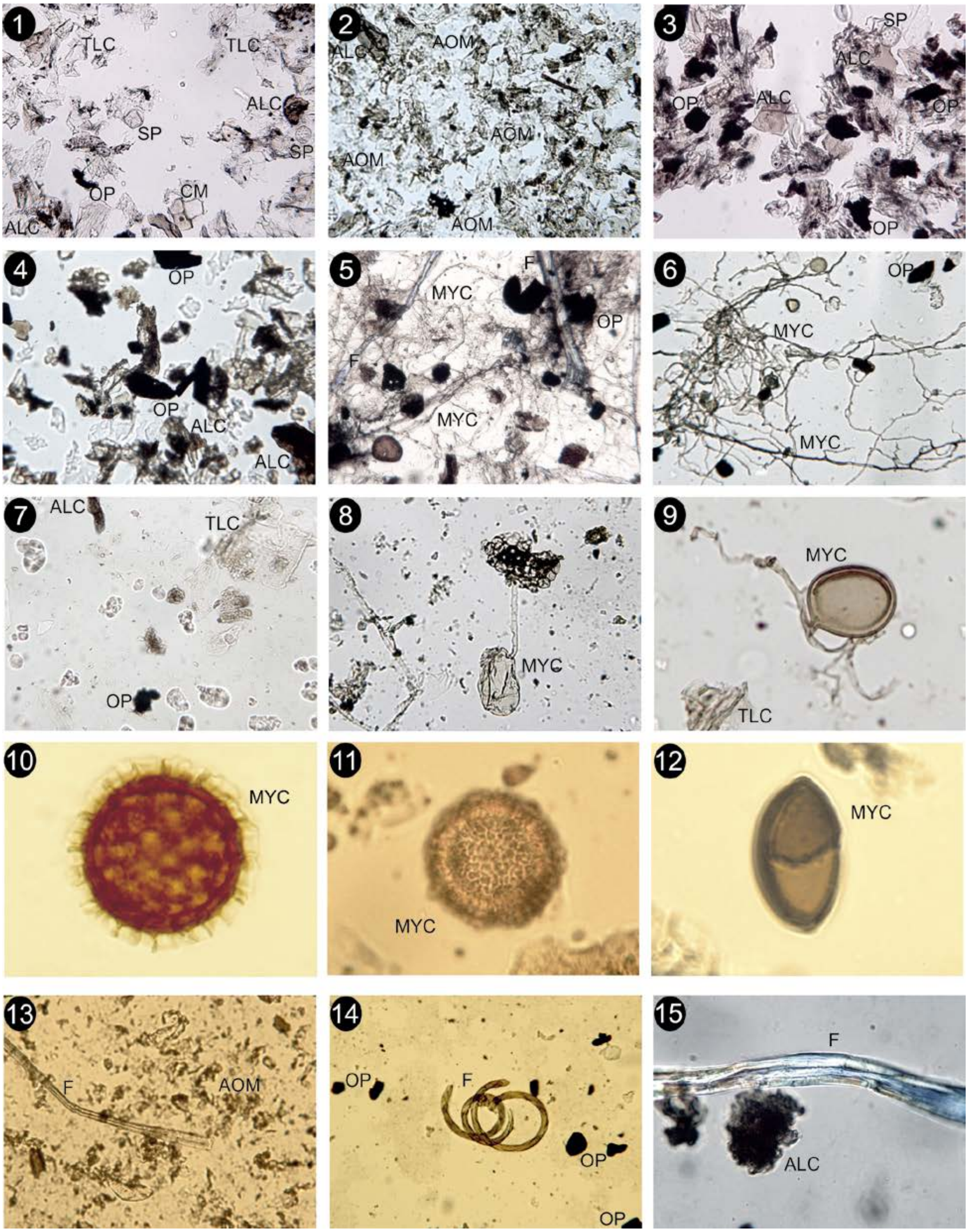


Plate 1. Main categories of **OM** (organic matter) observed by optical microscopy: **1–7** – different palynofacies with amorphous organic matter (**AOM**), transparent fragments (**TLC**), reddish altered fragments (**ALC**), spores and pollen (**SP**), cuticles and membranes (**CM**), opaque particles (**OP**), fungi remains (**MYC**), fibres (**F**) and phytoliths (**PY**); **8–9** – mycorrhizal fungi; **10–11** – pathogenic fungi; **12** – coprophilous fungi; **13** – vegetal fibre; **14** – wool fibre; **15** – vegetal fibre

mainly terrestrial in origin, with marine influence attested by the presence of dinocysts and foraminifers.

– **Cuticles and membranes** (CM, Pl. 1)

This category includes sheets or discrete fragments of plant tissues and cuticles that often reproduce stoma. The presence of these phytoclasts in sediment generally indicates waterlogged conditions and short transport.

– **Transparent lignocellulosic fragments and altered lignocellulosic remains** (TLC, Pl. 1; ALC, Pl. 1)

Glossy and transparent, these particles represent the best-preserved state and are cuticle material and tissues. An intermediate stage between TLC and altered particles is represented by reddish translucent particles that reflect a degree of carbonization (ALC).

– **Opaque particles** (OP, Pl. 1)

The OP include phytoclasts which were altered and oxidized to different degrees, from degradation to coalification, and derived from the geological substrate (Tyson 1995). The OP may represent combustion residues (charcoal). Their origin is terrestrial.

– Gelified particles (GP)

Woody fragments showing different stages of gelification, from totally obliterated original structures and moulded surfaces to partially preserved structures. The proportion of gelified materials in the samples seems to depend on the massive presence of plant debris. Intra- and extracellular amorphous material of plant origin (mainly associated with roots and bark) underwent gelification processes and are recognized as globular, oval and irregular particles. Some samples were orange. Humic amorphous content is highest in wet conditions (Tyson 1995).

– **Spores and pollen grains** (SP, Pl. 1)

Spores and pollen grains are discrete elements of terrestrial origin. Even though they differ in resistance to physicochemical conditions, coeval and reworked SP in sediment may be recognized by the different colour of the exine and the composition of the assemblages. The "Cerealia type" in pollen grains of wild grasses is recognized based on the size range of external diameter (larger than 50 μm) of the grain and the external diameter of the annulus (larger than 10 μm; Behre 2007).

– **Mycota fragments** (MYC, Pl. 1)

These consist of filaments of the mycelium of the vegetative phase of fungi. The category encompasses sporangia, spores, fruit bodies and hyphae. Slide observations showed that fungi fragments were active in the degradation of plant detritus (they may be passively transported by streams and flooding during erosional processes) and mycorrhizal fungi such as Glomeraceae (Pl. I, fig. 9). They are involved in symbiosis with plant roots and are dispersed in soils or lacustrine-pond sediments by erosional processes. Zygomycete pathogens of plants (Tilletiaceae), with their asexual spores, hyphae and rhizoids, were identified dispersed in soils and earth (Pl. I, figs 10, 11). The analysis also revealed the presence of coprophilous fungi, conidia and ascospores (Pl. I, fig. 12) of Sordariales (*Chaetomium*, *Podospora*), and other coprophilous fungi (*Delitschia*) that live mainly in the intestines of herbivorous animals and are released with faeces to the ground. Finding them is indicative of the presence of animals in the examined levels and areas (e.g. van Geel 2001, Davis & Shafer 2006, López-Sáez & López-Merino 2007, Mazier et al. 2009, Cugny et al. 2010).

– Phytoliths (PY)

PY consist of discrete elements of silica and ossalate carbonate of intra- and intercellular deposition inside plant tissues. The preservation of these elements in the ground may be useful in interpreting the vegetation and palaeoclimatic conditions when palynomorphs are scarce or absent. In general, herbaceous plants are the main producers of PY (Piperno 2006).

– **Fibres** (F, Pl. 1, figs 13–15)

Fibres are discrete elements of natural origin or processed by man. In this study their putative presence was recognized. The inclusion of this category in the overall palynofacies analyses/observations helps in understanding human activities.

Multivariate statistical techniques (Q-mode and R-mode cluster analyses, principal component analysis PCA) were performed using the Past Statistical Software suite (Hammer et al. 2001). The selected parameters used for multivariate analyses were amorphous organic matter (AOM), cuticles and membranes (CM), transparent lignocellulosic (TLC) and altered lignocellulosic (ALC) fragments, gelified particles (GP), opaque particles (OP), spores and pollen (SP), total Mycota fragments (MYC), mycorrhizal fungi (MYCO), pathogenic fungi (PATHO), coprophilous fungi (COPR), phytoliths (PY) and fibres (F). PCA was used to determine the relationships with different parameters at the sampled stations. This type of analysis attempts to identify underlying factors that explain the pattern of correlation within a set of observed variables. It is used to reduce data in such a way as to identify a small number of factors that explain most of the variance observed in a much larger number of variables. The findings of R-mode cluster analysis were then superimposed onto the graphical results.

Cluster analysis classifies samples into associations. Here, each cluster includes stations with a similar spatial distribution pattern. In this study, Euclidean-distance correlation coefficients were used to measure similarities, while Ward's linkage method was used to arrange pairs and groups into hierarchic dendrograms.

RESULTS

OM CHARACTERIZATION AND PALYNOLOGICAL ANALYSIS

Total organic matter (TOM) data are reported in Table 2 and Figure 2. Spore and pollen (SP) spectra from the studied areas are reported in Figure 3 and Appendix 1.

Site 1 (SG, Santa Giusta)

Organic matter characterization. The sediment in the studied core was characterized by very high ALC ranging from 20% (SG1) to 40% (SG2, SG3) to 60% (SG4, SG5). The SP values ranged between 5% (SG5) and 20% (SG3, SG4). The AOM values were high in SG2 (40%) and SG1 (50%), whereas those of OP, MYC and CM were negligible in all the examined samples.

Palynology. The NAP component of the Santa Giusta pollen spectra was more predominant than the AP component (Fig. 3A). The herbaceous vegetation was represented mainly by Chenopodiaceae and Poaceae (up

Table 2. Relative abundance of phytoclasts in each sample of the examined sediment

Sample ID	Locality	Depth (m)/ origin of samples	Cultural Phase	SP	MYC			CM	TLC	ALC	AOM	GP	OP	PY	F
				Spores and pollen	Mycorrhizal fungi	Pathogenic fungi	Coprophilous fungi	Cuticle and membraneous fragments	Transparent ligno-cellulosic fragments	Altered ligno-cellulosic remains	Amorphous organic matter	Gelified particles	Opaque particles	Phytoliths	Fibres
SG5	Santa Giusta	–6.45	Early Neolithic	5	0	0	0	5	10	60	15	0	<5	<5	0
SG4		–6.87		20	0	0	<5	<5	<5	60	<5	0	<5	<5	0
SG3		–7.14		20	0	0	<5	5	30	40	5	<5	<5	<5	<5
SG2		–7.65		10	0	0	0	<5	10	40	40	0	<5	<5	0
SG1		–8.12		10	0	0	<5	<5	15	20	50	0	<5	<5	<5
SAP10	Sa Punta	–0.86	Early Neolithic	5	5	0	5	0	10	25	<5	0	35	10	<5
SAP9		–0.92		5	5	0	<5	0	10	20	<5	<5	40	10	<5
SAP7		–1.03		5	<5	0	<5	0	10	30	5	<5	40	5	<5
SAP5		–1.15		5	<5	0	<5	0	10	30	<5	<5	50	5	<5
SAP3		–1.25		5	5	0	<5	0	10	20	<5	0	50	5	<5
SAP1		–1.4		5	5	0	5	0	5	20	5	0	40	10	<5
SL4	Sanluri	US38, US82 I4, sacca XXX	Eneolithic	10	<5	20	<5	<5	15	30	5	<5	15	<5	<5
SL3		US38, US82 I4, sacca XI		10	5	15	<5	<5	10	30	<5	<5	20	<5	<5
SL2		US37		<5	30	<5	<5	<5	10	5	<5	5	40	<5	<5
SL1		US77 sacca XVI		10	5	20	<5	10	20	20	10	<5	10	<5	<5
BS5	Baratili S.P.	–0.8	Bronze Age	5	15	<5	5	10	30	20	<5	<5	10	<5	0
BS4		–0.8		5	10	<5	<5	10	30	20	5	<5	15	<5	<5
BS3		–0.8		5	10	0	<5	5	15	15	5	<5	10	25	<5
BS2		–0.8		<5	<5	<5	15	5	40	10	<5	<5	10	20	0
BS1		–0.8		5	10	<5	5	20	25	15	5	<5	10	5	<5
LSG6	Santa Gilla Lagoon	F14 amphoras	Punic	<5	0	0	5	10	10	5	40	<5	20	<5	5
LSG5		E33 amphoras		5	<5	0	<5	20	30	30	5	<5	5	<5	<5
LSG4		E19A amphoras		5	<5	0	<5	20	20	20	5	<5	20	5	<5
LSG3		E5 amphoras		5	0	0	<5	30	40	20	5	<5	<5	<5	<5
LSG2		E3A amphoras		10	0	0	<5	20	30	30	<5	<5	5	<5	0
LSG1		E10 amphoras		5	<5	0	5	20	35	20	5	<5	10	<5	<5

to 50%), and the AP component by *Pinus* (up to 14%), followed by Ericaceae and *Pistacia*. Spores were present in high percentages in all the examined samples (up to 15%).

Site 2 (SAP, Sa Punta)

Organic matter characterization. The sediment from Sa Punta showed high values for OP (up to 50%), ALC (up to 30%), PY and TLC (up to 10%). The MYC and SP levels were low in all the samples (ca 5%); the AOM values were negligible and CM was absent. The TOM values did not vary appreciably in the examined samples.

Palynology. The pollen diagram of Sa Punta reported by Pittau et al. (2012) revealed that the assemblages were dominated by NAP, followed by AP, reaching ca 80% and ca 20% of the recognized taxa respectively (Fig. 3B). The local vegetation was characterized by high frequencies of Poaceae (ca 20%) and Chenopodiaceae (ca 20%), followed by Apiaceae, Cyperaceae/Juncaceae and Urticaceae among the herbaceous plants. The arboreal plants were represented mainly by Oleaceae (ca 15%) and conifers (ca 10%). Juncaceae, Liliaceae and *Ilex* (Aquifoliaceae) were very rarely present and never exceeded 1% in all the studied samples. The Chenopodiaceae pollen levels decreased from the bottom to the top of the section, whereas those of Urticaceae, *Potamogeton* and Oleaceae increased. The amounts of Plantaginaceae, Poaceae, Cyperaceae/Juncaceae, Fabaceae and Apiaceae remained relatively constant throughout the section.

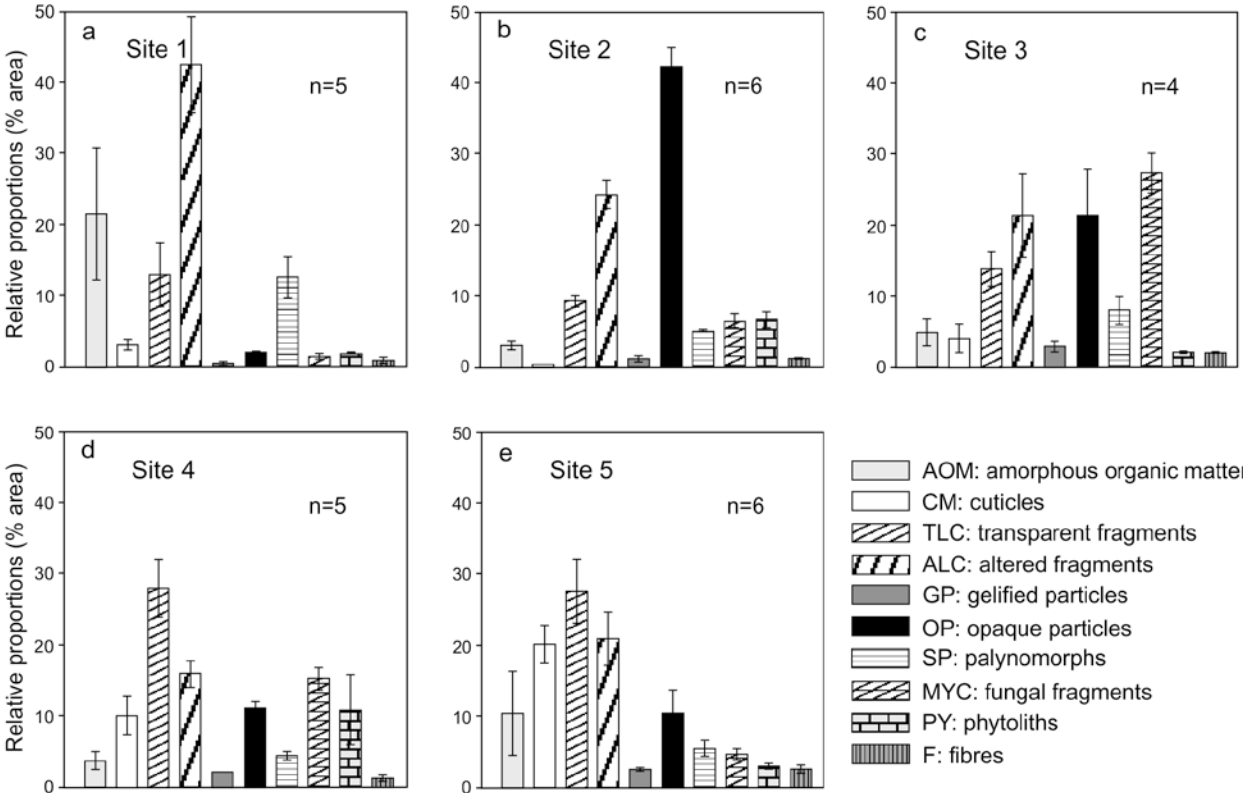


Fig. 2. Average distribution of organic particles established for each examined site

Site 3 (SL, Sanluri)

Organic matter characterization. Deposits from the examined graves showed the highest percentages of MYC fragments (up to 35% in SL2), consisting mainly of pathogenic fungi in SL1, SL4 (20%) and SL3 (15%), and mycorrhizal fungi in SL2 (30%). The observed teliospores of pathogenic fungi differed in morphology and surface pattern. They had a thick sporoderm structure with reticulate or verrucose/echinulate ornamentation, were light brown to orange, and ranged in size from 18 to 25 μm. Coprophilous fungi were negligible in all the samples (<5%). SP and TLC fragment levels were significant (ca 10%; Tab. 2). The OP fragments and ALC gave remarkable values from 10% (SL1) to 40% (SL2), and from 5% (SL2) to 30% (SL3, SL4).

Palynology. The local vegetation recognized in the Sanluri burials showed a high frequency of the NAP component, which ranged from 84–85% (SL2, SL4) to 96–97% (SL3, SL1; Fig. 3C). In SL1, the dominant taxa were Fabaceae (44%), Nymphaeaceae (16%), Malvaceae (ca 7%) and Poaceae (6%). Sample SL2 had high percentages of *Lemna* and Nymphaeaceae (ca 14%), followed by Liliaceae (ca 10%), Araceae, Chenopodiaceae, Fabaceae and Urticaceae (ca 8% each). Sample SL3 was dominated by Chenopodiaceae (31%), Nymphaeaceae (24%) and *Lemna* (ca 22%; Fig. 3C), and sample SL4 by *Lemna* (ca 26%), Fabaceae (13%) and Nymphaeaceae (13%). The AP component was represented in all the examined samples by *Pinus* pollen (up to 16% in SL2). "Cerealia-type" pollen grains were also recognized (ca 2%).

Site 4 (BS, Baratili San Pietro)

Organic matter characterization. In the examined samples collected at the stratigraphic level of the Nuragic huts, the MYC value was high (10%) in sample BS1, noticeably decreased in sample BS2, and rose in samples BS3 and BS4 (15%). In sample BS2 the coprophilous fungi values were high (ca 15%). TLC, representing fresh plant litter (Tyson 1995), ranged in relative frequency from 25% to 40% and was highest in BS2, while PY exhibited very high values in BS2 (20%) and BS3 (25%). The ALC values ranged between 10% and 20%. CM was high in BS1 but fell in the other samples (10% in BS4 and BS5; 5% in BS2 and BS3). OP and SP showed constant values in all the examined samples (ca 10% and 5% respectively).

Palynology. The SP diagram of the BS1 samples had the highest percentages of arboreal and shrub-like components (ca 50%), represented mainly by *Pinus* pollen (ca 40%), while non-arboreal pollen (NAP) was represented by Poaceae (ca 30%; Fig. 3D). The arboreal pollen (AP) values fell by up to 20% in the BS2 and BS5 samples, with *Pinus* pollen most abundant, followed by *Quercus* and *Juniperus*-type. Among the NAP component, Poaceae (up to 43%), Cichorioideae and Fabaceae (up to 15%; Fig. 3D) were the most frequent pollen grains in the BS4 and BS2 samples. Liliaceae, Asteroideae (NAP) and *Phillyrea* (AP) pollen grains were constant in all the samples examined. Pollen grains of aquatic plants such as *Typha* were found only in the BS2 and BS4 samples. In this archaeological area, anthropic indicators were represented by Poaceae, Cichorioideae and Urticaceae (*Urtica dioica*). In parallel with the occurrence of *Vitis*, the presence of "Cerealia-type" pollen grains and anthropic-indicator pollen such as Urticaceae is evidence of land designated for arable agriculture.

Site 5 (LSG, Lagoon of Santa Gilla)

Organic matter characterization. The amphora sediments showed high values for TLC (10–40%), ALC (5–30%) and CM fragments (10–30%; Tab. 2). SP and AOM content was generally at ca 5%, except in sample LSG6 where AOM reached 40%. MYC content was negligible. OP reached 20% of total organic matter (TOM) content only in samples LSG4 and LSG6, and was less abundant in the other samples, as were GP and PY.

Palynology. Pollen grains in a good state of preservation were abundant in all samples from the examined amphoras. The pollen spectra of these samples were quite similar, characterized by a high percentage of NAP (ca 80%; Fig. 3E), mainly Cyperaceae/Juncaceae (ca 20%), Amaranthaceae/Chenopodiaceae (ca 12%) and Poaceae (ca 10%), followed by Ranunculaceae and Liliaceae (10% each). The anthropic indicators were represented by "Cerealia-type" (ca 10%), *Urtica dioica* (3%), *Vitis* (3%), and *Asphodelus* (1%) pollen grains. The AP component was further represented by Ericaceae (ca 3%), *Juniperus* type (3%), and *Quercus ilex* and *Q. suber* type (3%; Fig. 3E).

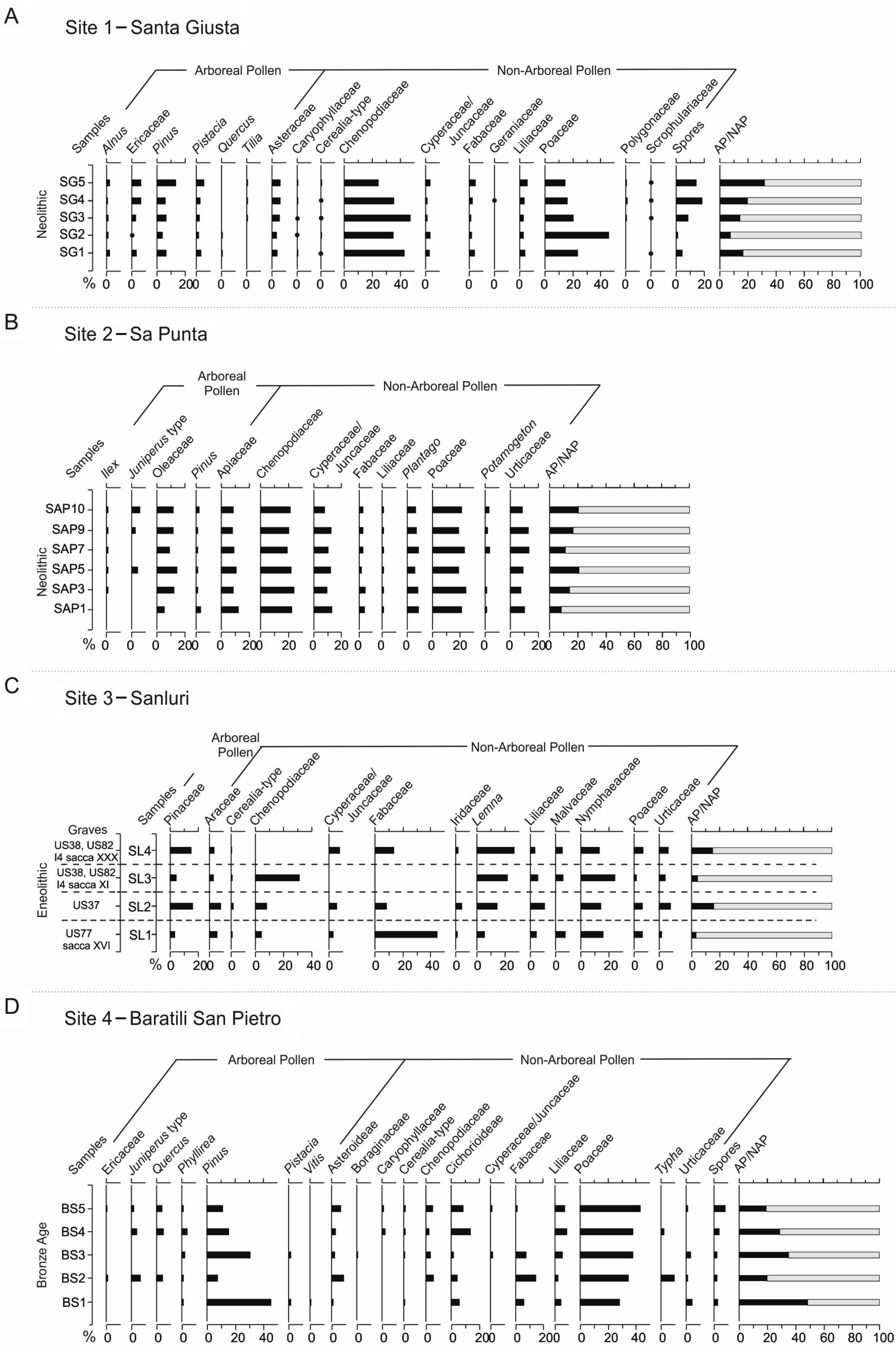
Spores and pollen grains (SP) were observed in the pond deposits (Santa Giusta), Eneolithic graves (Sanluri) and Punic amphoras through the entire record at different frequencies and in different maximum amounts (counted as thousands per gram). In general, SP values were low when the values for the OP category and ALC plant remains were significant. In terms of plant origins, the analysed Early Neolithic records were dominated by herbaceous vegetation; the Eneolithic also showed an abundant herbaceous layer, corresponding to a flat landscape frequented and inhabited by human beings and animals. During the Bronze Age, there were only a few records of Poaceae, Fabaceae and *Vitis* from the low vegetation. Among the arboreal species, it is worth noting that only *Pinus* pollen of the "*halepensis*" type was present in almost all the records from the Neolithic to the Punic Age.

MULTIVARIATE ANALYSIS

Cluster analysis of 13 parameters divided the stations into Clusters 1, 2 and 3, and the parameters into groups A, B and C (Fig. 4). Cluster 1 included the sampling sites with the highest percentages of ALC and AOM and a moderate amount of TLC. Cluster 2 included the sampling sites with the highest percentages of TLC, CM, MYC and PATHO, and less frequent ALC and OP. Cluster 3 included the stations with the highest values for OP and a moderate value for ALC. Cluster A grouped the variables that indicate alteration of organic particles (ALC and OP), Cluster B included non-degraded particles (TLC and CM), and Cluster C included AOM, mycorrhizal, pathogenic and coprophilous fungi, spores and pollen grains, phytoliths and GP (Fig. 4).

In PCA, 61.6% of the data variance could be explained by the first two principal components (Fig. 5A), and 54.3% of it by the first and third principal components (Fig. 5B). The eigenvalues of components 1, 2 and 3 were 36.9, 24.6 and 17.4 respectively (Fig. 5A and B). The percentages of OP, ALC and AOM were the predominant elements in the first component, while the major contributions in the second component were from ALC, TLC and CM; in the third component the predominant elements were AOM and ALC (Fig. 5C).

PCA analysis (component 1 vs component 2, Fig. 5A) placed the stations in approximately the same groups as obtained with Q mode cluster analysis. Accordingly, those sites (SL2, SAP1, SAP3, SAP5, SAP7, SAP9, SAP10) on the right part of the diagram (Fig. 5A) can be assumed to contain sediment with high values of OP, whereas those at bottom left (SG1,


A
Site 1 – Santa Giusta
Arboreal Pollen
Non-Arboreal Pollen
Samples
Alnus
Ericaceae
Pinus
Pistacia
Quercus
Tilia
Asteraceae
Caryophyllaceae
Cerealia-type
Chenopodiaceae
Cyperaceae/ Juncaceae
Fabaceae
Geraniaceae
Liliaceae
Poaceae
Polygonaceae
Scrophulariaceae
Spores
AP/NAP
Neolithic
SG5
SG4
SG3
SG2
SG1
%
B
Site 2 – Sa Punta
Arboreal Pollen
Non-Arboreal Pollen
Samples
Ilex
Juniperus type
Oleaceae
Pinus
Apiaceae
Chenopodiaceae
Cyperaceae/ Juncaceae
Fabaceae
Liliaceae
Plantago
Poaceae
Potamogeton
Urticaceae
AP/NAP
Neolithic
SAP10
SAP9
SAP7
SAP5
SAP3
SAP1
%
C
Site 3 – Sanluri
Arboreal Pollen
Non-Arboreal Pollen
Samples
Pinaceae
Araceae
Cerealia-type
Chenopodiaceae
Cyperaceae/ Juncaceae
Fabaceae
Iridaceae
Lemna
Liliaceae
Malvaceae
Nymphaeaceae
Poaceae
Urticaceae
AP/NAP
Graves
Eneolithic
US38, US82 I4 sacca XXX
SL4
US38, US82 I4 sacca XI
SL3
US37
SL2
US77 sacca XVI
SL1
%
D
Site 4 – Baratili San Pietro
Arboreal Pollen
Non-Arboreal Pollen
Samples
Ericaceae
Juniperus type
Quercus
Phyllirea
Pinus
Pistacia
Vitis
Asteroideae
Boraginaceae
Caryophyllaceae
Cerealia-type
Chenopodiaceae
Cichorioideae
Cyperaceae/Juncaceae
Fabaceae
Liliaceae
Poaceae
Typha
Urticaceae
Spores
AP/NAP
Bronze Age
BS5
BS4
BS3
BS2
BS1
%

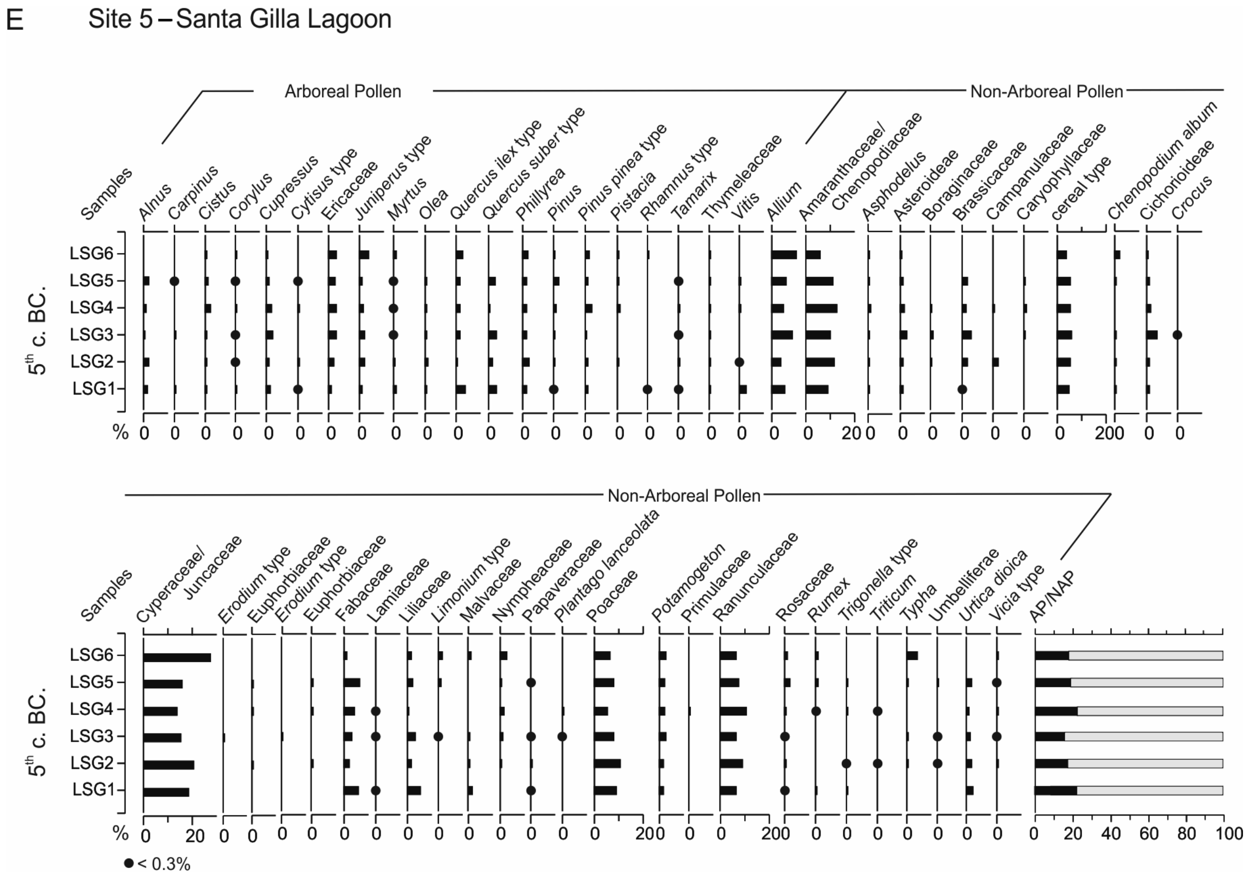


Fig. 3. **A–E**. Pollen spectra from the examined sediment

SG2, SG3, SG4, SG5, LSG6) are characterized by high content of ALC, AOM and SP (Fig. 5A). The sediment from the Santa Gilla Lagoon amphoras is in the upper left and is characterized by high presence of TLC and CM (LSG1, LSG2, LSG3, LSG5). Finally, the sites grouped at the top centre (SL3, SL4, BS1, BS2, BS3, BS4 and BS5, LSG4) contain sediment with high values for fungi (MYC, mycorrhizal, pathogenic and coprophilous fungi).

PCA analysis (component 1 vs component 3, Fig. 5B) grouped the sampling sites with high percentages of MYC, mycorrhizal, pathogenic and coprophilous fungi (BS3, SL3, SL4) and OP (SAP1, SAP3, SAP5, SAP7, SAP9, SAP10, SL2) at right on the diagram, while the stations with high values of ALC, TLC and CM (LSG1, LSG2, LSG3, LSG5, SG3, SG4, SG5) are at the bottom left. The sediment samples that contained important amounts of AOM (SG1, SG2, LSG6) are at the upper left.

DISCUSSION

Input of OM in recent deposits may originate from weathering of sedimentary rock, fluvial transport, and/or deposition on the alluvial plain by flooding. The OM particle distributions and content revealed by cluster analysis and PCA give grounds for suggested scenarios about the palaeoenvironment and land use at the examined sites, based on the origins of these OM particles and the presence of pollen and non-pollen palynomorphs. The occurrence and composition of OM in sediment are linked to different variables related to differences in origin, transport to the depositional site, and diagenetic alterations (Tyson 1995).

The sediment samples from Santa Giusta (SG1, SG2, SG4, SG5) and Santa Gilla Lagoon (LSG6), included in Cluster 1 (Fig. 4), show the highest AOM concentrations, indicating terrestrial conditions with high input of organic matter and bacterial action under reducing conditions in proximity to an aqueous environment (Noël et al. 2001, Sebag et al. 2006a). Palynological analysis reveals a landscape dominated by herbaceous plants, mainly Chenopodiaceae and Poaceae developed on an alluvial plain with wetlands, as shown by the presence of Juncaceae and Cyperaceae pollen grains. Arboreal and shrub-like species, represented by conifers (Pinaceae) and broadleaved taxa (*Alnus*,

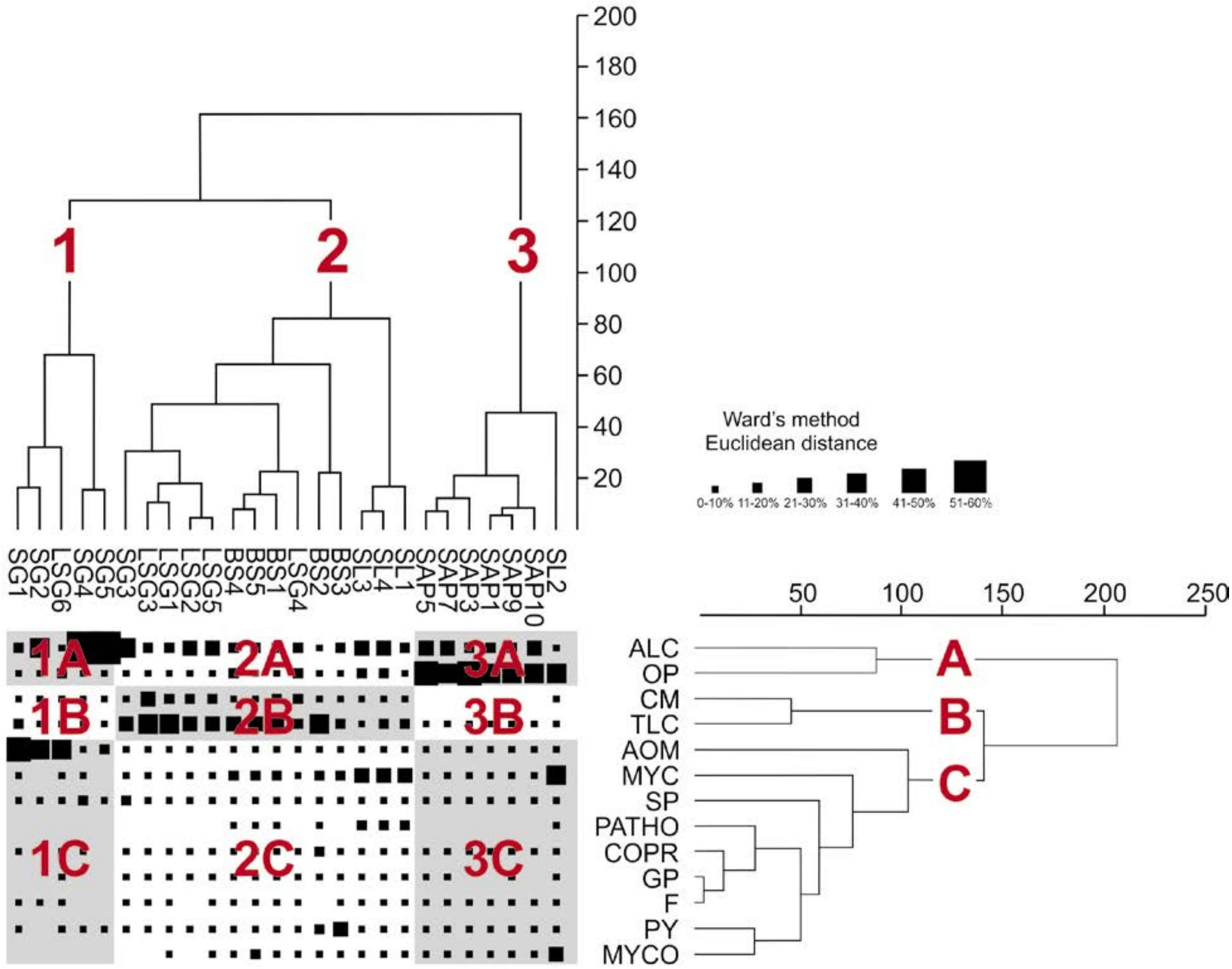


Fig. 4. Dendrogram of phytoclasts (right) and samples (top) produced by R-mode and Q-mode two-way cluster analyses using Euclidian distance

Quercus, *Corylus*, *Juglans*, *Tilia*), formed forest communities in the nearby mountains, also characterized by Ericaceae undergrowth. The data on the TLC, ALC and AOM categories, related to transport, sedimentation and diagenetic environments, seems to confirm the palynological interpretation. In fact, Table 2 shows that the Site 1 (Santa Giusta) sediment samples were composed of up to 70% altered lignocellulosic fragments (ALC) with transported, altered and opaque OM, representing a depositional area on the Oristano plain where erosional processes were predominant. Degradation of a higher amount of plant debris such as Cyperaceae/Juncaceae could have produced a high percentage of AOM. According to Sebag et al. (2006a), AOM content increases from terrestrial environments to fluvial deposits and reflects an abundance of aquatic production. Data from Site 1 (Santa Giusta) indicate that agriculture was not practised at the site during the Neolithic, as shown by the absence of mycorrhizal and coprophilous fungi and the low percentage (<1%) of "Cerealia-type" and anthropic-indicator pollen grains.

According to Sebag et al. (2006a), typical soil particles are dominated by TLC and ALC representing plant debris and reworked particles. Thus we can suggest a terrestrial soil origin of the particulate organic matter in the sediment samples from Santa Gilla Lagoon (LSG1–5), Santa Giusta (SG3), Baratili San Pietro (BS1–5) and Sanluri (SL1, SL3 and SL4) included in Cluster 2. These samples show dominance of translucent phytoclasts (TLC) accompanied by CM and to a lesser extent by MYC and ALC (Fig. 5). The high contribution of TLC indicates input of fresh plant litter of terrestrial origin and relatively rapid and relatively short transport. For Site 3 (Sanluri) the palynological spectrum suggests the presence of stagnant freshwater conditions, as indicated by the highest percentage of pollen of Nymphaeaceae and *Lemna*, which are known to live in aquatic environments. In addition, the abundance of the fungal fragments (MYC), especially

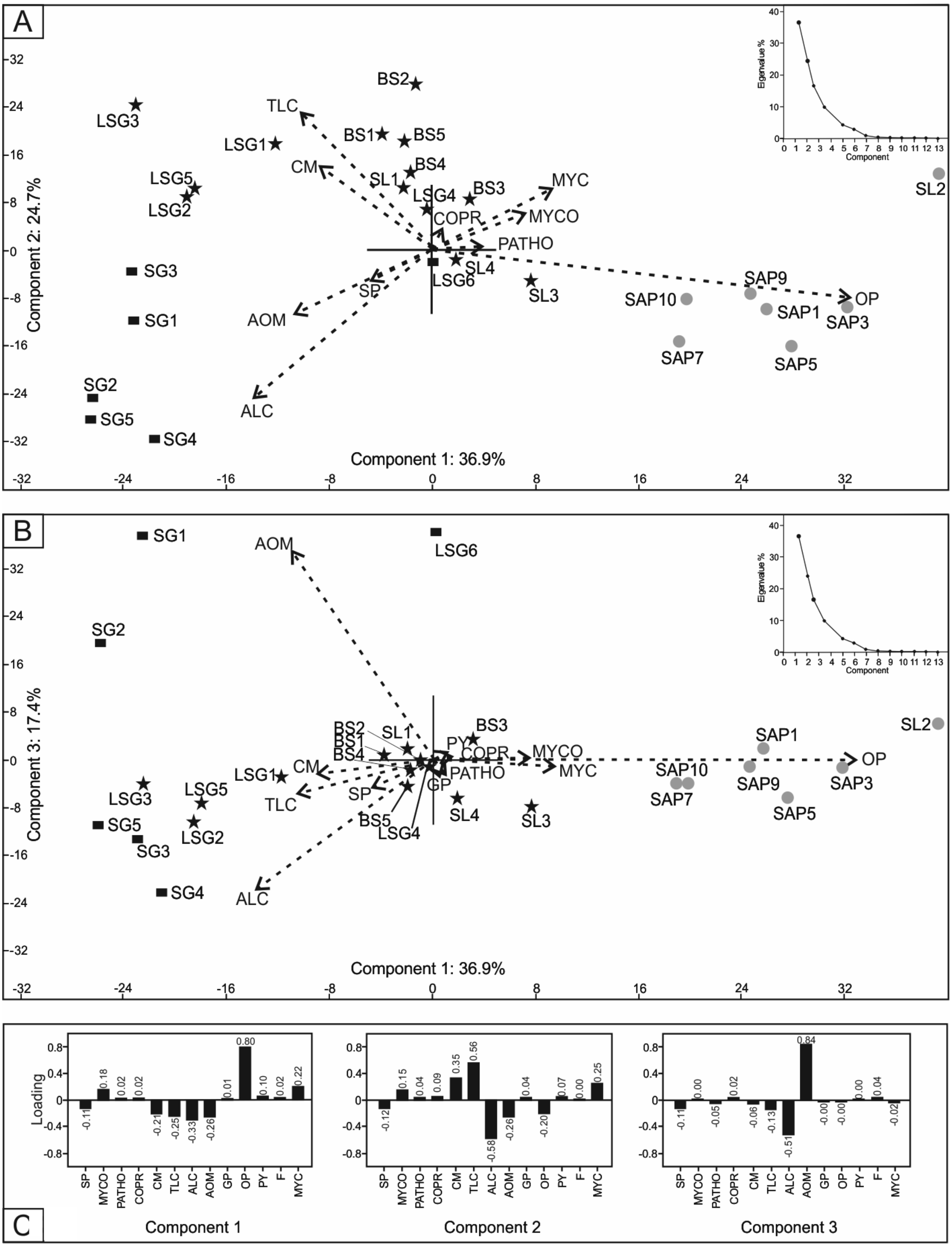


Fig. 5. PCA ordination diagram of sampling based on palynofacies assemblages: A: component 1 vs component 2; B: component 1 vs component 3; C: PCA loadings of components 1, 2 and 3

in the samples from Sites 3 and 4 (Sanluri and Baratili S. Pietro), is a useful marker of aerobic biodegradation of plant remains. In particular, the data from the Site 3 (Sanluri) record document relatively intensive agricultural practices, reflected in the presence of mycorrhizal (MYCO) and pathogenic (PATHO) fungi in the sediment; this is also attested by the presence of "Cerealia-type" pollen grains. The fungi identified are attributable to Tilletiaceae, which also contain economically important parasites of cultivated plants (cereals). Teliospores infect Graminaceae such as *Triticum*, *Elymus*, *Digitaria*, *Panicum* and others. In the samples from Site 4 (Baratili San Pietro) the notable abundance of coprophilous fungi (up to 10% at BS2) probably can be linked to domestic stock, as these ascospores indicate the dung of herbivores or decaying plant material (e.g. van Geel et al. 1981, Graf & Chmura 2006, van Geel & Aptroot 2006). The relative frequencies of *Vitis* and "Cerealia-type" pollen grains associated with mycorrhizal fungi and anthropic-indicator pollen grains (Cichorioideae, Urticaceae) could indicate that Middle Bronze Age people living in huts on the alluvial plain based their subsistence on agriculture and livestock. Cichorioideae (synonym of fenestrate pollen) are common in many habitats of southern Italy, where they prevail in secondary pastures and some types of primary open habitat (Florenzano et al. 2015). The recovery of high percentages of this pollen may be considered an indicator of these habitats even in past environments.

Palynological analysis of the samples from Site 5 (Santa Gilla Lagoon) suggests the occurrence of agro-pastoral practices on the plains or in the area behind the lagoon system. As shown in Figure 3E, rural plants and anthropic indicators like Liliaceae (*Asphodelus*), Papaveraceae, *Plantago lanceolata*, *Urtica dioica* and cultivated Poaceae (*Triticum*) are recurrent in the pollen spectra and are linked to the presence of human groups and herbivore herds. According to Buosi et al. (2017), the presence of *Vitis*, *Sorbus*, *Ficus*, *Olea* and *Prunus* seeds confirms the farming and trading of these plants in Sardinia during the Punic occupation. The pollen spectra document the presence of holm oak and cork oak forest (*Quercus ilex*, *Q. suber*), Mediterranean vegetation (*Juniperus*, *Pinus* and *Ericaceae*), and aquatic herbaceous plants growing on littoral dunes and saline soils (Chenopodiaceae and *Juniperus*) and in stagnant coastal systems (Cyperaceae/Juncaceae). These environmental conditions are also documented by the high percentages of TLC, CM and ALC particles indicating input of fresh plant litter of local terrestrial origin, fluvial sediment transport and consequent erosional processes. Among the fungi, coprophilous ones were recognized in all the examined samples of the LSG site, whereas mycorrhizal fungi (MYCO, Glomeraceae) were present only at LSG1 and LSG5. Their presence is linked to biodegradation of plant remains in an aquatic environment.

Finally, Cluster 3 (Fig. 4) groups sediments from the Sa Punta and Sanluri (SL2) sites. PCA (Fig. 5) shows that these samples are characterized by high percentages of transformed OM (OP, ALC), probably related to river transport facies. The OP category reaches very high levels (35–50%) and seems linked to charcoal accumulation. TLC, AOM fragments and cuticles were generally absent. The strong presence of OP and ALC particles is evidence of an open environment having grassland soil layers subject to fire practices during drier seasons. At the Sa Punta site this environment is also documented by the dominance of herbaceous vegetation (Poaceae, Chenopodiaceae) in the pollen spectra. The relatively high frequency of Cyperaceae/Juncaceae and Chenopodiaceae is related to the natural environment and wetlands. Chenopodiaceae are common in salt marsh vegetation, whereas Cyperaceae/Juncaceae and *Potamogeton* represent taxa of brackish and freshwater environments. Pollen grains of Oleaceae, *Juniperus*, *Ilex* and *Pinus* reflect the presence of forest and/or scrub at some distance. In the analysis of Poaceae pollen grains, the absence of "Cerealia-type" pollen and other anthropic indicators shows no evidence that arable agriculture was practised in the Early Neolithic community on the Oristano plain (Sa Punta), as also suggested by the modest levels of mychorrizal fungi (MYCO).

Sheep farming in this region cannot be excluded, however, due to the occurrence of coprophilous fungi in the examined samples, indicating the presence of dung, and the finding of an ovicaprine tooth (Lugliè et al. 2012, Pittau et al. 2012). The data for the Sa Punta site suggest a natural environment of low flatland formed of alluvial deposits, crossed by streaming waters and river channels. It was characterized by open low vegetation and poor abundance of trees, and was covered mainly by wild grasses and salt marsh vegetation. The main human activity appears to have been based on livestock, probably associated with fire practices. At Sanluri (SL2 sample) the very high content of pathogens and mycorrhizae and "Cerealia-type" pollen seem to attest to intensive agriculture on the Campidano plain. For this site the high percentages of

Nymphaeaceae and *Lemna* pollen grains suggest stagnant freshwater conditions.

Palynofacies analysis, which is a combination of palynological and OM analyses, were able to reveal additional information about the past environment of the studied sites, also providing new data concerning the vegetation, land uses and human impacts in Sardinia in the past. In particular, the palynological data grounded a reconstruction of the past vegetation cover, whereas the OM analyses were aimed at identifying the different organic constituents, distinguishing between those originating from aquatic (autochthonous) production and those derived from erosion and transport of different soil horizons (allochthonous). In the case of Sites 2 (Sa Punta), 3 (Sanluri) and 4 (Baratili San Pietro), characterized by their sparse palynological content, the description and interpretation of palynofacies also provided information about land uses and particularly about agricultural practices and pasturing.

CONCLUSIONS

In this study, optical characterization of organic matter particles was combined with standard pollen analyses in order to investigate sediments deposited in lagoons, deltas and ponds after flooding in areas of archaeological interest. The study revealed the distinct sources of OM, related to the past environment and land uses. The palynofacies method applied to the archaeological layers yielded adequate proxy evidence of the ancient environment and human activities. After statistical analyses, all samples of the studied localities were grouped in three clusters and along three parameters according to their composition. Terrestrial conditions with high input of organic matter and bacterial action under reducing conditions near an aquatic environment were indicated by high AOM concentrations and were confirmed at lagoon sites (Santa Giusta, Santa Gilla); these sites belong to Cluster 1. Cluster 2 includes samples with high percentages of TLC, CM, MYC and PATHO, indicating biodegradation of plant remains. Cluster 3 groups sediments from Sa Punta (Site 2) and Sanluri (Site 3), characterized by high OP values and moderate ALC percentages, indicating open environments.

These new data add to our knowledge of Sardinian archaeobotany, which has been little developed until very recently. Concerning the oldest analysed site (Sa Punta, Site 2), there is no strong evidence of agricultural practices in the Early Neolithic, due to the absence of "Cerealia-type" pollen grains and other anthropic indicators; this is also suggested by the modest levels of the mychorrizal fungi (MYCO) at this site. Neolithic agriculture at other sites in Sardinia has been demonstrated in recent work (Ucchesu et al. 2015). Our research intends to furnish new data for the Italian database of archaeobotany (BRAIN) by analysing four new sites not included yet.

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REFERENCES

ACQUARO E., CARAMIELLO R., VERGA F., ORTU E. & AROBBA D. 2001. Analyses palynologiques et anthracologiques du site phénicien-punique de Tharros (Sardaigne). Revue d'Archèometrie, 25: 45–51.

ANTONIOLI F., ANZIDEI M., LAMBECK K., AURIEMMA R., GADDI D., FURLANI S., ORRÙ P., SOLINAS E., GASPARI A., KARINJA S., KOVAC V. & SURACE L. 2007. Sea-level change during the Holocene in Sardinia and in the northeastern Adriatic (central Mediterranean Sea) from archaeological and geomorphological data. Quat. Sci. Rev., 26: 2463–2486.

ANTONIOLI F., FERRANTI L., FONTANA A., AMOROSI A., BONDESAN A., BRAITENBERG C., DUTTON A. FONTOLAN G., FURLANI S., LAMBECK K., MASTRONUZZI G., MONACO C., SPADA G. & STOCCHI P. 2009. Holocene relative sea-level changes and vertical movements along the Italian and Istrian coastlines. Quat. Int., 206: 102–133.

BARBACKA M., BODOR E., JARZYNKA A., KUSTATSCHER E., PACYNA G., POPA M.E., SCANU G.G., THÉVENARD F. & ZIAJA J. 2014. European Jurassic floras: Statistics and palaeoenvironmental proxies. Acta Palaeobot., 54: 173–195.

BATTEN D.J. 1996. Chapter 26A. Palynofacies and palaeoenvironmental interpretation: 1011–1064. In: JANSONIUS J. & McGREGOR D.C. (eds), Palynology: principles and applications, Volume 3, American Association of Stratigraphic Palynologists' Foundation, Dallas.

BEFFA G., PEDROTTA T., COLOMBAROLI D., HENNE P.D., VAN LEEUWEN J.F., SÜSSTRUNK P., KALTENRIEDER P., ADOLF C., VOGEL H., PASTA S., ANSELMETTI F.S., GOBET E. & TINNER W. 2016. Vegetation and fire history of coastal north-eastern Sardinia (Italy) under changing Holocene climates and land use. Veg. Hist.Archaeobot., 25: 271–289.

BEHRE K-E. 2007. Evidence for Mesolithic agriculture in and around central Europe? Veg. Hist. Archaeobot., 16: 203–219.

BERNARDINI P., SANTONI V. & SOLINAS E. 1993. Il Mistero di Santa Gilla. Archeologia Viva, 37: 26–40.

BOURDON S., LAGGOUN-DEFARGE F., DISNAR J.R., MAMAN O., GUILLET B., DERENNE S. & LARGEAU C. 2000. Organic matter sources and early diagenetic degradation in a tropical peaty marsh (Tritrivakely, Madagascar). Implications for environmental reconstruction during the Sub-Atlantic. Org. Geochem., 21: 421–438.

BUOSI C., PITTAU P., DEL RIO M., MUREDDU D. & LOCCI M.C. 2013. Palynological investigation of funerary urn contents from the Roman Imperial Age necropolis in Sardinia (Italy). Palynology, 37: 130–42.

BUOSI C., DEL RIO M., ORRÙ P., PITTAU P., SCANU G.G. & SOLINAS E. 2017. Sea level changes and past vegetation in the Punic period (5th–4th century BC): Archaeological, geomorphological and palaeobotanical indicators (South Sardinia–West Mediterranean Sea). Quat. Inter., 439: 141–157.

BUOSI C., PITTAU P., PAGLIETTI G., SCANU G.G., SERRA M., UCCHESU M. & TANDA G. 2015. A human occupation cave during the bronze age: archaeological and palynological applications of a case study in Sardinia (western Mediterranean). Archaeometry, 57 S1: 212–231.

CIRILLI S., BURATTI N., GUGLIOTTI L. & FRIXA A. 2015. Palynostratigraphy and palynofacies of the Upper Triassic Streppenosa Formation (SE Sicily, Italy) and inference on the main controlling factors in the organic rich shale deposition. Rev. Palaeobot. Palynol., 218: 67–79.

CLEAL C.J., SCANU G.G., BUOSI C., PITTAU P. & KUSTATSCHER E. 2017. Middle Pennsylvanian vegetation of the San Giorgio Basin, southern Sardinia (Italy). Geol. Magaz., 154: 1155–1170.

COHEN A.D., GAGE C.P. & MOORE W.S. 1999. Combining organic petrography and palynology to assess anthropogenic impacts on peatlands. Part 1. An example from the northern Everglades of Florida. Int. J. Coal. Geol., 39: 3–45.

COMBAZ A. 1964. Les palynofaciès. Rev. Micropaleontol., 7: 205–218.

CROSS A.T. 1964. Plant Microfossils and Geology an Introduction. Special publication (Society of Economic Paleontologists and Mineralogists) 11.

CUGNY C., MAZIER F. & GALOP D. 2010. Modern and fossil non-pollen palynomorphs from the Basque mountains (western Pyrenees, France): the use of coprophilous fungi to reconstruct pastoral activity. Veg. Hist. Archaeobot., 19: 391–408.

CURRÁS A., GHILARDI M., PECHE-QUILICHINI K., FAGEL N., VACCHI M., DELANGHE D., DUSSOUILLEZ P., VELLA C., BONTEMPI J.M. & OTTAVIANI J.C. 2017. Reconstructing past landscapes of the eastern plain of Corsica (NW Mediterranean) during the last 6000 years based on molluscan, sedimentological and palynological analyses. J. Archaeol. Sci. Rep., 12: 755–769.

DAVIS O.K. & SHAFER D.S. 2006. *Sporormiella* fungal spores, a palynological means of detecting herbivore density. Palaeogeogr. Palaeoclim. Palaeoecol., 237: 40–50.

DEPALMAS A. & MELIS R.T. 2011. The Nuragic People: Their Settlements, Economic Activities and Use of the Land, Sardinia, Italy: 167–186. In: Martini I.P., Chesworth W. (eds), Landscapes and Societies. Springer Science+Business Media B.V., Dordrecht.

DI GIOVANNI C., DISNAR J.R., CAMPY M. & MACAIRE J.J. 1999. Variability of the ancient organic supply in modern humus. Analusis, 27: 398–402.

DI RITA F. & MELIS R.T. 2013. The cultural landscape near the ancient city of Tharros (central West Sardinia): vegetation changes and human impact. J. Archaeol. Sci., 40: 4271–4282.

ERDTMAN G. 1986. Pollen Morphology and Plant Taxonomy: Angiosperms. The Netherlands, Leiden.

FAEGRI K. & IVERSEN J. 1989. Textbook of pollen analysis, 4th ed. Munksgaard, Copenhagen.

FIACCONI M. & HUNT C.O. 2015. Pollen taphonomy at Shanidar Cave (Kurdish Iraq): an initial evaluation. Rev. Palaeobot. Palynol., 223: 87–93.

FLORENZANO A., MARIGNANI M., ROSATI L., FASCETTI S. & MERCURI A. M. 2015. Are Cichorieae an indicator of open habitats and pastoralism in current and past vegetation studies? Plant Biosystems – An International Journal Dealing with all Aspects of Plant Biology, 149(1): 154–165.

FONZO O. 2005. Conservazione e trasporto delle carni a Cagliari in età punica: 365–369. In: Fiore I., Malerba G. & Chilardi S. (eds), Atti del terzo Convegno AIAZ, Roma.

FYFE R.M. 2012. Bronze Age landscape dynamics: spatially detailed pollen analysis from a ceremonial complex. J. Archaeol. Sci., 39: 2764–73.

GARCÍA MURO V.J., RUBINSTEIN C.V. & MARTÍNEZ M.A. 2016. Palynology and palynofacies analysis of a Silurian (Llandovery–Wenlock) marine succession from the Precordillera of western Argentina: Palaeobiogeographical and palaeoenvironmental significance. Mar. Micropaleontol., 126: 50–64.

GASTALDO R.A. & HUC A.Y. 1992. Sediment facies, depositional environments, and distribution of phytoclasts in the Recent Mahakam River delta, Kalimantan, Indonesia. Palaios, 7: 574–590.

GASTALDO R.A., RIEGEL W., PÜTTMANN W., LINNEMANN U.G. & ZETTER, R. 1998. A multidisciplinary approach to reconstruct the Late

Oligocene vegetation in central Europe. Rev. Palaeobot. Palynol., 101: 71–94.

GEIB P.R. & SMITH S.J. 2008. Palynology and archaeological inference: bridging the gap between pollen washes and past behaviour. J. Archaeol. Sci., 35: 2085–2101.

GRAF M. & CHMURA G.L. 2006. Development of modern analogues for natural, mowed and grazed grasslands using pollen assemblages and coprophilous fungi. Rev. Palaeobot. Palynol., 141: 139–149.

GRILL S., FRANCO V. & SALAZAR J. 2013. Condiciones climáticas y ambientales durante el primer milenio de la era en el Valle de Tafí, Tucumán, Argentina. Rev. Bras. Paleontol, 16: 495–506.

GRILL S., BORROMEI A., MARTÍNEZ G., GUTIERREZ M.A., CORNOU M.E. & OLIVERA D. 2007. Palynofacial analysis in alkaline soils and paleoenvironmental implications: The Paso Otero 5 archaeological site (Necochea district, Buenos Aires province, Argentina). J. South Am. Earth Sci., 24: 34–47.

HAMMER Ø., HARPER D.A.T. & RYAN P.D. 2001. PAST: Paleontological statistics software package for education and data analysis. Palaeontol. Electron., 4.

HOCHULI P.A., ROGHI G. & BRACK P. 2015. Palynological zonation and particulate organic matter of the Middle Triassic of the Southern Alps (Seceda and Val Gola–Margon sections, Northern Italy). Rev. Palaeobot. Palynol., 218: 28–47.

KOCH G., PRTOLJAN B., HUSINEC A. & HAJEK-TADESSE V. 2017. Palynofacies and paleoenvironment of the Upper Jurassic mud-supported carbonates, southern Croatia: Preliminary evaluation of the hydrocarbon source rock potential. Mar. Petrol. Geol., 80: 243–253.

KUMAR M., SPICER R. A., SPICER T.E.V., SHUKLA A., MEHROTRA R.C. & MONGA P. 2016. Palynostratigraphy and palynofacies of the early Eocene Gurha lignite mine, Rajasthan, India. Palaeogeogr. Palaeoclim. Palaeoecol., 461: 98–108.

LAGGOUN-DÉFARGE F., PRADIER B., BROSSE E., BELIN S. & OUDIN J.L. 1995. Analyse microtexturale des sédiments organiques du Delta de la Mahakam (Indonésie). Relations avec les environnements de dépôt. Comptes rendus de l'Académie des sciences de Paris. Série 2. Sciences de la Terre et des Planètes, 320: 1055–1061.

LÓPEZ P., LÓPEZ SÁEZ J.A. & ROSARIO M. 2005. Studio de la paleovegetación de algunos yacimientos de la Edad del Bronce en el SE de Cerdeña. Anejos de Complutum, 10: 91–105.

LOPEZ-SAEZ J.A. & LOPEZ-MERINO L. 2007. Coprophilous fungi as a source of information of anthropic activities during the Prehistory in the Amblés Valley (Ávila, Spain): The archaeopalynological record. Rev. Esp. Micropaleontol., 39: 103–116.

LUGLIÈ C., SANNA I., CONGIA C., PITTAU P. & BUOSI C. 2012. Il Neolitico antico terminale di Sa Punta – Marceddì (Terralba, OR). Atti della XLIV Riunione Scientifica – La Preistoria e la Protostoria della Sardegna, 463–470.

MARIOTTI LIPPI M., BELLINI C., MORI SECCI M. & GONNELLI T. 2009. Comparing seeds/fruits and pollen from a Middle Bronze Age pit in Florence (Italy). J. Archaeol. Sci., 36: 1135–41.

MARTELLA P., PUSCEDDU V. & FLORIS R. 2012. Human osteoarchaeology of Monte Claro culture Eneolithic remains in Southern-Central Sardinia. J. Biol. Res., 84: 85–87.

MAZIER F., GALOP D., GAILLARD M.J., RENDU C., CUGNY C., LEGAZ A., PEYRON O. & BUTTLER A. 2009. Multidisciplinary approach to reconstructing local pastoral activities: an example from the Pyrenean Mountains (Pays Basque). The Holocene, 19: 171–188.

MELIS R.T., DEPALMAS A., DI RITA F., MONTIS F. & VACCHI M. 2017. Mid to late Holocene environmental changes along the coast of western Sardinia (Mediterranean Sea). Glob. Plane. Change, 155: 29–41.

MERCURI A.M. 2008. Human influence, plant landscape evolution and climate inferences from the archaeobotanical records of the Wadi Teshuinat area (Libyan Sahara). J. Arid Environ., 72: 1950–67.

MERCURI A.M., SADORI L. & BLASI C. 2010. Archaeobotany for cultural landscape and human impact reconstructions. Plant Biosyst., 144: 860–864.

MERCURI A.M., ALLEVATO E., AROBBA D., BANDINI MAZZANTI M., BOSI G, CARAMIELLO R., CASTIGLIONI E., CARRA M.L., CELANT A., COSTANTINI L., DI PASQUALE G., FIORENTINO G., FLORENZANO A., GUIDO M., MARCHESINI M., MARIOTTI LIPPI M., MARVELLI S., MIOLA A., MONTANARI C., NISBET R., PEÑA-CHOCARRO L., PEREGO R., RAVAZZI C., ROTTOLI M., SADORI L., UCCHESU M. & RINALDI R. 2015. Pollen and macroremains from Holocene archaeological sites: A dataset for the understanding of the bio-cultural diversity of the Italian landscape. Rev. Palaeobot. Palynol., 218: 250–266.

MOORE P.D., WEBB J.A. & COLLINSON M.E. 1991. Pollen Analysis. Blackwell Scientific Publications, Oxford.

MORALES J., PÉREZ-JORDÀ G., PEÑA-CHOCARRO L., ZAPATA L., RUÍZ-ALONSO M., LÓPEZ-SÁEZ J.A. & LINSTÄDTER J. 2013. The origins of agriculture in North-West Africa: macro-botanical remains from Epipalaeolithic and Early Neolithic levels of Ifri Oudadane (Morocco). J. Archaeol. Sci., 40: 2659–2669.

NOËL H., GARBOLINO E., BRAUER A., LALLIER-VERGES E., DE BEAULIEU J.-L. & DISNAR J.-R. 2001. Human impact and soil erosion during the last 5000 yrs as recorded in lacustrine sedimentary organic matter at Lac d'Annecy, the French Alps. J. Paleolimnol., 25: 229–244.

NOVÁK J., ABRAHAM V., KOČÁR P., PETR L., KOČÁROVÁ R., NOVÁKOVÁ K., HOUFKOVÁ P., JANKOVSKÁ V. & VANĚČEK Z. 2017. Middle-and upper-Holocene woodland history in central Moravia

(Czech Republic) reveals biases of pollen and anthracological analysis. The Holocene, 27: 349–360.

OKEKE K.K. & UMEJI O.P. 2016. Palynostratigraphy, palynofacies and palaeoenvironment of deposition of Selandian to Aquitanian sediments, southeastern Nigeria. J. Afr. Earth Sci., 120: 102–124.

PESCINI V., MONTANARI C.A. & MORENO D.T. 2018. Multi-proxy record of environmental changes and past land use practices in a Mediterranean landscape: The Punta Mesco cape (Liguria – Italy) between the 15th and 20th century. Quat. Int., 463: 376–390.

PIGNATTI S. 1982. Flora d'Italia. Edagricole, Bologna.

PINI R., RAVAZZI C., RAITERI L., GUERRESCHI A., CASTELLANO L. & COMOLLI R. 2017. From pristine forests to high-altitude pastures: an ecological approach to prehistoric human impact on vegetation and landscapes in the western Italian Alps. J. Ecol., 105: 1580–1597.

PIPERNO D.R. 2006. Phytoliths. A comprehensive guide for archaeologists and palaeoecologists. Altamira Press, Oxford.

PITTAU P., LUGLIÈ C. BUOSI C., SANNA I. & DEL RIO M. 2012. Palynological interpretation of the Early Neolithic coastal open-air site at Sa Punta (central-western Sardinia, Italy). J. Archaeol. Sci., 39: 1260–1270.

PUSCEDDU V., MARTELLA P., FLORIS R. & DEL VAIS C. 2012. Phoenician-Punic inhumations from Othoca Necropolis (Santa Severa, Santa Giusta - Or). J. Biol. Res., 84: 190–193.

REILLE M. 1995. Pollen et Spores d'Europe et d'Afrique du Nord. Suppl. 1. Laboratoire de Botanique Historique et Palynologie, Marseille.

REILLE M. 1998. Pollen et spores d'Europe et d'Afrique du Nord. Suppl. 2. Laboratoire de Botanique Historique et Palynologie, Marseille.

REILLE M. 1999. Pollen et spores d'Europe et d'Afrique du Nord, seconde ed. Laboratoire de Botanique Historique et Palynologie, Marseille.

SABATO D., MASI A., PEPE C., UCCHESU M., PEÑA-CHOCARRO L., USAI A., GIACHI G. CAPRETTI C. & BACCHETTA G. 2015. Archaeobotanical analysis of a Bronze Age well from Sardinia: a wealth of knowledge. Plant Biosystems-An International Journal Dealing with all Aspects of Plant Biology, 149: 205–215.

SADORI L., MERCURI A.M. & MARIOTTI LIPPI M. 2010. Reconstructing past cultural landscape and human impact using pollen and plant macroremains. Plant Biosyst., 144: 940–51.

SADORI L., GIRAUDI C., MASI A., MAGNY M., ORTU E., ZANCHETTA G. & IDEBSKI A. 2016. Climate, environment and society in southern Italy during the last 2000 years. A review of the environmental, historical and archaeological evidence. Quat. Sci. Rev., 136: 173–188.

SEBAG D., COPARD Y., DI GIOVANNI C., DURAND A., LAIGNEL B. OGIER, S. & LALLIER-VERGES E. 2006a. Palynofacies as useful tool to study origins and transfers of particulate organic matter in recent terrestrial environments: Synopsis and prospects. Earth-Sci. Rev., 79: 241–259.

SEBAG D., DI GIOVANNI C., OGIER S., MESNAGE V., LAGGOUN-DÉFARGE F. & DURAND A. 2006b. Inventory of sedimentary organic matter in modern wetland (Marais Vernier, Normandy, France) as source-indicative tools to study Holocene alluvial deposits (Lower Seine Valley, France). Int. J. Coal. Geol., 67: 1–16.

SEBIS S. & PAU L. 2012. L'insediamento nuragico di Sipoi, Baratili S. Pietro (OR). La preistoria e protostoria della Sardegna. Atti della XVIV Riunione Scientifica, 1393–1398.

SERNA Y., VELEZ M.I. & ESCOBAR J. 2015. Microscopic organic matter particles in late Holocene riparian sediments near the Cauca River, Colombia. J. Paleolimnol., 54: 325–344.

SOLINAS E. & ORRÙ P. 2006. Santa Gilla: spiagge sommerse e frequentazione di epoca punica: 249–252. In: Giannattasio B.M. (Ed.), Aequora, pontos, jam, mare… Mare, uomini e merci nel Mediterraneo Antico. Atti del Convegno Internazionale (Genova, 9–10 dicembre 2004), All'insegna del Giglio, Firenze.

SOLINAS E. 1997. La laguna di Santa Gilla: testimonianze di età punica: 177–183. In: Bernardini P., D'Oriano R. & Spanu P.G. (eds), Phoinikes b Shrdn. I Fenici in Sardegna. Nuove Acquisizioni, Oristano.

STUIVER M., REIMER P.J. & REIMER R.W. 2016. CALIB 7.1 (WWW program) available from: http://calib.org. Accessed September 2017.

TRAVERSE A. 2007. Some factors affecting practical applications of paleopalynology: 581–613. Paleopalynology, second edition. Springer, Dordrecht.

TYSON R.V. 1995. Sedimentary organic matter: organic facies and palynofacies. Chapman & Hall, London.

UCCHESU M., PEÑA-CHOCARRO L., SABATO D. & TANDA G. 2015. Bronze Age subsistence in Sardinia, Italy: cultivated plants and wild resources. Veg. Hist. Archaeobot., 24: 343–355.

UGAS G. 1982. Il villaggio di fase Monte Claro di Corti Beccia e reperti della capanna 10 ovest. Ricerche archeologiche nel territorio di Sanluri: mostra grafica e fotografica, 13–18.

VAN DER ZWAN C.J. 1990. Palynostratigraphy and palynofacies reconstruction of the Upper Jurassic to lowermost Cretaceous of the Draugen field, offshore mid Norway. Rev. Palaeobot. Palynol., 62: 157–186.

VAN GEEL B. & APTROOT A. 2006. Fossil ascomycetes in Quaternary deposits. Nova Hedwigia, 82: 313–329.

VAN GEEL B. 2001. Non-pollen palynomorphs: 99–119. In: Smol J.P., Birks H.J.B., Last W.M. (eds) Tracking environmental change using lake sediments, volume 3: terrestrial, algal, and siliceous indicators. Kluwer Academic Publishers, Dordrecht.

VAN GEEL B., BOHNCKE S.J.P. & DEE H. 1981. A palaeoecological study of an Upper Late glacial and Holocene sequence from "de Borchert", the Netherlands. Rev. Palaeobot. Palynol., 31: 367–448.

Appendix 1

Palynomorphs contained in the examined sediments

Site 1 – Santa Giusta	SG1		SG2		SG3		SG4		SG5	
	n.	%	n.	%	n.	%	n.	%	n.	%
Arboreal pollen grains (AP)										
Alnus	45	2.5	15	0.9	29	1.4	7	0.6	19	2.2
Ericaceae	62	3.4	4	0.2	61	2.9	83	7.0	57	6.6
Pinus	124	6.8	57	3.5	137	6.5	73	6.2	124	14.4
Pistacia	63	3.4	30	1.8	52	2.5	34	2.9	50	5.8
Quercus	7	0.4	10	0.6	0	0.0	0	0.0	0	0.0
Tilia	2	0.1	4	0.2	9	0.4	7	0.6	6	0.7
Non-arboreal pollen grains (NAP)										
Asteraceae	74	4.0	56	3.4	116	5.5	76	6.4	56	6.5
Caryophyllaceae	7	0.4	2	0.1	2	0.1	10	0.8	4	0.5
Cerealia-type	2	0.1	4	0.2	2	0.1	1	0.1	4	0.5
Chenopodiaceae	829	45.2	582	35.4	1037	49.0	452	38.1	228	26.5
Cyperaceae	47	2.6	49	3.0	23	1.1	14	1.2	28	3.3
Fabaceae	75	4.1	27	1.6	26	1.2	27	2.3	41	4.8
Geraniaceae	0	0.0	0	0.0	0	0.0	1	0.1	0	0.0
Liliaceae	72	3.9	48	2.9	57	2.7	39	3.3	51	5.9
Poaceae	451	24.6	760	46.2	452	21.3	205	17.3	136	15.8
Polygonaceae	0	0.0	0	0.0	15	0.7	12	1.0	4	0.5
Scrophulariaceae	4	0.2	0	0.0	3	0.1	1	0.1	1	0.1
Total pollen grains	1864		1648		2021		1042		809	
Spores	78	4.3	21	1.3	189	8.9	235	19.8	132	15.3
Arboreal pollen grains (AP)	303	14.2	120	7.4	288	14.9	204	21.5	256	35.1
Non-arboreal pollen grains (NAP)	1561	85.8	1528	92.6	1733	85.1	838	78.5	553	64.9
Total palynomorphs	1942		1669		2210		1277		941	

Site 2 – Sa Punta	SAP1		SAP3		SAP5		SAP7		SAP9		SAP10	
	n.	%	n.	%	n.	%	n.	%	n.	%	n.	%
Arboreal pollen grains (AP)												
Ilex	0	0.0	1	0.9	1	0.9	1	1.0	1	0.9	1	1.0
Juniperus	0	0.0	0	0.0	5	4.5	0	0.0	3	2.7	6	5.8
Oleaceae	5	5.0	13	11.9	16	14.3	9	9.0	13	11.7	12	11.5
Pinus	3	3.0	1	0.9	1	0.9	1	1.0	1	0.9	2	1.9
Non-arboreal pollen grains (NAP)												
Apiaceae	12	12.0	9	8.3	12	10.7	9	9.0	9	8.1	9	8.7
Chenopodiaceae	22	22.0	26	23.9	24	21.4	19	19.0	22	19.8	22	21.2
Cyperaceae	13	13.0	9	8.3	12	10.7	10	10.0	14	12.6	7	6.7
Fabaceae	4	4.0	5	4.6	2	1.8	3	3.0	3	2.7	3	2.9
Juncaceae	0	0.0	1	0.9	1	0.9	0	0.0	0	0.0	1	1.0
Liliaceae	1	1.0	1	0.9	1	0.9	1	1.0	1	0.9	1	1.0
Plantago	8	8.0	8	7.3	6	5.4	8	8.0	7	6.3	6	5.8
Poaceae	21	21.0	26	23.9	21	18.8	23	23.0	21	18.9	22	21.2
Potamogetonaceae	1	1.0	1	0.9	0	0.0	3	3.0	2	1.8	3	2.9
Urticaceae	10	10.0	8	7.3	10	8.9	13	13.0	14	12.6	9	8.7
Total pollen grains	100		109		112		100		111		104	
Arboreal pollen grains (AP)	8	8.0	15	13.8	23	20.5	11	11.0	18	16.2	21	20.2
Non-arboreal pollen grains (NAP)	92	92.0	94	86.2	89	79.5	89	89.0	93	83.8	83	79.8
Total palynomorphs	100		109		112		100		111		104	

Site 3 – Sanluri	SL1		SL2		SL3		SL4	
	n.	%	n.	%	n.	%	n.	%
Arboreal pollen grains (AP)								
Pinus	4	3.4	8	15.7	3	4.1	9	14.5
Non-arboreal pollen grains (NAP)								
Araceae	6	5.0	4	7.8	2	2.7	2	3.2
Cerealia-type	2	1.7	1	2.0	1	1.4	1	1.6
Chenopodiaceae	5	4.2	4	7.8	23	31.1	0	0.0
Cyperaceae	2	1.7	2	3.9	0	0.0	4	6.5
Fabaceae	53	42.5	4	7.8	0	0.0	8	12.9
Iridaceae	1	0.8	2	3.9	0	0.0	1	1.6
Juncaceae	1	0.8	1	2.0	0	0.0	1	1.6
Lemnaceae	6	5.0	7	13.7	16	21.6	16	25.8
Liliaceae	5	4.2	5	9.8	4	5.4	2	3.2
Malvaceae	8	6.7	0	0.0	4	5.4	3	4.8
Nymphaeaceae	19	16.0	7	13.7	18	24.3	8	12.9
Poaceae	7	5.9	3	5.9	1	1.4	4	6.5
Urticaceae	2	1.7	4	7.8	3	4.1	4	6.5
Total pollen grains	121		52		75		63	
Spores	0	0.0	0	0.0	0	0.0	0	0.0
Arboreal pollen grains (AP)	4	3.4	8	15.7	3	4.1	9	14.5
Non-arboreal pollen grains (NAP)	117	96.6	44	84.3	72	95.9	54	85.5
Total palynomorphs	121		52		75		63	

Site 4 – Baratili San Pietro	BS1		BS2		BS3		BS4		BS5	
	n.	%	n.	%	n.	%	n.	%	n.	%
Arboreal pollen grains (AP)										
Ericaceae	0	0.0	1	1.0	0	0.0	0	0.0	1	0.4
Juniperus	0	0.0	6	6.3	0	0.0	4	3.8	4	1.7
Quercus	0	0.0	4	4.2	0	0.0	5	4.8	8	3.5
Phyllirea	1	0.9	1	1.0	3	2.3	4	3.8	2	0.9
Pinus	53	45.3	7	7.3	40	30.8	16	15.4	26	11.3
Pistacia	2	1.7	0	0.0	2	1.5	0	0.0	0	0.0
Vitis	1	0.9	0	0.0	0	0.0	0	0.0	0	0.0
Non-arboreal pollen grains (NAP)										
Asteroideae	1	0.9	8	8.3	3	2.3	3	2.9	15	6.5
Boraginaceae	0	0.0	0	0.0	1	0.8	0	0.0	0	0.0
Caryophyllaceae	0	0.0	0	0.0	0	0.0	2	1.9	2	0.9
Cerealia-type	1	0.9	1	1.0	1	0.8	0	0.0	2	0.9
Chenopodiaceae	0	0.0	5	5.2	4	3.1	2	1.9	11	4.8
Cichorioideae	7	6.0	4	4.2	2	1.5	14	13.5	20	8.7
Cyperaceae	0	0.0	0	0.0	2	1.5	0	0.0	3	1.3
Fabaceae	7	6.0	14	14.6	10	7.7	0	0.0	2	0.9
Liliaceae	5	4.3	2	2.1	7	5.4	9	8.7	17	7.4
Poaceae	32	28.2	33	34.4	48	37.7	39	37.5	100	43.3
Typha	0	0.0	9	9.4	0	0.0	2	1.9	0	0.0
Urticaceae	5	4.3	1	1.0	4	3.1	0	0.0	3	1.3
Total pollen grains	115		96		127		100		216	
Spores	3	2.6	2	2.1	3	2.3	4	3.8	18	7.8
Arboreal pollen grains (AP)	56	49.1	19	20.0	45	35.4	29	29.0	41	19.2
Non-arboreal pollen grains (NAP)	58	50.9	77	80.0	82	64.6	71	71.0	175	80.8
Total palynomorphs	117		98		130		104		234	

Site 5 – Santa Gilla Lagoon	LSG1		LSG2		LSG3		LSG4		LSG5		LSG6	
	n.	%	n.	%	n.	%	n.	%	n.	%	n.	%
Arboreal pollen grains (AP)												
Alnus	14	1.7	22	1.9	8	0.7	17	1.2	18	1.8	0	0.0
Carpinus	5	0.6	0	0.0	6	0.5	0	0.0	1	0.1	0	0.0
Cistus	4	0.5	6	0.5	8	0.7	28	1.9	10	1.0	2	0.6
Corylus	4	0.5	3	0.3	2	0.2	7	0.5	2	0.2	3	0.9
Cupressus	14	1.7	12	1.0	30	2.6	30	2.1	10	1.0	1	0.3
Cytisus type	2	0.2	5	0.4	0	0.0	5	0.3	2	0.2	0	0.0
Ephedraceae	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Ericaceae	11	1.3	21	1.8	32	2.8	50	3.5	26	2.7	11	3.1
Juniperus	8	1.0	24	2.1	22	1.9	22	1.5	10	1.0	12	3.4
Myrtus	10	1.2	6	0.5	2	0.2	3	0.2	2	0.2	3	0.9
Olea	3	0.4	12	1.0	8	0.7	9	0.6	6	0.6	0	0.0
Quercus ilex type	28	3.4	7	0.6	16	1.4	22	1.5	14	1.4	10	2.9
Quercus suber type	25	3.0	19	1.6	34	2.9	8	0.6	24	2.5	0	0.0
Phillyrea	13	1.6	32	2.7	16	1.4	25	1.7	14	1.4	8	2.3
Pinus	2	0.2	5	0.4	4	0.3	18	1.2	18	1.8	1	0.3
Pinus pinea type	10	1.2	14	1.2	4	0.3	40	2.8	10	1.0	6	1.7
Pistacia	0	0.0	6	0.5	0	0.0	14	1.0	5	0.5	2	0.6
Rhamnus type	1	0.1	0	0.0	0	0.0	0	0.0	0	0.0	1	0.3
Tamarix	2	0.2	5	0.4	1	0.1	10	0.7	2	0.2	0	0.0
Thymeleaceae	3	0.4	5	0.4	6	0.5	7	0.5	5	0.5	2	0.6
Vitis	24	2.9	2	0.2	0	0.0	11	0.8	4	0.4	0	0.0
Non-arboreal pollen grains (NAP)												
Allium	39	4.7	41	3.5	94	8.1	72	5.0	54	5.5	33	9.4
Amaranthaceae/Chenopodiaceae	69	8.4	128	10.9	111	9.6	186	12.8	106	10.9	20	5.7
Asphodelus	6	0.7	6	0.5	3	0.3	14	1.0	6	0.6	2	0.6
Asteroideae	10	1.2	14	1.2	26	2.2	26	1.8	10	1.0	2	0.6
Boraginaceae	0	0.0	6	0.5	14	1.2	10	0.7	0	0.0	0	0.0
Brassicaceae	1	0.1	22	1.9	42	3.6	19	1.3	19	2.0	0	0.0
Campanulaceae	0	0.0	21	1.8	0	0.0	4	0.3	0	0.0	0	0.0
Caryophyllaceae	0	0.0	0	0.0	4	0.3	12	0.8	4	0.4	0	0.0
Cereal type	75	9.1	104	8.9	107	9.3	129	8.9	92	9.5	24	6.9
Chenopodium album	3	0.4	7	0.6	4	0.3	0	0.0	3	0.3	7	2.0
Cichorioideae	8	1.0	14	1.2	44	3.8	26	1.8	8	0.8	2	0.6
Crocus	0	0.0	0	0.0	2	0.2	0	0.0	0	0.0	0	0.0
Cyperaceae/Juncaceae	162	19.6	231	19.8	195	16.9	201	13.9	147	15.1	94	26.9
Erodium type	0	0.0	0	0.0	3	0.3	0	0.0	0	0.0	0	0.0
Euphorbiaceae	0	0.0	6	0.5	0	0.0	5	0.3	6	0.6	0	0.0
Fabaceae	44	5.3	26	2.2	36	3.1	62	4.3	59	6.1	4	1.1
Lamiaceae	2	0.2	0	0.0	2	0.2	2	0.1	0	0.0	0	0.0
Liliaceae	41	5.0	20	1.7	34	2.9	10	0.7	20	2.1	5	1.4
Limonium type	0	0.0	0	0.0	2	0.2	0	0.0	8	0.8	6	1.7
Malvaceae	14	1.7	6	0.5	8	0.7	0	0.0	0	0.0	4	1.1
Nympheaceae	0	0.0	8	0.7	12	1.0	24	1.7	6	0.6	9	2.6
Papaveraceae	2	0.2	8	0.7	2	0.2	0	0.0	2	0.2	0	0.0
Plantago lanceolata	0	0.0	0	0.0	1	0.1	6	0.4	0	0.0	0	0.0
Poaceae	68	8.2	119	10.2	85	7.4	76	5.2	75	7.7	23	6.6
Potamogeton	14	1.7	16	1.4	30	2.6	29	2.0	17	1.7	9	2.6
Primulaceae	0	0.0	0	0.0	0	0.0	6	0.4	0	0.0	0	0.0
Ranunculaceae	49	5.9	102	8.7	68	5.9	160	11.0	72	7.4	22	6.3
Rosaceae	2	0.2	8	0.7	2	0.2	10	0.7	21	2.2	3	0.9
Rumex	6	0.7	0	0.0	0	0.0	1	0.1	10	1.0	4	1.1
Trigonella type	5	0.6	2	0.2	0	0.0	6	0.4	3	0.3	0	0.0
Triticum	0	0.0	3	0.3	0	0.0	2	0.1	0	0.0	0	0.0
Typha	1	0.1	6	0.5	8	0.7	2	0.1	6	0.6	14	4.0
Umbelliferae	0	0.0	3	0.3	2	0.2	0	0.0	4	0.4	0	0.0
Urtica dioica	22	2.7	32	2.7	15	1.3	16	1.1	30	3.1	0	0.0
Vicia type	0	0.0	4	0.3	1	0.1	7	0.5	2	0.2	1	0.3
Total pollen grains	826	100	1169	100	1156	100	1449	100	973	100	350	100
Arboreal pollen grains (AP)	183	22.2	206	17.6	199	17.2	326	22.5	183	18.8	62	17.7
Non-arboreal pollen grains (NAP)	643	77.8	963	82.4	957	82.8	1123	77.5	790	81.2	288	82.3
Total palynomorphs	826		1169		1156		1449		973		350	