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Human management and landscape changes at Palaikastro (Eastern Crete) from the Late Neolithic to the Early Minoan period

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Abstract

On the east Mediterranean island of Crete, a hierarchical society centred on large palatial complexes emerges during the Bronze Age. The economic basis for this significant social change has long been debated, particularly concerning the role of olive cultivation in the island's agricultural system. With the aim of studying vegetation changes and human management to understand the landscape history from Late Neolithic to Bronze Age, two palaeoenvironmental records have been studied at Kouremenos marsh, near the site of Palaikastro (Eastern Crete). Pollen, NPP and charcoal particles analyses evidenced seven phases of landscape change, resulting from different agricultural and pastoral practices and the use of fire probably to manage vegetation. Moreover, the Kouremenos records show the importance of the olive tree in the area. They reflect a clear trend for its increasing use and exploitation from 3600 cal yr BC (Final Neolithic) to the Early Minoan period, that is coeval with an opening of the landscape. The increase of Olea pollen was due to the expansion of the tree and its management using pruning and mechanical cleaning. The onset of olive expansion at c. 3600 cal yr BC places Crete among the first locales in the eastern Mediterranean in the management of this tree. Between c. 2780 and 2525 cal yr BC the landscape was largely occupied by olive and grasslands, coinciding with an increase in grazing practices. The high Olea pollen percentages (40-45%) suggest an intensive and large-scale exploitation of the olive tree. The results suggest that a complex and organized landscape with complementary land uses and activities was already in place since the Final Neolithic. The notable expansion of olive trees suggests the relevance of olive exploitation in the socio-economic development of Minoan towns of eastern Crete. Other crops, such as cereals and vine, and activities such as grazing have also played an important role in the configuration of the past landscape.

1. Introduction

During the Bronze Age, the island of Crete saw the emergence of the Minoan civilization, a culture characterized by a complex social and political organization, with the development of urban centres and state structure. The central role that the agricultural system as well as the control, storage and redistribution of food surplus by a centralized authority played in the growth of Minoan society has been the subject of much debate since the seminal work by Renfrew (1972a) (e. g. Galaty et al., 2011; Halstead, 1992, 1997; Halstead and O'Shea, 1982). Renfrew suggested that the specialised and large-scale cultivation of olives and grapes in particular was key in shaping the Early Bronze Age (EBA) of Crete (Renfrew, 1972a). According to this interpretation the intensive exploitation of olive and vine allowed the colonization of marginal land and hillsides, which otherwise would be unsuitable for food crops such as cereals, leading to surpluses and the growth of inter-regional exchange, among other socio-economic changes (Renfrew, 1972a).

Archaeobotanical data in support of the extensive cropping of olive and vine and the production of olive oil and wine in the EBA are inconclusive. Some evidence of olive and vine exploitation has been found in Neolithic and Early Bronze Age contexts, such as some grape pips and/or olive stones (e.g. at Knossos, Myrtos, Petras

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Kephala, Mochlos), charcoal fragments (e.g. at Myrtos) and organic residues, such as oil traces on pottery at Afrodite's Kephali (Koh and Betancourt, 2010; Livarda and Kotzamani, 2013; Margaritis, 2013; Rackham, 1972; Valamoti et al., 2017). The nature and general paucity of these and other material culture data in the EBA, however, have led several researchers to question the role of these crops and their by-products in the emergence of social complexity (Halstead and O'Shea, 1982; Hamilakis, 1996; Hansen, 1988; Runnels and Hansen, 1986; Sarpaki, 1992). According to these scholars, the large scale systematic, intensive/extensive management of olive trees and vineyards for the production of oil and wine can only be observed during the Late Minoan period (1700-1450 BC), which is when we find a series of artefacts related to their use, such as stone olive presses, spouted clay tubs, oil storage containers, and more abundant organic material, such as olive stones and carbonized olive wood (Hamilakis, 1996; Riley, 2002, 2004; Runnels and Hansen, 1986; Sarpaki, 2012). At the same time, several studies have highlighted both the general paucity of archaeobotanical studies for prehistoric Crete, especially for the Neolithic period, and the limitations of the archaeobotanical data that are available when it comes to discussing the scale of olive oil and wine production (Livarda and Kotzamani, 2013; Sarpaki, 2012). The relevance of the Neolithic period to the later palatial periods is increasingly recognized, with some scholars arguing that changes in the Final Neolithic prefigure some of the key processes occurring many centuries later (e.g. Nowicki, 2002, 2008; Sarpaki, 2012; Tomkins, 2004).

Due to our poor knowledge of the Neolithic period and the lack of clear indications of the beginning of olive and vine management or culture, several authors have highlighted the need to diversify the nature of the evidence to properly address these questions (Hamilakis, 1996; Livarda and Kotzamani, 2013; Margaritis, 2013; Sarpaki, 2012). In this regard, landscape and palaeoenvironmental studies have the potential to furnish new evidence that can significantly contribute to this debate. Multi-proxy palaeoenvironmental studies, including pollen, non-pollen palynomorphs (NPP) and charcoal data, can help us understand the interaction of people with their territories, highlighting human impacts on vegetation and providing information on land use practices and human exploitation of plant resources, such as olive crops (Faegri and Iversen, 1989; Mercuri et al., 2013, 2015). Multi-proxy palaeoenvironmental data can also provide important information on the practices employed by human communities to transform their environments through, for instance, agriculture and livestock management. Despite the intensive archaeological exploration of Bronze Age Crete, its landscape and vegetation history remain poorly understood. This lacuna is especially problematic in Eastern Crete, where only one palaeoenvironmental study has been published (Pavlopoulos et al., 2007); this study did not result in a continuous record, due to the very poor pollen concentration (Pavlopoulos et al., 2007). Other palaeoenvironmental sequences in the island include few other proxies apart from pollen and present time-depth models of limited reliability. Some palynological sequences have been studied in the western and central part of the island, such as Aghia Galini (Bottema, 1980), Akrotiri peninsula (Moody et al., 1996), Kouras-Delphinous region (Bottema and Sarpaki, 2003; Jouffroy-Bapicot et al., 2017), and Asia Gonia, at high elevation in the White Mountains (Atherden and Hall, 1999; Joufrroy-Bapicot et al. 2016). These studies have addressed several questions such as: a) the plant landscape configuration before the human arrival on the island; b) the role of shrubland/ forest communities; c) the native presence/absence of olive trees; d) the dynamics and causes of olive expansion; e) the agriculture-related deforestations; f) the role of pastoralism in shaping the landscape; and g) the high variability of landscape histories in the island, among others. However, the small number of sequences analyzed, together with their low chronological resolution and control hampers an in-depth understanding of these issues, which remain largely unresolved. This is a concerning state of research given the centrality of the island in past and current discussion on the emergence of social complexity and the potential it has for the study of the environmental impact of the first states and towns on Mediterranean island environments.

This paper reports the first high-resolution records in eastern Crete carried out on sedimentary cores recovered from the Kouremenos wetland, near the village and archaeological site of Palaikastro. The palaeoenvironmental records include the study of pollen, non-pollen palynomorphs (NPP) and charcoal particles. This study covers the time-span from the Late Neolithic to the EBA.

2. The study area

The study area is located in the far east of Crete, the largest island of the Aegean Sea. The sedimentary records were obtained from the Kouremenos wetland (35° 12' 14" N, 26° 16' 21" E) at the Kouremenos deltaic plain, at about 50 m from the shoreline and at an altitude of 0.5 masl (Fig. 1). The plain is near the archaeological site of Palaikastro (Fig. 1), a large Bronze Age (Minoan) town located 750 m to the south. Topographically, the area is characterized by limestone ranges reaching to the sea, configuring a rocky coast with only small littoral plains, such as that of Kouremenos.

The climate of the island is typically Mediterranean, with hot and dry summers, and mild damp winters. Precipitation is mainly concentrated during the colder period (November to March); from June to August rainfall is rare. Many variations in precipitation and temperature occur in the island due to its topography; the eastern and southern parts of the island being drier than the north and west (Barclay, 1986; Rackham and Moody, 1996). Our study area is one of the driest regions of Crete, characterized by a semi-arid Mediterranean climate regime, with mean annual precipitation between 300 and 500 mm (c. 475 mm at the town of Sitia, 19 km west of Palaikastro, -Hellenic National Meteorological Services; Voudouris et al., 2006-). Summer monthly temperatures at Sitia reach c. 30 °C, and 10 °C in winter months (Fassoulas, 2013; Hellenic National Meteorological services; Rackham and Moody, 1996). Strong winds are common in the region, especially during July and August.

The flora of Crete consists of approximately 1800 plant species (Barclay, 1986; Zohary and Orshan, 1965), c. 10% of which are endemic, most of them in the mountain areas. The current vegetation is thought to be highly disturbed by human activities, resulting predominantly in a mosaic of maquis, undershrub formation of garigue (phrygana), and steppe-like grasslands, with some deciduous woodland and coniferous forest in the mountains and more protected areas (Bottema, 1980; Moody, 1987; Zohary and Orshan, 1965). The maquis, in the broad sense of communities of shrubs and low stature trees, expand between 0 and 600 masl, but may reach to 1000 masl. Two major types are recognized (Bottema, 1980; Zohary and Orshan, 1965). In the lower zones and coastal plains until c. 400 masl maquis communities are mainly dominated by mastic (Pistacia lentiscus), with the presence of carob (Ceratonia siliqua), Phoenician juniper (Juniperus phoenicea), and wild olive (Olea europaea var. sylvestris) (Bottema, 1980; Turland et al., 1993; Zohary and Orshan, 1965). A second maquis community is found usually above 300 m and is formed by kermes oak (Quercus coccifera) together with strawberry tree (Arbutus unedo), tree heath (Erica arborea), spiny broom (Calicotome villosa), Cretan dwarf broom (Chamaecytisus creticus), sage-leaved rockrose (Cistus salviifolius), French broom (Genista monspessulana) and broom (G. acanthoclada) (Bottema, 1980; Moody, 1987; Turland et al., 1993;

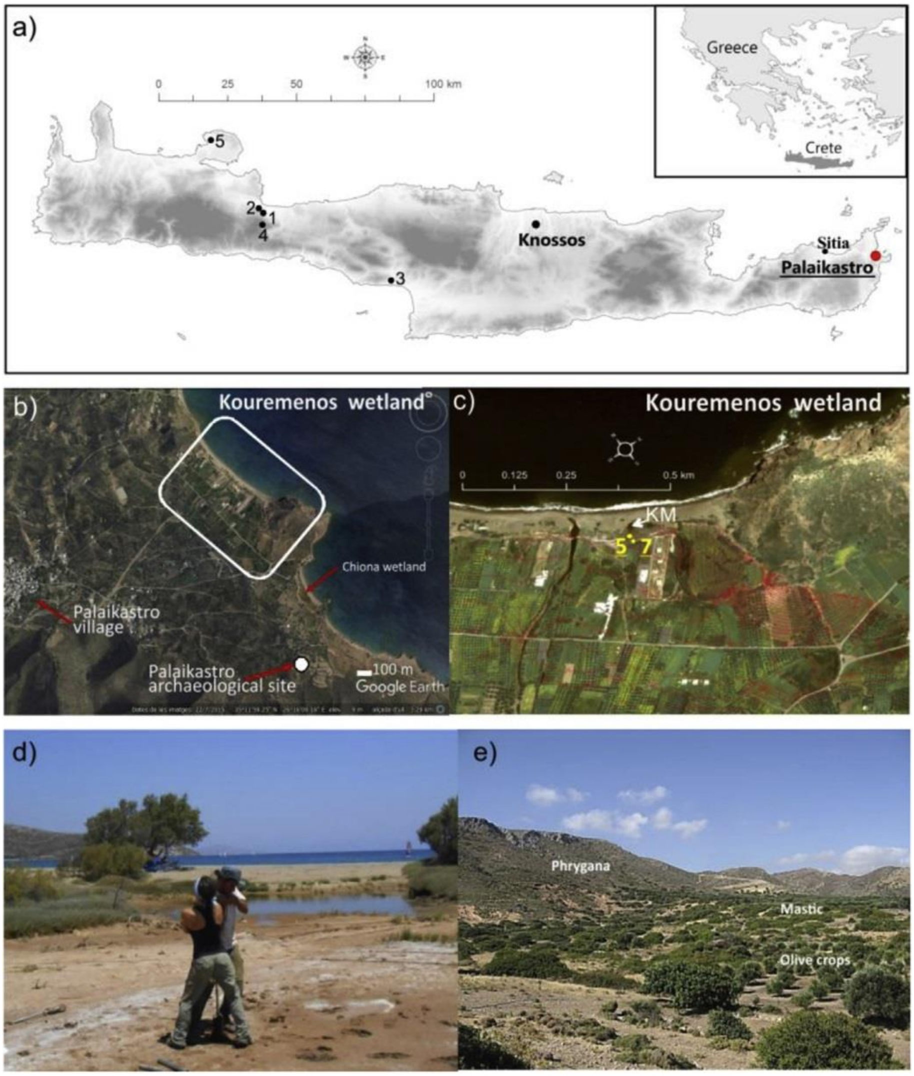


Fig. 1. Study area. a) Map of Crete and the location of Palaikastro. Other pollen records are indicated by numbers: 1) Kournas (Bottema and Sarpaki, 2003); 2) Delphinos (Bottema and Sarpaki, 2003); 3) Agia Gallini (Bottema, 1980); 4) Asia Gonia (Atherden and Hall, 1999; Jouffroy-Bapicot et al., 2016); 5) Tersana (Moody, 1987; Moody et al., 1996); b) Location of Palaikastro village, Palaikastro archaeological site, Kouremenos, and Chiona wetland; c) Location of two cores extracted at the Kouremenos wetland (core K5 and K7). The Kouremenos marsh (KM) is indicated; d) Photograph of the extraction of the cores with a hand-operated Russian Corer near Kouremenos marsh; e) Photograph showing the current surrounding landscape.

Zohary and Orshan, 1965). Garigue (also called phrygana) consists of dwarf, gray-green shrubs, often aromatic and spiny. Noteworthy among the species that constitute this formation are thorny burnet (Sarcopoterium spinosum), thyme (Coridothymus capitatus), spiny broom (Calicotome villosa), broom (Genista acanthoclada), winter savory (Satureja thymbra), Greek spiny spurge (Euphorbia acanthathamos), heather (Erica manuliflora), Greek horehound (Ballota acetabulosa), and several Lamiaceae and Cistaceae species like Greek sage (Salvia fruticosa), rock rose (Cistus creticus) and sage-leaved rockrose (Cistus salviifolius) (Bottema, 1980; Moody, 1987; Turland et al., 1993). The grasslands (or steppe) consist of a herbaceous plant community, which includes grasses, bulbous or tuberous perennials and annuals (Moody, 1987; Moody et al., 1996). Cretan woods are mainly found in mountain areas. In lower and middle montane elevations, forests are composed of Mediterranean sclerophyllous trees, such as the Mediterranean cypress (Cupressus sempervirens), green olive tree (Phillyrea latifolia), terebinth (Pistacia terebinthus), kermes oak (Quercus coccifera), holm oak (Q. ilex) and Cretan maple (Acer sempervirens). Richer soils on soft rocks may support non-sclerophyllous species, such as the deciduous downy oak (Q. pubescens) (Barbero and Quezel, 1980; Bottema, 1980; Turland et al., 1993). Cretan maple forests can be found on the Lefka, Psiloritis and Lasithi Mountains (Bottema, 1980), while cypress woods are mainly found at Lasithi and White Mountains. Patches of Turkish pine (Pinus brutia) are found between 0 and 1100 m.

The vegetation in the study area is mainly dominated by low scrublands and undershrubs, forming low and dense garigue or phrygana on the hill slopes. The phrygana community occupies areas with dry conditions, and is well adapted to browsing pressure and burning. The alluvial fans and the littoral plain are mainly occupied by maquis. Olive is the main crop in the plain, but grape, pear, almond, quince, fig and carob are also present (Fassoulas, 2013). There are no large forests or clusters of trees in the area, except for the palm forest of Vai where the Cretan date palm (Phoenix theophrasti) prevails and small patches of kermes oak, Oriental planes (Platanus orientalis) and carob appear in canyons and ravines (Fassoulas, 2013).

2.1. Archaeological setting

The Minoan town at Palaikastro, one of the largest centres in Crete after Knossos and Phaistos, is located in the area known as ‘Roussolakkos’, just inland from the small bay of Chiona. Although no harbour installations have been found, the site's coastal location strongly suggests the town functioned as one of the main way stations for maritime exchange in east Crete. This particular location seems not to have been inhabited in the Late Neolithic (LN) period (c. 4500-3600 BC). Indeed, occupation in this period has not been established anywhere on the Palaikastro plain, with the nearest locales showing signs of LN habitation being Magasa (Nowicki, 2014), c. 9 km in the mountains to the southwest, and Pelekita cave (Davaras, 1989), some 10 km south along the coast near Zakros. In the subsequent Final Neolithic period (c. 3600-3100 BC), it is only survey surface finds that indicate some occupation, for example on the low hill of Kastri (c. 90 masl), between the Chiona and Kouremenos bays, with pottery assignable to the Final Neolithic II period (Nowicki, 2014). Occupation in the EM I period is again only really identified through surface remains, on both the slopes of Kastri and on another rocky knoll close to the sea some 2 km to the northwest, at Maridati (Nowicki, 2014). By the EM IIA period, however, which begins c. 2650 BC, we do see signs of occupation at the Roussolakkos site, through both burial and settlement evidence (MacGillivray and Driessen, 1990). It is this locale that is then occupied continuously throughout much of the Bronze Age, becoming a fairly extensive town at some point in the later part of the Middle Minoan period, c. 1700 BC (MacGillivray and Sackett, 2010). This pattern is quite typical for many sites on the island, not least nearby Petras (close to Sitia), which also sees FN-EM I occupation on higher ground, before occupation of a new, lower locale in EM IIA sets the trend for the coming centuries of urbanization.

3. Material and methods

Two cores, Core K5 (770 cm deep) and Core K7 (640 cm deep), were retrieved using a hand-operated ‘Russian’ auger. The cores are 50 m apart and record similar sedimentological sequences which are characterized by the following main units from bottom to top (Fig. 2): a) a bottom layer formed by greyish and organic clays with faunal remains; b) a level of coarse sands and gravels in a silt matrix; c) an intermediate layer with predominance of orange clays and interbedded sands, isolated gravels, carbonated nodules and vegetal debris; d) greyish organic clays; e) a level formed by layered silts, clays and sands with gravels.

Multi-proxy analysis has been carried out on both cores, including pollen, fern spores, non-pollen palynomorphs (NPPs) and macrocharcoal particles. Samples of 1 cm thick, taken at intervals of 5e10 cm, have been chemically treated at the Laboratory of Archaeology of the University of Barcelona, following the standard methods used for palynological analysis, which include sieving (through a 200 µm mesh screen) and KOH, HCl and HF digestions (Faegri and Iversen, 1989; Moore et al., 1991). A 7 mm mesh was used to remove clays. Two tables of Lycopodium spores have been added to each sample when starting the chemical processing as an exotic marker (Lycopodium batch 3862) (Stockmarr, 1971). Microscopic slides have been mounted in glycerine and pollen counting has been conducted until reaching a minimum of 300 pollen grains, excluding local taxa (Cyperaceae, aquatic taxa, such as Ruppia, and fern spores). Even after counting 300 palynomorphs, counts continued until the saturation of diversity was reached (Rull, 1987). Pollen identification was done with the aid of palynological atlases (Chester and Raine, 2001; Faegri and Iversen, 1989; Moore et al., 1991; Reille, 1992, 1995, 1998) and the pollen reference collection of the Seminar of Studies and Prehistoric Research, University of Barcelona (SERP). NPPs identification was made according to published morphological keys and illustrations (e.g. van Geel, 2001; van Geel and Aptroot, 2006; van Geel et al., 1989, 2011). Ascospores of dung-related fungi (e.g. Sporormiella, Delistchia) were used to assess the presence of fauna, in particular herbivores and grazing activities (Cugny et al., 2010; van Geel, 2001; Van Geel et al., 2003). The pollen and NPP data are presented as a percentage of total land pollen excluding Cyperaceae, aquatic taxa and fern spores. The diagrams were plotted using psimpoll 4.26 software (Bennett, 2009), and the pollen assemblage zones were established using CONISS on land pollen taxa recording abundances >1% (Grimm, 1987). Macrocharcoal particles were quantified at intervals of 5 cm with the aid of a stereomicroscope, after being sieved through a 200 mm wide mesh. Macrocharcoal data were expressed in concentration (particles/gr of sediment).

The sections of the cores that are rich enough in pollen content correspond to 770-620 cm depth of core K5, as well as 640-545 cm and 180-150 cm depth of core K7. Therefore, the present work studied these sections, which include a total set of 36 pollen samples (25 from core K5 and 11 from core K7) and 51 samples (29 samples from K5 and 22 from K7) for charcoal particle quantification. In addition, a modern pollen assemblage was obtained from the uppermost sediments from the nearby Chiona wetland (Fig. 1). The Chiona sample and the four samples from the upper section of core Kouremenos-7 (from 180 to 150 cm), corresponding to c. 14th - 15th centuries AD according to radiocarbon dating, were used as a current and historical reference to increase the accuracy of the interpretation of past pollen assemblages. These pollen samples from the 14th - 15th centuries AD were also compared with written sources of the Venetian period (Gasparis, 1997, 2005; Stallsmith, 2007), allowing a more accurate interpretation of crop presence from pollen signal.

The chronological framework was established according to eight AMS radiocarbon dates (4 in each core), seven from plant macroremains and one from a Cerastoderma cf. shell, at Beta Analytic Radiocarbon Dating laboratory. The dates obtained from plant remains were calibrated using Calib 7.2, which uses the IntCal13 radiocarbon calibration curve, while the brackish shells were calibrated with the Marine 13 radiocarbon calibration curve (Reimer et al., 2013) and using the closest value of ΔR calculated in the area according to the Marine Reservoir correction database (ΔR = 40, http://calib.org/calib/). Age-depth models for both sequences were constructed using linear interpolation between adjacent radiocarbon dates with Clam-software (Blaauw, 2010), since this method gave the best fit with the data. The age-depth models were performed within the lithological level a, which records homogenous sedimentology and where the discussion of this paper is mainly focussed. The chronological correspondence between the sequence and archaeo-cultural periods in Crete are based on chronologies established by Nowicki (2014).

4. Results

4.1. Chronological framework

The eight radiocarbon dates obtained for the K5 and K7 cores are shown in Table 1. Pollen is present in the layers composed by fine and organic sediment (levels a and d), while coarse layers b, c and d (Fig. 2), formed by sands and clay, are poor or even sterile in pollen grains and NPP.

The present multi-proxy study covers the period between the Late Neolithic (LN) and the EBA (Early Minoan I-II). Fig. 3 shows the age-depth models for the sections and the sedimentological levels studied. The K5 section covers the time-span from 4300 to

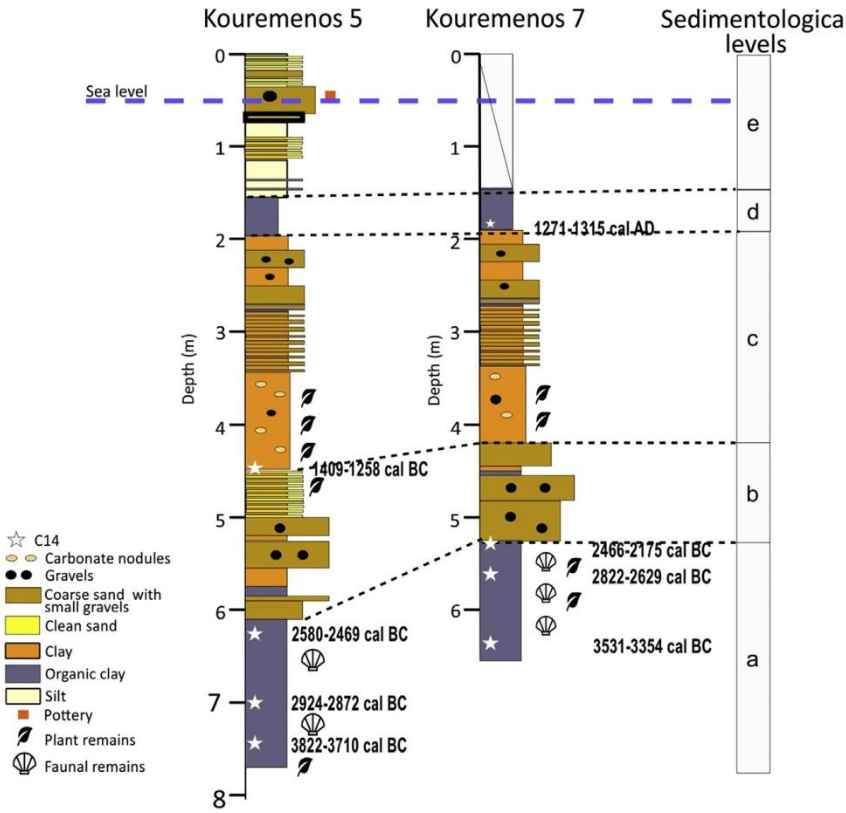


Fig. 2. Sedimentological sequence recorded at K5 and K7 cores.

Core	Depth (cm)	Lab Code	Material	Measured Yr BP	Conventional Yr BP	dC_{13}	Calibrated Cal yr BC
K5	450	394457	Plant remains	3100þ-30	3060þ-30	-27.4	1409-1258 cal yr BC
K5	620-621	429623	Plant remains	3920þ-30	4010þ-30	-19.7	2580-2469 cal yr BC
K5	699-701	437306	Plant remains	4280þ-30	4270þ-30	-25.8	2924-2872 cal yr BC
K5	745	394455	Plant remains	4870 þ-30	5020þ-30	-15.7	3822-3710 cal yr BC
K7	184	394459	Plant remains	680þ-30	680þ-30	-27.8	1271-1315 AD
K7	530	394458	Cerastoderma Shell	3920þ-30	4230þ-30	-5.8	2466-2175 cal yr BC [a]
K7	561-562	429896	Wood	4190þ-30	4150þ-30	-27.4	2822-2629 cal yr BC
K7	634 -638	437405	Plant remains	4700 þ-50	4660 þ-50	-27.6	3531-3354 cal yr BC

[a] $\Delta R = 40$.

Table 1
^{14}C AMS radiocarbon dates obtained from core K5 and K7.

2500 cal yr BC, with sedimentation rates of 0.047 cm/yr between 770 and 700 cm depth, and 0.22 cm/yr between 700 and 620 cm depth (Fig. 3). In addition, the K7 section spans from 3600 to 2600 cal yr BC, with a sedimentation rate of 0.093 cm/yr (Fig. 3). On the basis of both chronological models, core K5 covers a wider lapse of time than K7. For this reason, K5 provided the main chronological framework and was employed to describe long-term landscape changes. Sedimentation rates, the integration of the chronological framework with the sedimentary layers and the time resolution between samples is summarized in Table 2. The values of the best ages given by the chronological model have been used in the discussion of the palaeoenvironmental data.

4.2. Pollen, NPP and macrocharcoal results

4.2.1. Core K5 (Fig. 4)

From Coniss sample aggregation, three pollen zones and eight subzones were identified in the K5 sequence (Fig. 4).

The zone K5-1 (770-731 cm depth) was characterized by high abundance of shrub pollen, particularly of Ericaceae (>30%), and percentages of Olea around 15%. Notable values of Sarcopoterium-type, Cistaceae and Lamiaceae pollen taxa were also recorded. Among herb taxa, the abundance of Asteraceae pollen, particularly Cichorioideae (c. 10%) are noteworthy, while Poaceae are present with values of 5-10% and Chenopodiaceae with percentages of 3-6%. Other herb pollen, such as Brassicaceae, Apiaceae, Liliaceae and Asphodelus, are present, although in low quantity. Trees are scarce in the whole sequence, but few pollen grains of Quercus (deciduous and ilex-types) and Pinus are observed throughout this zone. Likewise low percentages of Cyperaceae and fern spores, mainly Botrychium and Selaginella denticulata-type were recorded. In addition, there was a significant presence of coprophilous fungal spores, mainly Sporormiella and Delistchia. Inside the K5-1 zone an upper subzone K5-1b (748-731 cm) can be distinguished by a decrease in the Ericaceae pollen, and the appearance of Tamarix, Ruppia and some herb pollen taxa, such as Plantago undiff., Carlina-

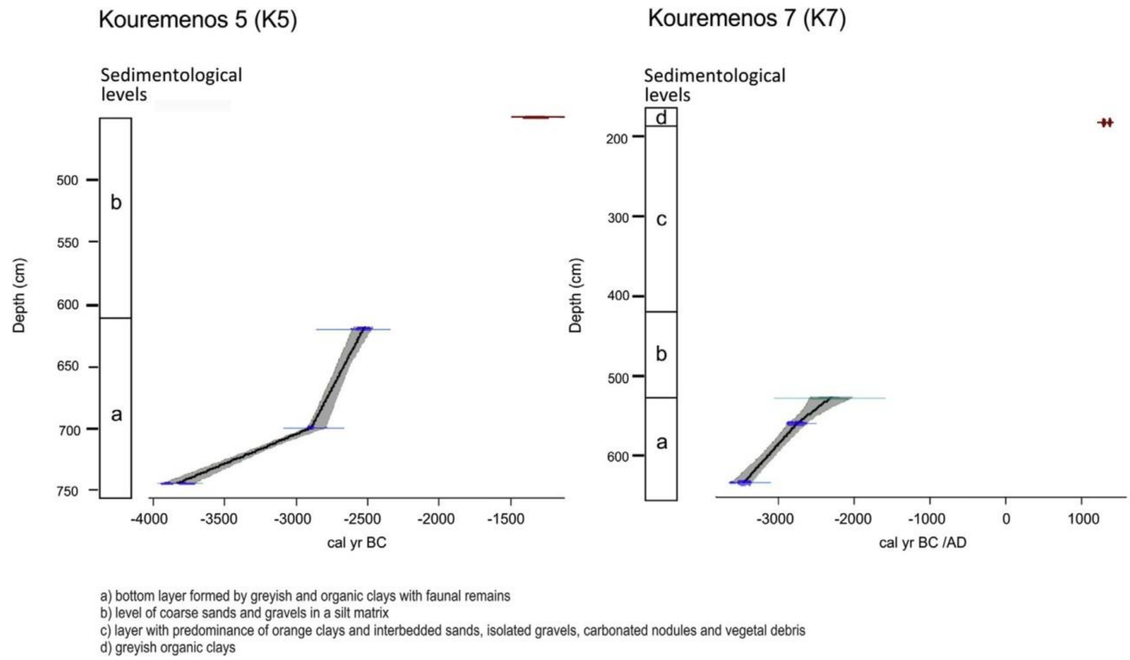


Fig. 3. Age-depth models of cores K5 and K7 performed with Clam software. The sedimentological levels are also indicated.

Table 2
Sedimentation rate and resolution of the studied sections of K5 and K7.

Core	Depth section (cm)	Sedimentation rate (cm/yr)	Time integrated in 1 cm slice thick (yr)	Elapse time each 5 cm (yr)	Elapse time each 10 cm (yr)
K5	770-700	0.047	21	105	210
K5	700-620	0.22	4.5	22.5	45
K7	640-545	0.093	10.75	53.8	107.5

type and Cerealia-type, and the occurrence of Caryophyllaceae. Pollen grains of deciduous trees Alnus and Tilia were also recorded. Other minor changes included an increase in Vitis, Sarcopoterium-type and Fabaceae and a slight decline in Cichorioideae and Asteroideae. Coprophilous fungal spores markedly decreased in this subzone. In contrast, a conspicuous rise in charcoal particles was observed.

Zone K5-2 (731-676 cm depth) recorded a striking drop of Ericaceae pollen to c. 10-20%, accompanied by a rise in Olea percentages up to 30%. At the same time Sarcopoterium-type maintained high values while Asphodelus, Helianthemum and Cistus increased notably. Three subzones can be distinguished. In the first subzone K5-2a (731-717 cm depth) Cichorioideae showed a significant decrease, reaching low values of around 4%, and Lamiaceae also slightly declined. In contrast, Apiaceae, Brassicaceae and Cerealia-type pollen taxa slightly increased. Low percentages of coprophilous fungal spores (mainly Sporormiella) were recorded. Glomus and Anthrinium-type also slightly rose. The subzone K5-2b (717-706 cm depth) was characterized by a marked decline in Olea pollen to 20%. In constrast, Ericaceae, Asteroideae, Cichorioideae and Plantago markedly increase. Lamiaceae, Cistaceae and Sarcopoterium-type underwent an initial slight decline, but they increased afterwards. In contrast, Poaceae and Chenopodiaceae initially rose, but declined in the upper half of the zone. Apiaceae and Cerealia-type pollen decreased. Ruppia increased significantly.

Sporormiella and Delistchia showed a striking increase in the middle of the zone, while an overall increment of charcoal particles was noteworthy. The subzone K5-2c (706-676 cm depth) had similar features to subzone K5-2a, but with higher percentages of Cichorioideae, and rises in Lamiaceae, Poaceae and other herb pollen, such as Plantago undiff. and Carlina-type among others. At the same time lower percentages of Sarcopoterium-type were observed. Artemisia and Ruppia were constantly present in this subzone. A more frequent occurrence of deciduous trees, such as Tilia, Alnus and Corylus was noticeable. Higher percentages of Sporormiella and Delistchia and high charcoal particles concentra- tion could be also observed.

Zone K5-3 (676-620 cm depth) was characterized by a notable increase in herb pollen, mainly Poaceae and Cichorioideae, and an overall rise in Olea, reaching values of 40-45%. Overall, arboreal pollen showed also a slight increase, including a rise of Pinus, deciduous Quercus and Q. ilex-type. In contrast, shrubs and dwarf-shrubs, such as Ericaceae, Lamiaceae, Cistaceae and Sarcopoterium-type, declined and Asteroideae decreased notably. An increase in Sporomiella fungal spores was observed as well as an overall decline of charcoal. Three subzones were distinguished. The lower subzone K5-3a (676-670 cm depth) recorded a percentage peak in Poaceae, Cyperaceae and Ruppia, together with a decrease in Olea pollen values. The subzone K5-3b (670-646 cm depth) was characterized by high percentages of Poaceae, Asteraceae and Chenopodiaceae. Crop taxa recorded higher values, such as Olea, Vitis and Cerealia-type. Notable abundances of Plantago undiff. and coprophilous fungal spores (mainly Sporormiella and Coniochaeta) were also observed. The highest values of arboreal pollen were recorded in this subzone, as well as an increase in fungi TM-H type and Glomus. Finally, the subzone K5-3c (646-620 cm depth) was characterized by a marked Olea increase, reaching the highest value in the sequence at c. 45%, although an overall decline in arboreal

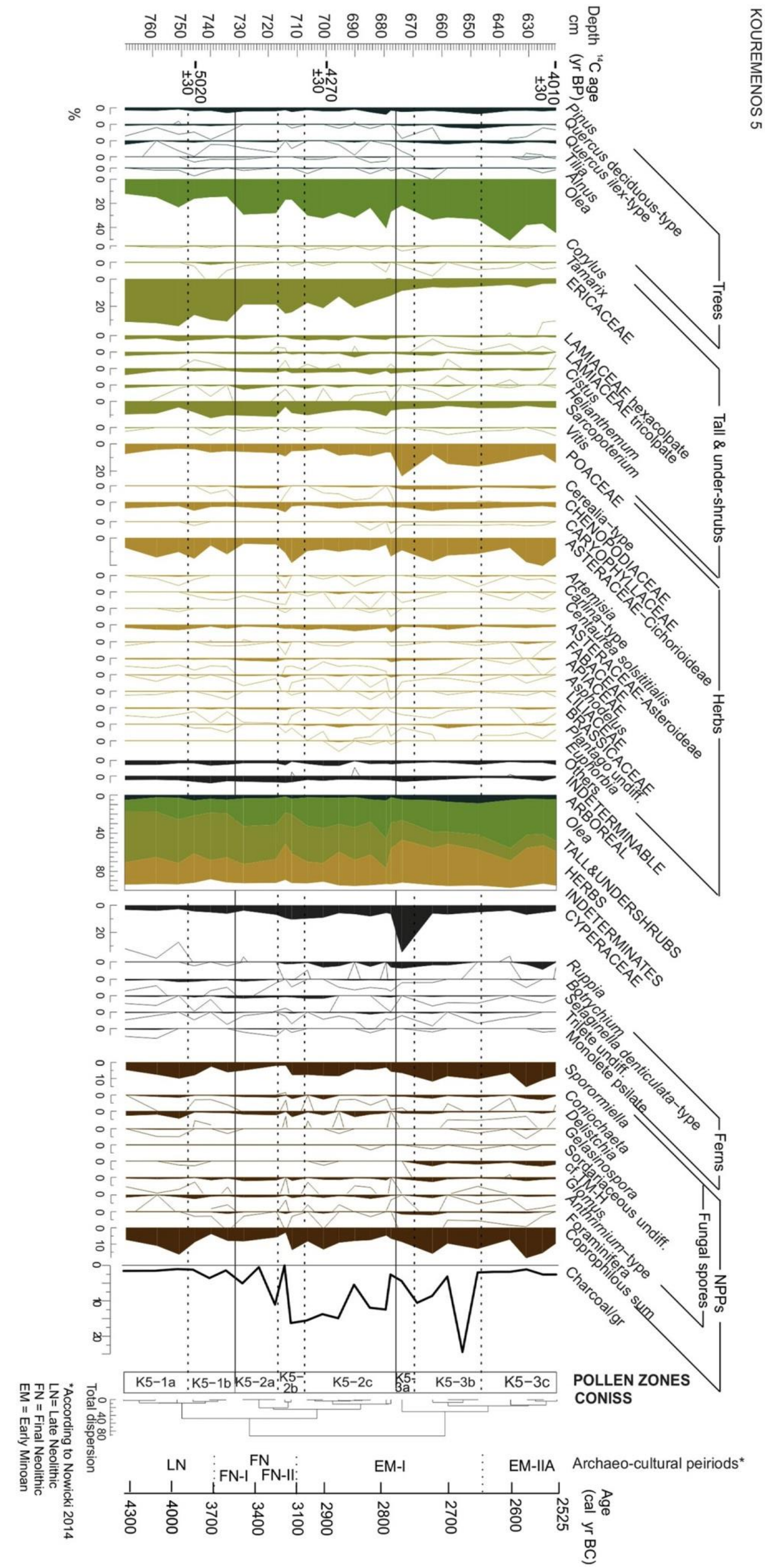


Fig. 4. Diagram of the main pollen, NPP and macrocharcoal particles from core K5. AMS^{14}C radiocarbon dates are indicated on the left of the diagram and calibrated dates on the right.

pollen occurred. Lastly, a prominent decrease in charcoal particles was noted.

4.2.2. Core K7 (Fig. 5)

From Coniss sample aggregation, two pollen zones were identified in the K7 sequence (Fig. 5).

Zone K7-1 (640-600 cm depth) was distinguished mainly by the high abundances of Olea pollen, recording values of 40%, and accompanied by notable percentages of Ericaceae (c. 15%), Sarcopoterium-type (10%) and Cichorioideae (c. 6%). Other minor components of the assemblage were Poaceae, Asteroideae, Apiaceae and Caryophyllaceae. Low percentages of Cistus and Lamiaceae were observed. Wetland and aquatic plants, such as Cyperaceae and Ruppia, were fairly abundant. On the other hand, relatively high abundances of coprophilous fungal spores, such as Sporormiella and Delistchia, were present.

Zone K7-2 (600-545 cm depth) saw a decline of Olea pollen accompanied by an overall increase in herb pollen and coprophilous fungal spores, mainly Sporormiella. Two subzones could be differentiated. In the lower subzone K7-2a (600-568 cm depth) Olea pollen underwent a marked decline and showed percentages of around 20%. This decrease coincided with a prominent increase in Poaceae and Chenopodiaceae pollen grains, which occurred at the beginning of this zone. Apiaceae and Cerealia-type also rose. At the middle of the subzone, Lamiaceae, Cistaceae (Cistus, Helianthemum) and Cichorioideae underwent a conspicuous increment, coeval with the decrease of Sarcopoterium-type. Yet, Cyperaceae and Ruppia notably declined. A marked increment of coprophilous fungal spores (mainly Sporormiella) and Glomus was observed. The upper subzone K7-2b (568-545 cm depth) was characterized by the recovery of the Olea values to c. 30-40% and an increase in herb pollen taxa, such as Poaceae and Chenopodiaceae. Liliaceae, Brassicaceae, Artemisia, Cerealia-type and Plantago undiff. also rose. In arboreal pollen of mainly Quercus a slight increase was observed. In contrast, shrubby taxa, such as Lamiaceae, Cistaceae and Ericaceae, showed a considerable decline. Cyperaceae also decreased as well as the coprophilous fungal spores.

4.3. Historical and modern pollen assemblages

The upper organic level d of K7 (from 180 to 150 cm depth) were rich enough in pollen grains, NPPs, and charcoal particles (Fig. 6). The lower sample of this level was dated to the 14th century AD, which means that the four successive pollen samples record the medieval landscape, probably corresponding to the Venetian occupation. The pollen record (Fig. 6) was dominated by shrubs and herbaceous types, with a high abundance of Chenopodiaceae (with values c. 20%). High percentages of Pistacia (c. 15%) together with high presence of Asteraceae, particularly Cichorioideae (5-35%), were noticeably present. The shrubby component was mainly formed by abundant Ericaceae (between 3 and 13%) and low presence of phrygana pollen indicators like Sarcopoterium-type and Cistus. The relatively high values of Poaceae (4-9%) and Plantago (2-4%) were also noteworthy. In contrast, scarce arboreal pollen (mainly Pinus and Quercus) grains were observed. Olea had values of 2-6%, whilst other crops, such as Cerealia and Ceratonia, were also present. Occurrences of Vitis, Linum usitatisimum, Cannabaceae and Castanea were recorded. Relatively high percentages of coprophilous fungal spores (2-12%), mainly Sporormiella, were identified, as well as Glomus.

The modern pollen assemblage obtained at the Chiona wetland (Table 3) shows the dominance of Olea (22%), and Tamarix (14%) and the near absence of other arboreal taxa. Shrubs and small trees, such as Pistacia, Ceratonia siliqua and Ericaceae were present with very low values, as well as dwarf-shrubs like Sarcopoterium-type, Cistaceae and Lamiaceae. Between herb taxa, Chenopodiaceae (21%) and Asteraceae, mainly Cichorioideae (9%), were dominant, with the presence of Poaceae and Cyperaceae. Relatively low percentages of Brassicaceae and Plantago were observed, together with few occurrences of Asphodelus, Fabaceae, Apiaceae and Liliaceae. Regarding the NPP assemblage, what stood out was the relatively high percentage (c. 6%) of coprophilous fungal spores like Sporormiella.

5. Discussion

5.1. The history of landscape from the LN to the EBA

Seven main phases of landscape formation can be inferred from the main changes observed in pollen assemblages, fungal spores and charcoal particles between the LN and EBA, in the Kouremenos cores (Fig. 7). Some of these phases correlate broadly with the main chrono-cultural periods attested in the archaeological literature.

5.1.1. Landscape Phase I (LK-1): 4300-3900 cal yr BC (LN) (zone K5- 1a)

According to pollen data, the plant landscape in the Palaikastro area between 4300 and 3900 cal yr BC (corresponding to part of the LN, see Nowicki, 2014) was dominated by shrubs and bushes, mainly heath communities (Ericaceae family), with the presence of several Cistaceae (mainly Cistus) and Lamiaceae taxa (Figs. 4 and 7). The notable abundance of these entomophilous plants, which are usually under-represented in the pollen assemblages, suggests the preponderance of such shrubby communities across the landscape (Moore et al., 1991). The low percentages of arboreal pollen, together with the relatively high abundance of dwarf shrubs, such as the light-demanding Sarcopoterium-type and herbs (mainly Asteraceae) indicate an open landscape. In this context, Sarcopoterium-type, together with Lamiaceae and Cistaceae indicate the presence of phryganic communities (Bergmeier and Matthäs, 1996; Bottema and Sarpaki, 2003; Bottema and Woldring, 1990). Likewise, the low values of Pinus and Quercus, similar to those recorded in the modern sample (Table 3), indicates that the scarce forest patches were probably confined to more protected areas, such as inland elevations and in ravines, as is the case today, places which are characterized by higher moisture (Fassoulas, 2013). Olea pollen was identified during this period with relatively high values, a fact that attests to the presence of this plant in the area since at least 4300 cal yr BC (see section 5.2). The relative abundance of coprophilous fungal spores reveals the existence of flocks in the delta plain (Cugny et al., 2010; van Geel, 2001; Van Geel et al., 2003). These values are similar to those observed during the Venetian period (Fig. 6) when historical sources report herding, especially of sheep and goats, as an important activity in the island but secondary to agriculture (Gasparis, 1997). This grazing pressure could also contribute to the presence of phrygana formation (Bergmeier and Matthas 1996). In summary, these data suggest that the landscape in eastern Crete in the LN was dominated by low and open vegetation corresponding to shrubs, dwarf-shrub phryganic plant communities, with maquis and Olea trees probably located in the lowlands, and a sizeable grazing activity in the littoral plain.

This landscape configuration of the Palaikastro region, characterized by a very scarce forest cover, strongly contrasts with the vegetation of the western part of the island, where a wider oak forest cover was recorded during this period (Bottema and Sarpaki, 2003; Moody, 1987; Moody et al., 1996). In particular, in the Akrotiri peninsula, a mosaic of garigue, maquis and mixed oak woodland dominated the landscape (Moody, 1987; Moody et al., 1996) while the Lake Kournas region was characterized by the presence of

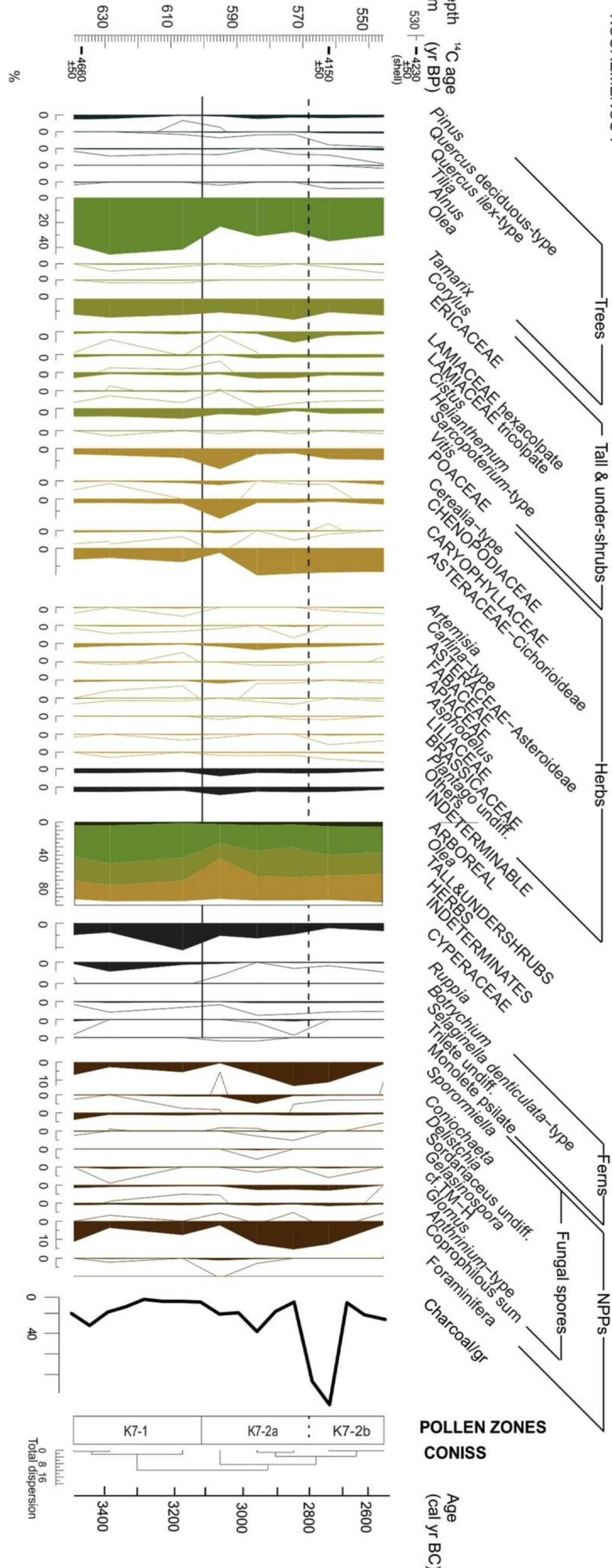


Fig. 5. Diagram of the main pollen, NPP and macrocharcoal particles from K7. AMS^{14}C radiocarbon dates are indicated on the left of the diagram and calibrated dates on the right.

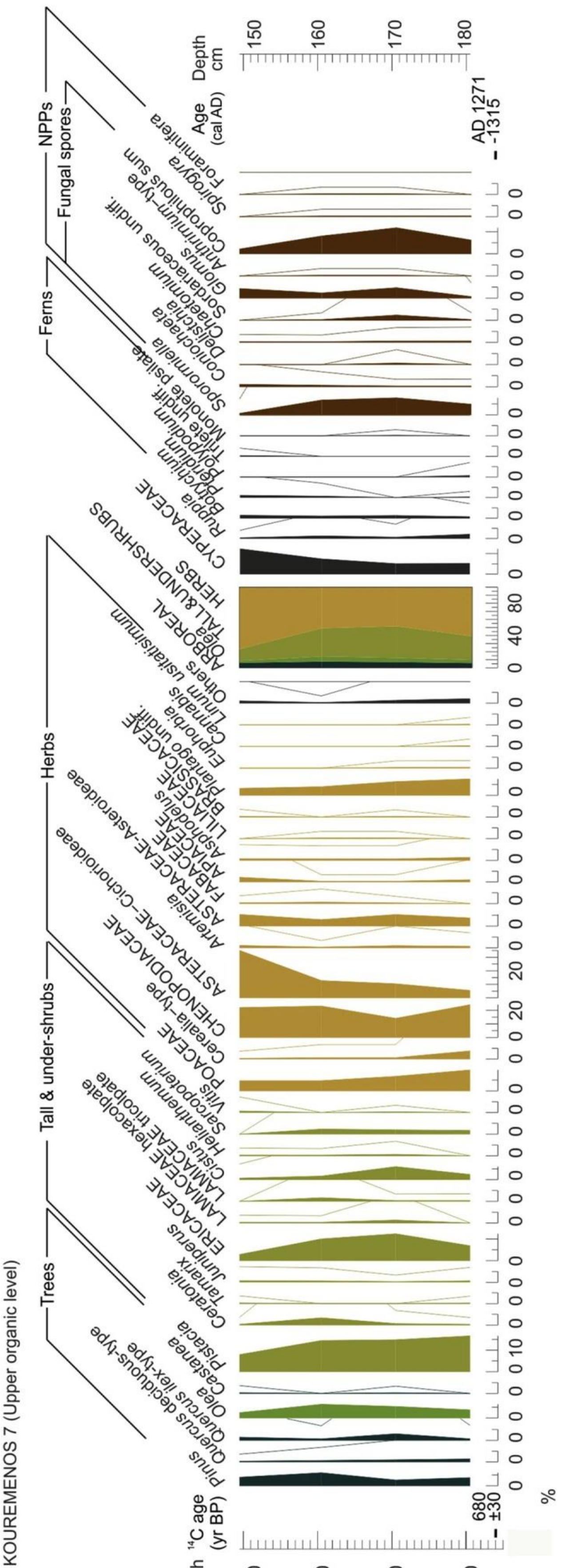


Fig. 6. Diagram of the main pollen and NPP from the upper organic layer of core K7. The AMS ^{14}C radiocarbon date is indicated on the left of the diagram and the calibrated date on the right.

mixed oak woodlands of deciduous Quercus and Q. ilex-type combined with grasslands (Bottema and Sarpaki, 2003). The dominance of heaths in the vegetation of the Palaikastro region differs markedly from the western records, where Erica constituted a minor component, only expanded after woodland clearance (Bottema and Sarpaki, 2003; Moody et al., 1996). However, shrubby communities could be the natural vegetation in our study area, probably as a result of climatic and edaphic differences across the island, given that the littoral stretch in Eastern Crete is one of the driest areas of the island and the low precipitation and calcareous bedrock could constrain forest development. Nevertheless, another possibility is that the shrubby vegetation recorded during this phase in Palaikastro is the result of disturbance starting before 4300 cal yr BC, since human activities, associated mainly with keeping of grazing animals, were identified from the earliest samples of the sequence. This early grazing could have favoured phryganic vegetation. This could thus indicate human impact earlier than this date, which is in accordance with other studies, such as that at Aghia Galini, with human impact dating back to c. 5500 cal yr BC (Bottema, 1980). While there is evidence of human activity during this period in nearby regions, such as at the Pelekita Cave, near Zakros, so far LN occupation has not been documented at Palaikastro. However, this could be due to the lack of systematic surveying in the area and to site location choices during LN. If sites were preferentially located in low-lying areas near lagoons, then the LN sites in the area may be very deeply buried (Bonga pers. comm.).

5.1.2. Landscape Phase II (LK-2): c. 3900-3600 cal yr BC (end of LN) (K5-1b)

A landscape change occurred around 3900 cal yr BC, corresponding to the latter part of the LN period (see Nowicki, 2014). The slight decline in Ericaceae shrubs combined with the increase of dwarf-shrub Sarcopoterium-type and several herb taxa, such as Poaceae and Chenopodiaceae, suggest disturbances and clearances of shrubby plant communities. This landscape clearance coincides with a slight rise of charcoal concentration indicating increasing fire frequency, which could be used to enlarge open spaces devoted to farming activities. In this context, agricultural practices were recorded close to coring site in the delta plain, as indicated by the first occurrences of low pollen dispersal taxa like Cerealia-type and Vitis, and the presence of weed taxa like Plantago undiff. and Carlina-type (Bottema, 1980; Turland et al., 2004). Nevertheless, the low percentages in which these taxa occur probably indicate a rather restricted presence of such crops close to the study area. Indeed, bioarchaeological data from elsewhere in Crete (Hansen, 1988; Livarda and Kotzamani, 2013; Sarpaki, 2012) show the prevalence of an agriculture based on cereals and legumes since the Neolithic period. Conversely, the decrease of coprophilous fungal spores, such as Sporormiella, Delistchia, and Coniochaeta, suggests a decline in the local grazing pressure near the coast (Cugny et al., 2010; van Geel, 2001; Van Geel et al., 2003), which is corroborated by the reduction of certain pollen taxa like Cichorioideae, which have been related to grazing activities in Mediterranean contexts (Bottema, 1980; Florenzano et al., 2014).

5.1.3. Landscape phase III (LK-3): c. 3600-3200 cal yr BC (FN I and FN II) (K5-2a)

At 3600 cal yr BC, approximately the beginning of FN I according to Nowicki's relative chronology (Nowicki, 2014), a significant landscape change occurred, involving a dramatic retreat of Ericaceae shrubby formation and the spread of dwarf-shrubby phrygana communities with high presence of Sarcopoterium-type and Cistus. This could suggests an increase of human pressure on the landscape (Bergmeier and Matthas 1996; Bottema, 1980). The

Table 3
Main pollen and NPP data from sediment surface of Chiona wetland. The Pollen and NPP values are expressed in percentages of total land pollen, excluding Cyperaceae, aquatic plants such as Ruppia and fern spores. In brackets percentages excluding Chenopodiaceae and Tamarix from the pollen sum.

Pollen taxa	percentage	Pollen taxa	percentage
Pinus	2.8 (4.4)	ASTERACEAE Asteroideae	1.9 (2.9)
Quercus deciduous-type	0.3 (0.5)	FABACEAE	0.6 (1)
Quercus ilex-type	0.3 (0.5)	APIACEAE	0.6 (1)
Alnus	0.3 (0.5)	Asphodelus	0.6 (1)
Olea	22 (34)	LILIACEAE	0.6 (1)
Tamarix	14.5 (22.5)	BRASSICACEAE	1.9 (2.9)
Pistacia	3.1 (4.9)	Plantago undiff	2.5 (3.9)
ERICACEAE	0.9 (1.5)	Rumex	0.3 (0.5)
LAMIACEAE hexacolpate	0.3 (0.5)	Ceratonia	1.3 (2)
LAMIACEAE tricolpate	0.9 (1.5)	CYPERACEAE	4.1 (6.4)
Cistus	1.6 (2.5)	Ruppia	0.3 (0.5)
Helianthemum	0.9 (1.5)	Trilete undiff.	0.3 (0.5)
Sarcopoterium-type	0.6 (1)		
POACEAE	4.7 (7.4)	Sporormiella,	6 (9.3)
CHENOPODIACEAE	21.4 (33.3)	Gelasinospora	0.3 (0.5)
ASTERACEAE-Cichorioideae	8.8 (13.7)	Anthririum-type	0.9 (1.5)
Artemisia	0.3 (0.5)	Glomus	1.3 (2)
Achillea-type	0.3 (0.5)		
Carlina-type	0.3 (0.5)		

increase of the light-demanding Asphodelus corroborates this opening of the vegetation and expansion of grasslands (Bottema, 1980; Moody, 1987). The increase of Olea in this context of human pressure, reaching elevated values of 45% at K7, could indicate that the spread of the olive tree was probably favoured by some kind of human management (see section 5.2). In this sense, the coeval expansion of both cereals and olive and the concomitant increase in weeds (Carlina-type, Asphodelus, Brassicaceae) suggests the expansion of agricultural practices in the nearby coring site in a period of decreasing local grazing activity, as suggested by the relatively low values of strict coprophilous fungi (mainly Sporormiella), and Cichorioideae (Florenzano et al., 2014). This coincides with a rise in macrocharcoal fragments pointing to the increase in the occurrence of fires, which could have probably been used to enlarge cleared spaces and to maintain the open structure of the landscape.

This striking landscape shift roughly coincides with the first archaeological evidence of settlement in the Palaikastro area. However, those archaeological studies that have documented an increase in the number of settlementsdwith expansion of coastal occupation, often in well-defined villages, as well as smaller sites representing isolated houses and hamlets (Nowicki, 2002, 2008, 2014; Tomkins, 2008)dsee this process occurring towards the end of the period in question, that is to say c. 3300-3200 cal yr BC. In our study area both Kastri and Petsophas seem to be first occupied during the FN II (Nowicki, 2008, 2014). However, with the pollen results suggesting an increase of human impact on the landscape from c. 3600 BC, it is possible to suggest that such processes of settlement expansion had started earlier than thus far recognized in the archaeological data. Indeed, Nowicki does wonder if there might have been an occupation of Kastri as early as FN I (Nowicki, 2014).

The substantial rise in the number of settlements has generally been explained by population growth and the result of continuous indigenous development, with only limited input from increasing oversea contacts (Papadatos, 2012; Tomkins, 2008; Watrous, 1994). Yet, some researchers have suggested that the changes in the settlement patterns and discontinuities in the material culture could indicate possible migration from nearby regions outside Crete (Nowicki, 2002, 2008). However, the pollen diagram indicates an evolution of the existing landscape, rather than the introduction of foreign elements such as different crops and a landscape restructuration.

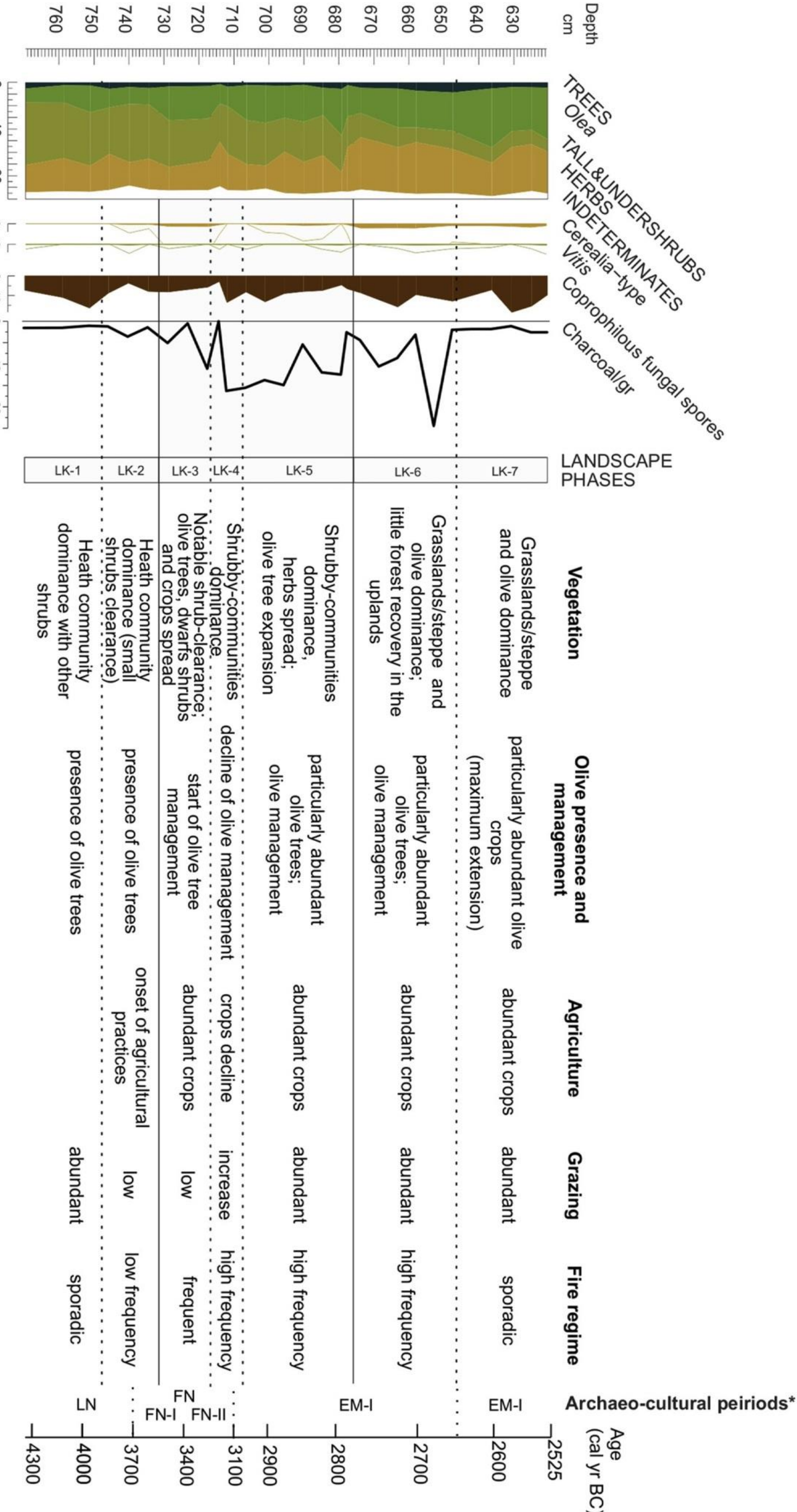
5.1.4. Landscape phase IV (LK-4): c. 3200-3000 cal yr BC; (late FN II/ early EM I) (K5-2b; K7-2a)

This phase shows a significant olive decline and grassland expansion (LK-4) which is dated to between 3200 and 3000 cal yr BC in K5 and between 3100 and 2800 cal yr BC in K7 (Figs. 4 and 5). The age disagreement between the two cores of about 100e200 years could be explained by the uncertainty of time depth models from radiocarbon dating. In this sense, the uncertainty ages for this period are ±50 years in K5, and ±100 years in K7. Several prominent changes in the vegetation took place during this phase. Pollen data indicate a short period of agricultural decline of Olea and cereals, triggering a plant succession through this period. In this regard, in the K7 sequence the initial increase in grasslands (Poaceae, etc.) coeval with the Olea decline was clearly followed by the rise of low shrubs, such as Cistaceae and Lamiaceae (Fig. 5), and later on by the recovery of heath vegetation, which is especially evident in the K5 sequence (Fig. 4). These changes suggest a process of plant recovery after field abandonment. The fact that in 200 years this succession process did not result in forest recovery could suggest that forest was not a primary community in the area. At the beginning of this phase, the notable decrease in dung-related fungal spores suggests an initial period of low herding activity. Later on, at c. 3100 cal yr BC, the sharp rise of Sporormiella and Coniochaeta, coeval with a great increase in Cichorioideae and other ruderal taxa, such as Plantago, suggests the recovery of grazing activity, probably in littoral sectors whereas inland, shrubby vegetation was still recovering (Florenzano et al., 2014). Therefore, the data suggest a phase of agricultural decline and expansion of grazing practices mainly in littoral sectors with the use of fire to maintain the open landscape.

5.1.5. Landscape phase V (LK-5): c. 3000-2780 cal yr BC; (EM I early) (K5-2c)

According to the chronological model of K5, at c. 3000 cal yr BC, the landscape in the Palaikastro area recovered similar characteristics to the former landscape phase III with Olea percentages reaching again values of 30% at the K5 sequence, or even higher at the K7 sequence. This suggests a new wave of Olea tree expansion (see section 5.2). The higher percentages of herb pollen suggest the thriving of more open spaces with grasslands expanding at the expense of shrubs and undershrub plants, as indicated by the reduction in Ericaceae and Sarcopoterium-type. These clearances could have been caused by the use of fire as indicated by the high concentration of charcoal particles in both diagrams. This in turn

Fig. 7. Summary of the main features of landscape phases described in Kouremenos cores (see discussion



seems to have caused a high degree of land degradation, as shown by the presence of Asphodelus and Euphorbia (Rhizopoulou et al., 1997). These changes were due to a new phase of higher human impact resulting from the combination of higher agricultural production and grazing pressure. The agricultural recovery is shown by a slight increase in annual crops like cereals, and the spread of common weeds, such as Plantago and Carlina-type, while the increase in grazing pressure can be deduced from the high values of coprophilous fungal spores and Cichorioideae and Asphodelus pollen taxa (Florenzano et al., 2014; Rhizopoulou et al., 1997; Turland et al., 2004).

5.1.6. Landscape phase VI (LK-6): c. 2780 - 2650 cal yr BC (EM I late) (K5-3a, K5-3b)

This phase integrates two pollen subzones of core K5 (3a and 3b). A significant vegetation change took place at c. 2780 cal yr BC during EM I, characterized by a new and wide spread of grasslands and a retraction of shrubland and dwarf shrub phryganic communities, as shown by the steep decline of Ericaceae and Sarcopoterium-type. The higher presence of dung-related fungal spores and Cichorioideae indicate the increase in grazing activities (Florenzano et al., 2014). Burning was commonly used to manage vegetation and probably favoured grassland expansion as pasture.

The expansion of olive continued during this phase, together with an enlargement of the annual crops as indicated by Cerealia-type values and the presence of weeds, such as Plantago and Caryophyllaceae (Bottema, 1980; Turland et al., 2004). The continuous curve of Vitis pollen, with slightly higher values than before, suggests as well the possible presence of grape crops during this period of agricultural development, taking into consideration that cultivated Vitis has low pollen production and dispersion (Bottema, 1980; Fall 2012; Turner and Brown, 2004). Regarding this, Bottema and Sarpaki (2003) give values of 2.3% in a vineyard near Akrotiri. Likewise in pollen samples from the Venetian period at Kouremenos, values of c. 0.7% were recorded during a period of dedicated Vitis cultivation and wine trade (Gasparis, 1997; Stallsmith, 2007). Archaeobotanical data support the exploitation of grape at a similar period (Livarda and Kotzamani, 2013; Sarpaki, 2012), with the presence for instance, of possible must remains at Prepalatial Myrtos Fournou Korifi (Renfrew, 1972b). On the other hand, a slight increase in oak and pine pollen points to partial forest recovery in inland elevations during this period. Therefore, the data suggest an important agropastoral expansion in the area, with clear evidence for both agricultural and pastoral activities. This marked landscape shift with a spatial organization of land uses suggests a more continuous occupation of the littoral plain and the definitive use of slopes. This functional restructuring of the landscape could be related to the growth of the town of Palaikastro at Roussolakkos, that could have contributed to new landscape changes, spatial distribution of land uses and wider and greater human impact on the littoral plain. Thus, the results suggest a possible expansion of the Palaikastro settlement earlier than suggested by archaeological evidence, which points to its establishment in EM IIA (e.g. MacGillivray and Driessen, 1990; MacGillivray and Sackett, 2010).

5.1.7. Landscape phase VII (LK-7): 2650-2525 cal yr BC (Early Minoan IIA)(K5-3c)

Similar vegetation to that of the former landscape phase was recorded in the area since 2650 cal yr BC coinciding with the Early Minoan IIA period, but with a new expansion of olive orchards (see section 5.2), which reach their maximum value in the sequence. During this phase pastoral grazing activities continue to be attested through the occurrence of coprophilous fungal spores and Cichorioideae. The most important shift is a change in human practices, mainly the sharp decrease in charcoal particle concentration, indicating the reduction of burning frequency. This could result from the stabilization of crops and the fact that flock presence was enough to avoid shrubby regeneration maintaining the landscape opened without the use of fire. Our data suggest that a complex landscape with complementary land uses and activities was already in place.

5.1.8. Comparing the LN-EM Palaikastro landscape to the Venetian period

The landscape structure during the LN-EM periods greatly differs from that shaped during the Venetian rule (14th-17th centuries AD). Although similar high and low shrubby formations occupied the area during these periods with the likely presence of phrygana community on the slopes and maquis on the plaindimportant differences in plant composition and landscape structure can be observed (Figs. 4-6).

In contrast to the prehistoric period, the maquis community was mainly dominated by mastic (Pistacia) during the Venetian period, as indicated by the high percentage of this commonly underrepresented pollen type (Fall 2012), together with Ericaceae and Juniperus (Fig. 6). Hence, a great expansion of the mastic community occurred in the area at some point between the Early Minoan and the Venetian period. The lower abundances of Lamiaceae and Cistaceae pollen, as well as Sarcopoterium-type, suggest a decrease in the presence of phrygana community during the Venetian period. On the other hand, a more diversified agricultural system during the Venetian period can be inferred by the high diversity of crop taxa, including orchards of Olea, Vitis, Ceratonia, and Castanea, and dryland crops like Cerealia and flax (Linum usitatissimum) and irrigated ones, such as hemp (Cannabis). The relatively low values of Olea pollen suggest the restricted distribution of this tree, and consequently its low exploitation, which clearly contrasts with the EM period. Instead, higher Cerealia values suggest an agricultural system more focused on cereals. This is in accordance with written sources, which indicate that the Venetian economic policy was principally directed towards the export of wheat and wine, while olive oil production was not encouraged and olives were only cultivated for local consumption (Gasparis, 1997, 2005; Stallsmith, 2007). The presence of the carob tree (Ceratonia siliqua), in contrast to its absence in FN-EM periods, suggests its relatively late introduction in this area although records from the west of the island have identified carob at c. 3500 yr BP (Bottema and Sarpaki, 2003). The values of carob recorded during the Venetian rule suggest the presence of orchards, as indicated by modern pollen studies (Fall 2012). Likewise, Castanea was not observed in the EM record, but is first found during the Byzantine period (650e800 AD) at Asia Gonia (Jouffroy-Bapicot et al., 2016). The higher abundance of weeds in comparison to the EM period, such as Plantago (including Plantago lanceolata-type), Rumex, Euphorbia, Asphodelus, and Artemisia, suggest a high human pressure during the Venetian period, which is in accordance with other Cretan records (Atherden and Hall, 1999; Bottema and Sarpaki, 2003; Jouffroy-Bapicot et al., 2016). Nevertheless, the percentages of coprophilous spores suggest only a moderate presence of grazing activity in the delta plain.

5.2. Landscape and olive culture in the LN and EM periods

The olive (Olea europaea) is one of the most prominent and economically important fruit trees in the Mediterranean basin (Zohary and Hopf, 2000). As mentioned above, in regards to prehistoric Crete, its intensive cultivation for the production of olive oil was put forward as one of the main factors that triggered the development of redistributive centres in the Early Bronze Age and the complex Minoan society (e.g. Renfrew, 1972a), whereas others have argued that its large scale exploitation only started in the Late

Minoan period (e.g. Hansen, 1988) as a means of elite competition (e.g. Hamilakis, 1996). More recently on the basis of archaeobotanical data Margaritis (2013) argued that there was some presence of olive in the Neolithic period and a significant increase in the Bronze Age while olive oil according to residue analysis was in use since the Neolithic (but see Sarpaki, 2012). Hence, the dynamic role of olives in the transition between the Neolithic and Bronze Age deserves special attention as it can add crucial information that will contribute and help resolve the question of the development of the earliest complex European societies.

The Kouremenos records show the importance of the olive tree in the area, and for this reason, they could constitute key sequences for the understanding of the expansion of the olive tree in the Palaikastro landscape and Crete. They reflect a clear trend for its increasing use and exploitation from the LN to the EM period. Significant values along the whole sequence testify the presence of this tree in the area at least since 4300 cal yr BC (LN). This is in line with palynological studies from northwestern Crete which pinpoint the beginning of the Olea pollen record in the fifth millennium BC (Bottema and Sarpaki, 2003; Moody et al., 1996). In the Tersana record (Akrotiri peninsula), olive is present since c. 4750 cal yr BC (Moody et al., 1996), while in the Delphino-Kournas sequence a continuous olive curve starts at c. 4800 cal yr BC (Bottema and Sarpaki, 2003). The native presence of olive in Crete is currently under debate. The relatively late appearance of Olea in the record, dated at c. 5000 cal yr BC, led Bottema and Sarpaki (2003) to suggest that it could have been an introduction, brought to the island by oversea contacts. This is in accordance with the absence of olive charcoal in the Neolithic levels at Knossos (Badal and Ntinou, 2013). In contrast, Moody et al. (1996) favour the hypothesis that the olive was a natural element of the Pleistocene vegetation of Crete that survived in refuges somewhere in the island, probably growing in ravines and localities with favourable microenvironmental conditions, and link its appearance in the record to its expansion due to human management. It is worth mentioning at this stage that it is not possible to distinguish between domesticated and wild olive varieties from the pollen morphology (Bottema, 1980; Bottema and Sarpaki, 2003; Langgut et al., 2014; Liphschitz et al., 1991), hampering the unequivocal identification of olive cultivation from pollen data. In several pollen studies of past records and present-day samples, percentages of 15%, such as those recorded in Kouremenos at c. 4300 cal yr BC, have been commonly interpreted as likely olive tree cultivation (e.g. Bottema and Sarpaki, 2003; Moody et al., 1996). Otherwise, historical pollen from the Venetian period recorded in Kouremenos show the highest pollen values of Olea at around 7% (Fig. 6), in a context where olive production was in place aiming at meeting local consumption needs (Gasparis, 1997, 2005; Stallsmith, 2007). These values are clearly lower that those reported during the LN and FN in the Kouremenos cores. Nevertheless, between 4300 and 3600 cal yr BC (landscape phase I and II, LN period), the almost complete absence of fires and other signs of landscape clearance suggests the limited human impact on the surrounding vegetation of Palaikastro. For this reason, we tentatively put forward the hypothesis that wild olive was present in the area during the second half of the 5th millennium BC as a significant tree in garigue formations. The overall native area where this plant thrives, located around the East Mediterranean, and the ecological requirements of the plant, give support to its presence in the island even if direct human management is not attested at this early stage (Carrión et al., 2010; Guerrero-Maldonado et al., 2016; Turland et al., 1993). The olive tree is a xerophytic plant, which requires mild temperatures, commonly thriving under Mediterranean climate, growing in shrubland communities at low altitude, and occupying the coastal fringe (Carrión et al., 2010; Guerrero-Maldonado et al., 2016; Zohary and Hopf, 2000). The relatively higher percentages of Olea pollen at Kouremenos (15%) compared with values observed in the western diagrams, point to a higher presence of this plant in the East sector of the island, where wider garigue/maquis formations developed. The drier climate of this region could have favoured the spread of this tree (landscape phases I, II) in contrast to western localities where oak forest predominates (Bottema and Sarpaki, 2003). On the other hand, the high values of olive recorded in Kouremenos also imply that the eastern region of the island could be one of the earlier areas where this tree expanded. Further palaeoenvironmental work, using older registers in other areas of east Crete would be necessary to elucidate these issues.

Between 3600 cal yr BC (at the onset of the FN period) and 2780 cal yr BC (EM I) the notable increase in Olea pollen, reaching values higher than 30% in K5 and 40% in K7, strongly suggests large extensions of olive trees in the area, which very likely entail human management (landscape phase III-V). These percentages are similar or even higher than those observed in the modern surface pollen samples of Chiona with values of 22-34% (see Table 3) while nowadays olive orchards constitute the main crop in the study area, occupying wide extensions of the plain and lower slopes. According to the Hellenic Statistical Authority (http://www.statistics.gr/en/statistics/-/publication/SPG31/-), in 2014, in the province of Lasithi 20,500 ha (c. 12% of territory) was occupied by olive crops. Likewise, percentages of 30% recorded during the FN and EM are clearly higher than those observed during the Venetian period (Fig. 6).

The vegetation clearance, the increasing degradation of the plant community and the use of fire coinciding with the rise of Olea since 3600 cal yr BC (see section 5.1.) corroborate the higher human pressure on the landscape during this period of olive expansion (landscape phase III-V). This fact lends support to the likely human management of this tree favouring its expansion. The coeval expansion of cereals in the area (see section 5.1) suggests that this phase was more focused on agrarian activities, further reinforcing the likely close relation between olive trees and human practices. Hence, this supports the idea that the high reported values in olive pollen could be related to tree management. The continuity of abundant shrub and undershrub communities (heath and phrygana) could indicate that olive was mainly expanding in the coastal plain during this period, while these shrubby communities occupied the limestone substrate.

Therefore, our data point to significant landscape changes probably resulting from the intensification of olive management in the area, indicating possibly an early exploitation of this tree in the Kouremenos plain. Similarly, western Cretan pollen records show a rise of olive in the 4th millennium BC, coeval with an oak forest clearance and a very significant increase of crops and anthropogenic indicators (Bottema and Sarpaki, 2003; Moody et al., 1996). These authors suggest that this increase was due to olive cultivation (Bottema and Sarpaki, 2003; Moody et al., 1996).

The Kouremenos pollen sequences suggest that Neolithic communities in Crete were actively engaged in the management of olive trees. The few archaeobotanical finds of olive wood and stones in the FN have been interpreted as possibly for timber use and olive collection (Margaritis, 2013). Although data are scarce, the landscape transformation evidenced by the pollen records suggests that since the end of FN I olive trees underwent a continuous expansion process in the landscape of the Palaikastro region, indicating human use and exploitation of this tree. The relative paucity of the archaeobotanical record could be explained by (1) taphonomic issues, such as the poor preservation of plant remains at the site of Palaikastro as well as general biases that stem from the relatively limited number of archaeobotanical remains recovered through large scale sampling and flotation across the island and/or (2) the use of the olive tree but not for human consumption of olives or the production of olive oil.

The early stages of olive tree management need not imply cultivation/domestication of the tree. The ancient use of wild Olea trees to pick olive fruits or to obtain wood, fuel and fodder (Sansourcy, 1985) has been suggested in many palaeoenvironmental works in the Aegean and the Levant region preceding olive cultivation and domestication (Asouti, 2003; Dighton et al., 2017). These activities usually involve human interaction with olive-trees (management), such as active pruning and me- chanical cleaning, which could favour the tree growth and vigour, easy fruit collection and reduction of biennial bearing (Langgut et al., 2014). Moreover, such tree management can increase the number of racemes in each branch, and thus flower production, and in consequence, higher pollen and fruit production (Aguilera and Ruiz, 2012; Langgut et al., 2014; Terral, 2000). Therefore, the in- crease in Olea pollen in our sequence could result from the com- bination of tree management by pruning and crop expansion in the area, as has been proposed for prehistoric Levant (Langgut et al., 2014).

In this context, the expansion of olive at c. 3600 cal yr BC inferred from the K5 record puts Crete among the first places in the eastern Mediterranean where management of this tree is observed. Several studies have suggested the Southern Levant as the geographic origin of olive cultivation (Besnard et al., 2013; Liphschitz et al., 1991; Zohary and Hopf, 2000) from the wild olive (Olea europaea var. oleaster), which is part of the ancient Levantine natural flora (Besnard et al., 2013; Langgut et al., 2014; van-Zeist et al., 2009). In particular, olive cultivation is reported to have started in Palestine during the 4th millennium BC (Litt et al., 2012; Salavert, 2008; Schwab et al., 2004; Zohary and Hopf, 2000). The first evidence of olive oil production dates to the Late Neolithic to Early Chalcolithic from submerged sites along the Carmel coast (Galili et al., 1997), but it was probably from wild olive (Kislev, 1994). Significant cultivation of olives most probably began in the Chalcolithic, for which high increases in Olea pollen were recorded in Levantine sequences (Baruch, 1990; Litt et al., 2012; van Zeist et al., 2009), and more abundant wood and/or fruits of olive were identified at several sites (Liphschitz et al., 1991; Zohary and Hopf, 2000).

From 2780 to 2525 cal yr BC (EM I to EM IIA, landscape phase VI and VII), the Kouremenos pollen records indicate a largely open and degraded landscape, mainly occupied by olive trees and grasses, while shrubby communities (maquis-garigues) remained very restricted. This landscape pattern suggests that olive cultivation expanded inland, probably occupying the hill slopes. The expansion of olive trees during this period supports the idea that olives expanded towards marginal sectors, such as the limestone hills surrounding the Kouremenos plain. The reduction of fire as a tool for landscape management from 2650 cal yr BC points to the sta- bility of olive crops and landscape structure in the area. The very high values of Olea pollen of about 40-45% during landscape phase VII (EM IIA), which are five times higher than those observed during the Venetian period domestic exploitation and twice as high compared to current commercial cultivation (Table 3), suggest a large scale and intensive olive tree management and exploitation, which suggests a more organized production. Although with less accurate chronological age-depth models, Olea peaks have been also identified in the Tersana and Delphinous-Kournas cores at northwestern Crete roughly at the same time, with values of c. 40% and 10% respectively (Bottema and Sarpaki, 2003; Moody et al., 1996), pointing to an extensive olive culture at this period across the whole island (Bottema and Sarpaki, 2003; Moody et al., 1996), which coincides with a likely increase in population, nucleation at coastal centres, and corollary changes in economy (Tomkins and Schoep, 2010).

Despite the general trend towards an increased presence of olive, its expansion was not continuous during the studied period. Some periods of Olea retreat were observed along the path of the formation of an olive culture economy. Pollen records of Tersana and Delphinous-Kournas also show similar periods of decrease (Bottema and Sarpaki, 2003; Moody et al., 1996). Particularly noteworthy is the period between 3200 and 2900 cal yr BC, when a clear decline of olive in the landscape is recorded, suggesting a decrease in its exploitation. During this period, the maquis/garigue communities underwent some recovery at Kouremenos. The reversion of cultivated trees to their wild form (feral), which happens when managed trees are neglected, may reduce their pollen production (Langgut et al., 2014; Moody et al., 1996). At c. 2900 cal yr BC (landscape phase LK-5) pollen values recovered and rapidly reached again values of 30%. This could be due to the quick recovery of pollen production after the rehabilitation of abandoned olive orchards (Langgut et al., 2014).

6. Conclusions and final remarks

Our palaeoenvironmental multi-proxy study carried out in the Palaikastro region of Eastern Crete provided new information on landscape and land use changes, allowing novel insights into long standing debates. The two records analyzed constitute a significant resource for the investigation of the emergence of Minoan society during the Early Bronze Age in Crete, shedding light on issues related to farming development and in particular olive oil production and distribution that have been considered key for the later rise of urbanism and state society. Substantial landscape changes due to human activities have been identified in the Palaikastro region from the FN to the EM period. Seven landscape phases were observed between 4300 cal yr BC (LN) and 2525 cal yr BC (EM-IIA), resulting from the combination of different intensity of agricultural and pastoral practices in the area, and the use of fire as a tool for vegetation and landscape management. Since 4300 cal yr BC, this eastern region has been mainly characterized by an open landscape dominated by shrubland vegetation. Human activities were limited but pastoral practices were recorded since 4300 cal yr BC. The first evidence of agricultural activity in the lower plain occurred at 3900 cal yr BC, coinciding with increasing fire frequency. Olive trees were present in the area since 4300 cal yr BC possibly as an important component of the maquis communities. This tree underwent a notable expansion since 3600 cal yr BC (FN) that involved the beginning of a major landscape transformation, characterized by an opening of the landscape. The increase in Olea pollen is related to the expansion of olive trees but also probably to its human management, such as pruning and mechanical cleaning. This type of management could be geared towards the collection of diverse products of the olive tree, such as fruits, timber and fodder. From 3600 to 2780 cal yr BC the Palaikastro landscape became progressively dominated by olive trees. During this period, olives expanded probably in the lowlands, indicating their early exploitation in the Kouremenos plain, while dwarf-shrubby phryganic communities occupied mainly the slopes, suggesting the dominance of grazing activities in close elevations. Between c. 2780 and 2525 cal yr BC there was a largely open and degraded landscape, mainly occupied by olive trees and grasslands, coinciding with an increase in grazing practices. The high pollen percentages of 40-45% of olive indicate that this was an intensive and large-scale exploitation, probably including lower slopes of limestone littoral elevations. This means that the olive trees expanded to more marginal and less productive areas during this period. At c. 2650 cal yr BC, the reduction of fire frequency suggest the possible stabilization of crops and the fact that flock pressure was enough to maintain the landscape open avoiding plant regeneration. The history of olive tree management and expansion is not strictly unilineal, as a transitional period of lower human pressure and plant recovery was recorded between c. 3200 and 3000 cal yr BC.

Our data suggest that a complex and organized landscape with complementary land uses and activities was already in place during the FN. The results allow us to draw several significant conclusions: (1) the olive trees were probably native to Crete where (2) one of the earliest occurrences of its management is recorded at c. 3600 cal yr BC in Kouremenos area; (3) the ancient date and high percentages of Olea pollen recorded at Kouremenos in relation to the other pollen studies in the island allow us to hypothesize that eastern Crete was one of the oldest areas of olive trees management in the island; (4) the olive presence and management during the EM period reached values well above those recorded in olive production areas today, which indicates an intensive (and probably also extensive) economic use of this tree; (5) an expansion of olive from the coastal plain to the surrounding coastal mountain ranges is attested during the late EM I and EM II probably indicating an economic use of this plant, which required the use of wider areas of the landscape; (6) olive management was complementary to other economic activities, such as cereal production and, particularly, pastoralism. In this sense, a complex and integrated system of land use could be in use during the FN and EM periods, which is suggestive of the existence of an organized social system at this early stage; (7) the direct use of the olive fruit or its by-products, such as olive oil, is still open to discussion as this use cannot be inferred from pollen data. This issue can only be properly addressed through the use of multidisciplinary data in which landscape archaeology, geoarchaeology and the bioarchaeological analysis of on-site recovered remains will be key.

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