Quaternary Research 85 (2016) 227–244

Contents lists available at ScienceDirect

Quaternary Research

journal homepage: www.elsevier.com/locate/yqres

Middle Holocene rapid environmental changes and human adaptation in Greece

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ARTICLE INFO

Article history:
Received 22 May 2015
Available online 12 March 2016

Keywords:
Bronze Age
Climate change
Fluvial system
Human adaptation
Mediterranean
Mid-Holocene
Neolithic
Non-Pollen Palynomorphs
Pollen
South-East Balkans

ABSTRACT

Numerous researchers discuss of the collapse of civilizations in response to abrupt climate change in the Mediterranean region. The period between 6500 and 5000 cal yr BP is one of the least studied episodes of rapid climate change at the end of the Late Neolithic. This period is characterized by a dramatic decline in settlement and a cultural break in the Balkans. High-resolution paleoenvironmental proxy data obtained in the Lower Angitis Valley enables an examination of the societal responses to rapid climatic change in Greece. Development of a lasting fluvio-lacustrine environment followed by enhanced fluvial activity is evident from 6000 cal yr BP. Paleoecological data show a succession of dry events at 5800–5700, 5450 and 5000–4900 cal yr BP. These events correspond to incursion of cold air masses to the eastern Mediterranean, confirming the climatic instability of the middle Holocene climate transition. Two periods with farming and pastural activities (6300–5600 and 5100–4700 cal BP) are evident. The intervening period is marked by environmental changes, but the continuous occurrence of anthropogenic taxa suggests the persistence of human activities despite the absence of archaeological evidence. The environmental factors alone were not sufficient to trigger the observed societal changes.

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Introduction

Over the past twenty years, palaeoenvironmental research in the eastern Mediterranean and Balkans has progressed significantly, mainly based on marine (e.g., Rohling et al., 2002; Kotthoff et al., 2008a,b; Triantaphyllou et al., 2009, 2014; Geraga et al., 2010; Kotthoff et al., 2011), lake and marsh (e.g. Digerfeldt et al., 2007; Pross et al., 2009; Peyron et al., 2011; Magny et al., 2012), peat bog (e.g. Bozilova and Tonkov, 2000; Stefanova and Ammann, 2003; Marinova et al., 2012), and more rarely fluvial (e.g. Benito et al., 2015) archives. These records provide evidence of significant climatic instability during the Holocene with notable periods of rapid climatic change (RCC) that are observed at the global scale (Bond et al., 2001; Mayewski et al., 2004; Wanner et al., 2011). At the same time, there has been an increase in numbers of scientific publications that connect cultural to environmental changes (e.g., Weiss et al., 1993; DeMenocal, 2001; Weninger et al., 2006; Büntgen et al., 2011; Drake, 2012; Kaniewski et al., 2013; Wiener, 2014). Such publications often propose a decisive role on modifications in biophysical factors in the emergence, decline or collapse of different societies, even if others suggest that these changes are more complex (Berglund, 2003) and propose non-deterministic explanations (e.g., Berger and Guilaine, 2009; Kuzucuoğlu, 2010, 2014; Mercuri et al., 2011; Roberts et al., 2011; Butzer, 2012; Lespez et al., 2014). Most of these studies have focused on the 8200 and 4200 cal yr BP events. For the first period, the main question concerns the consequences of RCC on human migration and the spread of Neolithic cultures from the Near East across Anatolia and Aegean towards Europe (e.g., Weninger et al., 2006, 2014; Berger and Guilaine, 2009; Lemmen and Wirtz, 2014). The second focuses on the effects of the 4200–4000 cal yr BP aridification on Middle Bronze Age societies in the Near East and eastern Mediterranean regions (e.g., Weiss et al., 1993; DeMenocal, 2001; Weninger et al., 2006, 2009; Weninger and Clare, 2011; Kaniewski et al., 2013; Wiener, 2014).

In this paper, we focus on the 6500–5000 cal yr BP period, which corresponds to one of the less studied RCC episodes in the Eastern Mediterranean and Balkans. This episode is evident at the global scale, but its timing is still unclear. Mayewski et al. (2004) provide evidence of a cool period from 6000 to 5000 cal yr BP, whilst Wanner et al. (2011) identify a cold spell between 6500 and 5900 cal yr BP. This uncertainty is related to the nature of RCC events that involve a combination of

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http://dx.doi.org/10.1016/j.yqres.2016.02.002
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https://doi.org/10.1016/j.yqres.2016.02.002 Published online by Cambridge University Press

orbital, ice-sheet, ocean circulation, large tropical volcanic eruptions, and solar forcing factors (Finné et al., 2011; Wanner et al., 2011) and the complexity of the middle Holocene climate transition (Triantaphyllou et al., 2009; Magny et al., 2013). Indeed, the beginning of the climate reversal following the Holocene climate optimum is characterized by complex interactions between changes in orbital forcing, ocean circulation, and solar activity (Magny et al., 2006; 2013).

In the southeastern part of the Balkans and the Aegean (Bulgaria, Greece and Southern Romania), this middle Holocene climate transition corresponds to the transition from the Late–Final Neolithic or Chalcolithic (~6500–5300 cal yr BP, according to the Greek terminology) to the Bronze Age (~5300–3000 cal yr BP). Many signs of cultural breaks have been identified, with the disappearance of certain characteristic material and cultural features of the final phases of the Neolithic, including decorated ceramics (black-on-red, graphite-painted, incised and incrusted types), zoomorphic and anthropomorphic figurines, clay models, and ornaments (e.g. *Spondylus* bracelets and beads) (Anthony and Chi, 2009; Papadimitriou and Tsirtsoni, 2010). On the other hand, the persistence of some techniques (architecture, stone and metal tools) and the permanence in the location of certain settlements suggest that a degree of continuity existed or at least that there were some ties between the two periods (Tsirtsoni, 2010, 2014).

The radiocarbon ages obtained recently confirm the break between the Neolithic and the Bronze Age, because they show that, at sites where both periods are represented, several centuries separate the last levels of the Neolithic from the first levels of the Bronze Age. Depending on the site and the precision of the ages, the hiatus extends from ~6300–6000 to 5400–5000 cal yr BP (Maniatis and Kromer, 1990; Görsdorf and Bojadžiev, 1996; Tsirtsoni, 2014). Furthermore, very few sites have been dated within this interval (Boyadžiev, 1995; Maniatis et al., 2014; Tsirtsoni, 2014). A chronological gap of seven to eight centuries is apparent in the entire area. Interpretation of these data remains the focus of debate. Some researchers tend to underestimate the problem, pointing out the provisional nature of the radiocarbon ages and emphasising signs of continuity (Andreou et al., 1996; Demakopoulou, 1996; Treuil et al., 2008). But others, particularly in Bulgaria, propose a range of hypotheses to explain the causes of what is often perceived as the total collapse of Chalcolithic civilization. Some evoke human factors, in the form of invasions of people from the steppes north of the Black Sea (Boyadžiev, 1995, 1998), whilst others favour the role of environmental factors in relation to social changes: climate change resulting in a global rise of the water level and flood intensification (Todorova, 1978, 1995, 2007) or, on the contrary, a severe drought (Nikolov, 2012), has been suggested as a potential factor. Based on the available palaeoenvironmental data in the southeastern part of the Balkans, Weninger et al. (2009) put forward the role of overall cooling and the succession of catastrophic cold winters in the triggering of societal change. In these hypotheses, the gap in the 4th millennium BC may be the result of movement towards more favourable areas: in particular, the southern mountainous zones (Rhodope Mountains) that constitute one of the regions where the Chalcolithic seems to persist the longest in Bulgaria, until 5800–5700 cal yr BP, and more generally southwards to the Aegean.

To assess the causal link between settlement decline and RCC periods, we need to examine more precisely the relationship between climate change and the paleoenvironmental conditions at archaeological sites. In the framework of the French project "Balkans 4000" that addresses climate–society interactions during the 4th millennium BC, we develop archaeological and palaeoenvironmental investigations to show that the hiatus is real and define its age based on numerous archaeological sites in the southeastern Balkans (Tsirtsoni, in press). To be able to detect the spatial organisation of the results, we studied sites distributed as equally as possible, taking into account the density of the archaeological sites and possibilities for sampling (Fig. 1). Broadening the framework of the study region was essential to be able to examine evidence for existence of specific sanctuary areas or the progression of site abandonment in the Balkans. Our study area extends from Attica to the lower Danube Valley, covering ~360,000 km^2. Observations were at the site scale within this vast area. The sites examined have different profiles, in terms of nature (habitats, cemeteries), installation type (flat site, tells, caves), location (plains, mountains, coastal), and duration of occupation. The results of the archaeological research are presented in Tsirtsoni (in press) and the aims of this paper are to identify and describe changes in the environment near archaeological sites occupied during the Late Neolithic and the Early Bronze Age to examine the nature of paleoenvironmental transformation and its potential effects on changes in settlement patterns and land use.

Previous research and study area

Research was conducted in the current floodplain of the Lower Angitis River near the confluence with the Strymon River (40°55′11″ N; 23°49′23″ E). This area is located 15 km from the Aegean Sea and the mouth of the Strymon River, and was chosen because of its archaeological and palaeoenvironmental potential as shown by previous investigations conducted in Greek eastern Macedonia (Lespez, 2003, 2007, 2011, Lespez et al., 2013). From an archaeological perspective, this area has the advantage of being situated at the outlet of a north–south axis that has repeatedly played a crucial role in the population dynamics of the Balkans and in exchanges between the Aegean world and southeast Europe (Todorova et al., 2007). The region is also in the middle of a zone where archaeological studies have been extensively developed and contains many sites occupied during the Late Neolithic and the Early Bronze Age. The well-known excavated sites of Dimitra (Grammenos, 1997), Sitagri (Renfrew et al., 1986; Fig. 1, site 9), and Dikili Tash (Darcque and Tsirtsoni, 2010) show a hiatus of 800–1000 yr during the 4th millennium BC in the settlement history, which according to the available archaeological information has been interpreted as an abandonment of the site by Late Neolithic people. In the lower Angitis valley, we focus our investigation at the bottom of the archaeological site of Fidokoryphi that is one of the four Late Neolithic and Early Bronze Age sites within a radius of 10 km (with Dimitra, AÏri Baïri and Kryoneri; Grammenos and Fotiadis, 1980; Fig. 2). Fidokoryphi is established on a small-elongated Neogene hill (330 × 100 m), which reaches 19 m above sea level (asl) and dominates the alluvial plain of the Angitis River (Fig. 2). The previous investigations conducted on the Holocene deposits show a thick fill of more than 10 m that is composed of alluvial and shallow lake deposits that reveal a significant potential for high resolution palaeoenvironmental studies (Lespez, 2007).

The lower Strymon Valley forms a subsiding basin along a Cenozoic detachment system (Dinter and Royden, 1993), situated between the Serbo–Macedonian massif to the west and the southern Rhodope Mountains to the east that rise to between 1300 and 2100 m asl. Tectonic activity was high during the middle Pleistocene and decreases during the late Pleistocene, with the studied area being relatively stable during the Holocene (Broussoulis et al., 1991; Lespez and Dalongeville, 1998). The valley bottom lies 5 to 100 m asl and is fringed by faulted Neogene hills with calcimagnesic soils and coalescing series of middle and upper Pleistocene alluvial fans composed of gravelly reddish-brown sediments (Psilovikos, 1986; Broussoulis et al., 1991; Lespez and Dalongeville, 1998). The distal parts of these alluvial fans are covered by vertic soils (Lespez, 2008). The Angitis River drains the Drama–Philippi basin. Given the karstic nature of the southern Rhodopes (marbles), stream flow is perennial and the monthly discharges vary between 6 and 29 m^3/s. In its lower course, the Angitis River has been extensively modified due to the complete drainage of the Achinos Lake which occupied the valley bottom until the early 20th century (Ancel, 1930). Travel accounts available from the 16th century highlight the large size of the lake and its marshy shores that were characterized by seasonal change (Fig. 2). The historical data for older periods suggests the continuance of the marshy lake landscapes

https://doi.org/10.1016/j.yqres.2016.02.002 Published online by Cambridge University Press



Figure 1. Study area with archaeological sites studied in the "Balkans 4000" programme (black circles indicate sites dated during the programme and grey circles other settlements) and the location of the main previously published palaeoenvironmental investigations discussed in the text. A. Study area; B. Tenaghi Philippon; C. Core SL 152; D. Lake Prespa; E. Lake Ioannina; F. Lake Xinias; G. Lake Kopais; H. Lake Gölhisar; I. Core LC 21. Archaeological sites: 1. Tatul; 2. Orlitsa; 3. Varhari; 4. Yunatsite; 5. Haramiiska; 6. Yagodina; 7. Dolno Dryanovo; 8. Slatino; 9. Sitagroi; 10. Promachon Topolnitsa; 11. Sidirokastro; 12. Kryoneri; 13. Dikili Tash; 14. Polyplatano; 15. Megalo Nissi Galanis; 16. Dispilio; 17. Maliq; 18. Makriyalos; 19. Doliana; 20. Mandalo Dikili Tash; 21. Makrychori; 22. Rachmani; 23. Galini; 24. Mandra; 25. Palioskala; 26. Vassilis; 27. Prodromos; 28. Sykeon; 29. Dimini; 30. Mikrothives; 31. Astakos; 32. Drakaina; 33. Sarakinos; 34. Tharounia; 35. Athens; 36. Merenda; 37. Kitsos; 38. Agia Triada; 39. Limnes; 40. Agios Dimitrios; 41. Franchthi; 42. Kouveleiki; 43. Diros; 44. Kastri; 45. Limenaria; 46. Agios Ioannis; 47. Agios Antonios; 48. Mikro Vouni; 49. Poliochni; 50. Kum Tepe; 51. Youra; 52. Emborio; 53. Strophilas; 54. Kephala; 55. Ftelia; 56. Saliagos; 57. Zas; 58. Knossos; 59. Phaistos; 60. Kephala.

during Byzantine times. Earlier testimonies are rare but those of Herodotus, Thucydides and Appian also provide evidence of a large lake in the lower Strymon and valley, which could have been affected by the same seasonal rhythms as those described for modern times (Bellier et al., 1986).

The climate is sub-Mediterranean with a continental influence. The mean annual temperature is 15°C and the annual precipitation in the plains is about 600–650 mm (Horvat et al., 1974). The mountainous areas are characterized by sub-Mediterranean vegetation (Horvat et al., 1974). On the foothills, grazing pressure has led to the replacement of the woodlands with Mediterranean shrub (Atherden, 2000). According to Gerasimidis (2000) the lower part (below 600–800 m) of the Lailias Mountains, inside the Strymon catchment, is dominated by shrub or low woodland with hornbeam (*Ostrya carpinifolia*), juniper (*Juniperus oxycedrus*), evergreen oaks (*Quercus ilex* and *Q. coccifera*), and elm (*Ulmus minor*). Mixed deciduous oak forest (*Quercus pubescens*) and Scots pine forest (*Pinus sylvestris*) dominate between 800 and 1200–1400 m asl. Above this subzone, up to 1700–1800 m asl, the slopes are occupied by beech (*Fagus sylvatica*) forest with occasional willow (*Salix* sp.), birch (*Betula* sp.) and fir (*Abies cephalonica*). In the upper part of the mountain, different sub-alpine or alpine plant communities are well-developed, such as perennial grasses (Strid and Tan, 1997).

Materials and methods

Geomorphic and sedimentological investigations

We applied standard geomorphic and sedimentological methods that include examination of texture, structure and geometry of the sedimentary units such as used by Miall (1996) and Brown (2008). The

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Figure 2. The study area in the lower Strymon and Angitis Valley and location of the cores. 1. Border of the Neogene and Quaternary formations; Blue lines show lakeshore changes derived from old maps (1904: German map of Salonik area, 1/200,000; 1918: British map of Achinos Lake, 1/20,000; 1927: Greek map of Rhodolivos, 1/100,000).

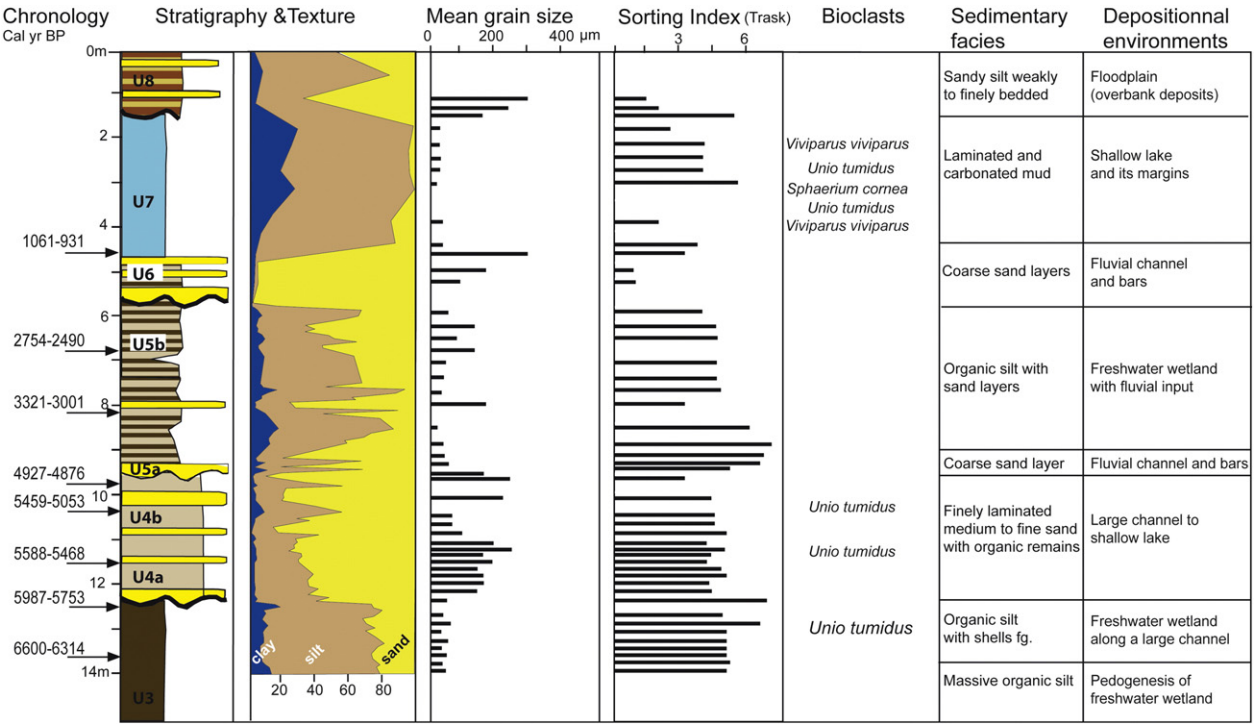


Figure 3. Synthetic diagram for core FC1 sedimentological and bioclast analyses.

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artificial entrenchment of the Angitis River (5–6 m) provided the opportunity to describe the upper part of stratigraphic units and lithofacies using the bank exposure (FCp1). Additional fieldwork mainly included coring organised in a cross-section to document the lateral and longitudinal patterns of the Holocene fill. A total of five cores (6–12 m deep) located on both sides of the hillock were obtained using a percussion drilling machine (Fig. 2). Core FC1 is located at the bottom of the FCp1 section. Each core was described in the field and laboratory. Further analyses were undertaken on samples from cores FC1 and FC4 (Fig. 3). Grain size was measured for 285 samples using a laser particle analyser (Coulter LS 200), adjusting for measurements on the >2 mm fraction. Coarse material was removed and grain size was determined using 5 sieves with mesh sizes of 2, 2.5, 3.15, 4 and 5 mm. Deposits were described using two variables, the coarsest percentile (C) and the median (M), extracted from the cumulative curve of grain size distribution in a sample following the method developed by Passega (1957) and completed by Bravard and Peiry (1999) for the floodplain deposits. C and M have been plotted on a log–log graph and give the C–M pattern of the alluvial deposits (Fig. 4).

Carbonate content of 124 samples of FC4 was determined using a Bernard calcimeter. High-resolution scanning, magnetic susceptibility (SI) and gamma-ray attenuation bulk density were also measured in core FC4 at 5 mm resolution using a Geotek multisensor core logger.

Micromorphological analyses were conducted to identify the sedimentary microfacies for core FC2. Fifty large-size thin sections (12 cm × 6 cm) were examined at 1.25–40× magnification using a petrological and incident UV light microscope for precise descriptions of the laminated sediments and more generally to detect micro-bedded sediment structures and describe sedimentary facies, some pedological features (humification, biological activity, micro-aggregation, hydromorphic features, oxidation, and desiccation features), and organic matter content. Facies assemblages were identified and interpreted in terms of architectural elements based on standard models (Miall, 1996). In addition, architectural elements and sediment transport types were identified combining facies assemblage and grain-size analyses.

Dating

The chronostratigraphy of the cores was determined using a series of 24 AMS and one conventional radiocarbon age from in situ charcoal, plant remains and total organic matter (Table 1). Radiocarbon ages and age–depth model of FC1 were calibrated using OxCal v4.2.3 (Bronk Ramsey, 2013) and the IntCal13 atmospheric calibration curve (Reimer et al., 2013). Figure 5 shows the age–depth model calculated for the pollen diagram with linear interpolation (2σ) using Tilia 2.0.

Palaeoecological analyses

The macroscopic shells of freshwater bivalves and molluscs were identified to further help reconstruct the paleoenvironment. Fresh water mussels (*Unio tumidus*) indicate sandy environment whilst fresh water snails (*Viviparus viviparus*) are more typical of silty sedimentation, characteristic of low energy to standing water (Fig. 3).

Despite the problem of preservation and waterborne contamination, several studies highlight the potential value of pollen data obtained in floodplain and shallow lake contexts to reconstruct the environments (e.g., Brown, 1999). Analyses focused on identification of pollen and non-pollen palynomorphs (NPPs) to reconstruct land cover changes. Eighty-nine 1 cm^3 samples were analysed from depths of between 3 and 10 m on FC1. All samples were treated following the Faegri and Iversen (1989) method although acetolysis was not carried out to allow the identification of any contamination by modern pollen. One *Lycopodium* tablet per sample was added to calculate pollen concentrations (Stockmarr, 1971). Small aliquots of the residues were mounted in glycerine, sealed with Histolaque and all recognisable pollen and spores were counted under a light microscope using 400× magnification, until a pollen amount of at least 500 units was reached. The average total land pollen (TLP) sum was 520 terrestrial pollen grains, excluding hydro-hygrophytic taxa and NPPs (expressed as percentages of the TLP). The identification of pollen grains was supported by a reference collection at the Archaeobiology laboratory of Madrid (CCHS, CSIC), identification keys and atlases (Moore et al., 1991; Reille, 1992). NPPs were mainly identified according to van Geel (2001); Carrión and Navarro (2002); van Geel et al. (2003) and van Geel and Aptroot (2006) following the nomenclature of Hugo de Vries (HdV Laboratory, University of Amsterdam). Pollen diagrams were constructed using Tilia 2.0 (Grimm, 1992). Due to fluvial to lake nature of the sedimentation the pollen concentration is variable, indicating aerial and fluvial inputs. Nevertheless, the pollen concentration is always high as shown by the synthetic diagram (56,738 grain/cm^3 for the least rich sample; Fig. 10), and it enables a precise restitution of the vegetation cover changes.

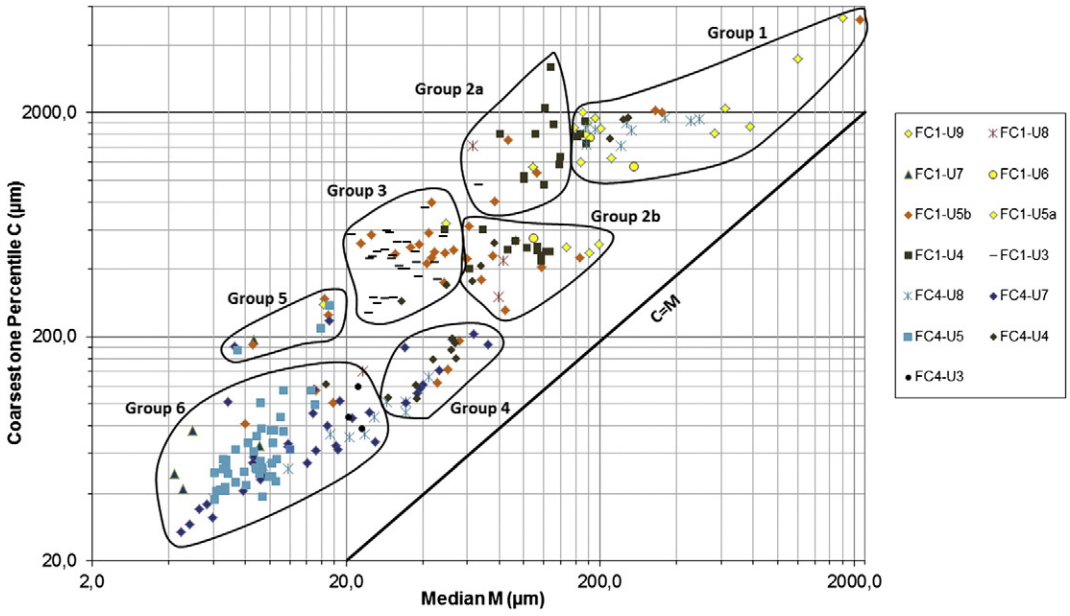


Figure 4. CM image representing the coarsest percentile (C) and the median (M) of Holocene and modern formations.

https://doi.org/10.1016/j.yqres.2016.02.002 Published online by Cambridge University Press

Table 1
Radiocarbon ages for Holocene deposits.

Site	Core	Depth	Ech.	Material	Measure	Lab. code	Dates ^{14}C yr BP (1 σ)	Calibrated ages cal yr BP (2 σ)	Remarks
Fidokoryphi	Cp1	4.51–4.63		Charcoal	Conventional	Ly-2323 (Poz)	1091 ± 38	1071–928	
Fidokoryphi	Cp1	4.51–4.63		Charcoal	Conventional	Dem-1116	1179 ± 26	1170–995	
Fidokoryphi	FC1	1.90–1.92	FC1-2	Plant remain	AMS	Lyon-7187	2350 ± 30	2465–2331	
Fidokoryphi	FC1	2.52–2.54	FC1-3	Charcoal	AMS	Erl-8790	2545 ± 40	2754–2490	
Fidokoryphi	FC1	3.45	FC1-4	Charcoal	AMS	Erl-8789	2969 ± 43	3321–3001	
Fidokoryphi	FC1	5.36	FC1-6	Twig	AMS	Lyon-6022	4270 ± 30	4927–4876	
Fidokoryphi	FC1	5.68	FC1-6	Charcoal	AMS	Erl-8789	4585 ± 46	5459–5053	
Fidokoryphi	FC1	6.90	FC1-7	Twig	AMS	Lyon-6023	4775 ± 30	5588–5468	
Fidokoryphi	FC1	7.80–7.82	FC1-8	Plant remain	AMS	Lyon-6392	5135 ± 35	5987–5753	
Fidokoryphi	FC1	8.84–8.88	FC1-9	Charcoal	AMS	Erl-8789	5663 ± 51	6600–6314	
Fidokoryphi	FC1	9.92–9.95	FC1-10	Pollen	AMS	Lyon-6393	5095 ± 35	5918–5746	Excluded
Fidokoryphi	FC2	2.79–2.82	FC2-3	Plant remain	AMS	Erl-12812	291 ± 49	435–285	
Fidokoryphi	FC2	3.89	FC2-4	Plant remain	AMS	Erl-12813	955 ± 49	957–746	
Fidokoryphi	FC2	4.25	FC2-5	Plant remain	AMS	Lyon-6024	1920 ± 30	1948–1746	
Fidokoryphi	FC2	7.93–7.94	FC2-8	Peat	AMS	Erl-12814	4841 ± 52	5710–5337	
Fidokoryphi	FC2	8.91–8.92	FC2-9	Organic silt	AMS	Erl-12815	8495 ± 68	9584–9310	Excluded
Fidokoryphi	FC2	8.98	FC2-9B	Organic silt	AMS	Lyon-7188	6665 ± 35	7591–7475	
Fidokoryphi	FC2	9.86	FC2-10	Plant remain	AMS	Lyon-6025	6275 ± 35	7275–7030	
Fidokoryphi	FC3	2.64	FC3-3	Plant remain	AMS	Lyon-6026	1215 ± 30	1256–1062	
Fidokoryphi	FC4	1.28	FC4-2	Charcoal	AMS	Lyon-7189	>45,000		Excluded
Fidokoryphi	FC4	3.38	FC4-4	Charcoal	AMS	Erl-15209	264 ± 30	431–262	
Fidokoryphi	FC4	663–665	FC4-663	Organic silt	AMS	Lyon-8119	1925 ± 30	2488–2279	
Fidokoryphi	FC4	9.68–9.70	FC4-10	Organic silt	AMS	Beta-273957	3310 ± 40	3640–3450	
Fidokoryphi	FC4	11.98–12.0	FC4-12	Organic silt	AMS	Erl-15213	6268 ± 48	7291–7017	
Fidokoryphi	FC7	4.60–4.63	FC7-5	Organic silt	AMS	Lyon-7192	2255 ± 30	2342–2157	
Fidokoryphi	FC7	6.62–6.72	FC7-7	Plant remain	AMS	Lyon-7193	2610 ± 30	2778–2716	

OxCal v4.0.5 (Bronk Ramsey, 2013); r:5 IntCal04 atmospheric curve (Reimer et al 2004).

We also added a macroscopic charcoal particle analysis to improve knowledge of the local fire regimes (Clark, 1988; Carcaillet et al., 2001; Whitlock and Anderson, 2003). Core sampling provided the opportunity to detect the main stages of the evolution of the fire regime even if the discrimination of specific events from the background levels of charcoal is much more difficult in fluvial wetlands than in a lake due to the regular fluvial input to the sedimentation. After sieving and chemical treatment with hydrogen peroxide charcoal particles >100 μm were counted using a binocular microscope under incident light (Tinner et al., 1998). Eighty charcoal samples from core FC1 were counted and recorded in particles per gramme ($p \cdot g^{-1}$).

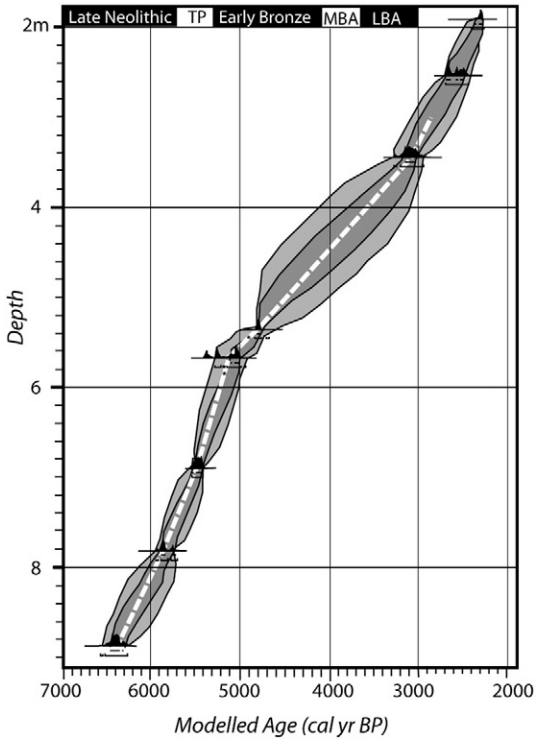


Figure 5. Age–depth model for core FC1 (OxCal v4.2.3, Bronk Ramsey, 2013; Calibration IntCal 13 atmospheric curve, Reimer et al., 2013). The dashed white line is the age–depth model calculated for the pollen diagram with linear interpolation (2σ) using Tilia 2.0. The cultural chronology for the studied area is from Treuil et al., 2008 and Tsirtsoni, 2014. TP: transitional period; MBA: Middle Bronze Age; LBA: Late Bronze Age.

Results and interpretation

Eight main stratigraphic units with ages that span the middle to late Holocene were identified; which we name U1 to U8 (Fig. 6). They correspond to the progressive filling of the valley bottom by alluvial and shallow lake deposits, resulting in a vertical accretion of 6 to 14 m. In this paper, the focus is on units U2 to U5 that cover the period from 8000 to 2500 cal yr BP.

Lithofacies of the Holocene deposits

The grain size classification, based on the C–M diagram, provides evidence for six groups of sediments that can be defined on the basis of grain size (Table 2, Fig. 4). Within these groups, ten facies were identified according to grain size, organic content, and micromorphology (Table 3, Fig. 7). Facies F1 and F2 are typical of mid-channel and lateral bars. F1 indicates the predominance of rolling processes for the gravel transportation, whilst the F2 results from saltation and suspension transport of sand and silt. Facies F3 to F6 are composed of very well-preserved laminated fine sand to silt deposits. These are rich in organic matter, particularly in leaf and branch remains that are commonly found in subhorizontal position indicating that the deposit was always below the surface of the water. These facies were deposited in standing water, such as the shallow lake, which occupied the lower Strymon Valley in historical times. These deposits always have high values of SI. In lake and fluvial environments, magnetic susceptibility often reflects the terrigenous flux derived from fluvial transport (Dearing, 1999). Moreover, in the study area, the dominance of the metamorphic basement (Psilovikos, 1986) may increase the ferromagnetic mineral contents of the fluvial input. So, the high SI value indicates the significance of the fluvial input and the dominant metamorphic origin

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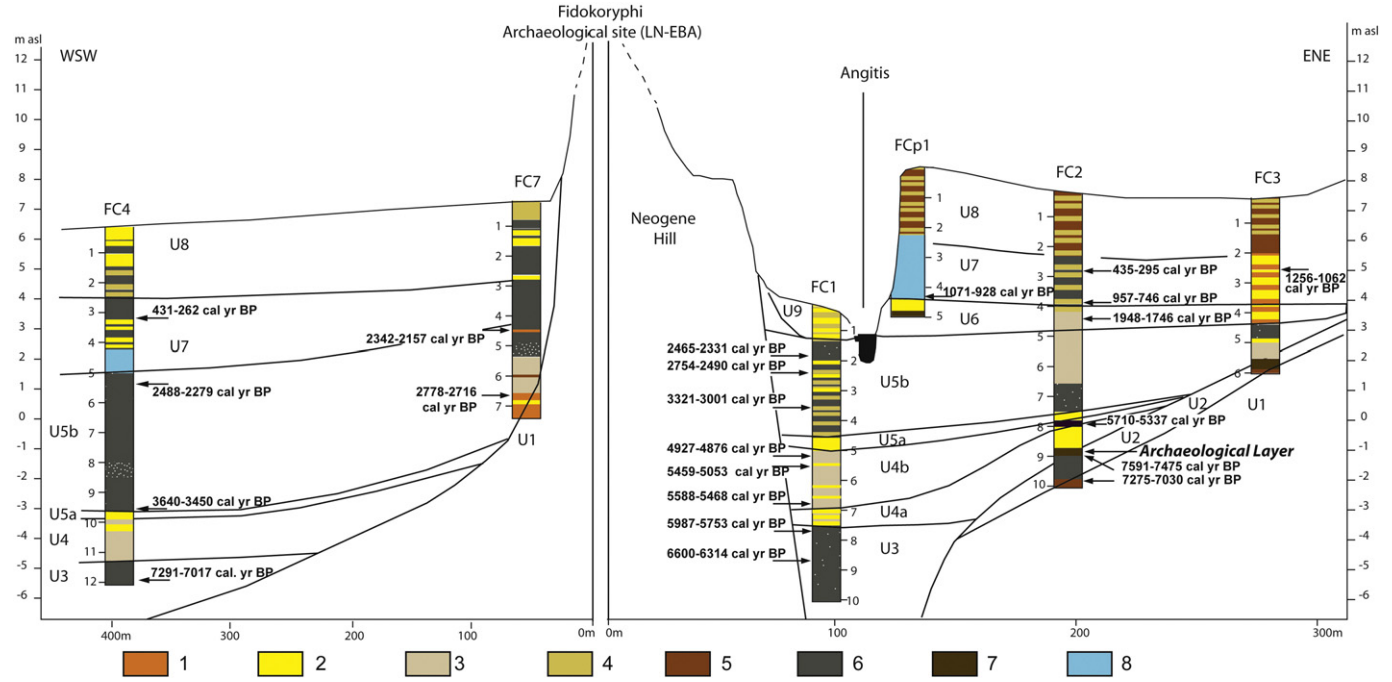


Figure 6. Holocene alluvial deposits along the Fidokoryphi transect. The sedimentary units are numbered from U1 to U8. 1. Coarse sand, gravels; 2. Medium to coarse sand; 3. Micaceous fine sand; 4. Sandy silt; 5. Silt; 6. Grey silt; 7. Organic to peaty silt; 8. Laminated carbonated silt.

of the sand grains. Facies F7 and F8 are interpreted as sediments transported by uniform suspension and deposited by decantation in a shallow carbonaceous lake as indicated by the high carbonate content of these deposits, always higher than 20% on the samples obtained on FC4. The reduced fluvial input is assessed by the low SI value and the low grain size of the metamorphic sand grains. Facies F9 presents silt deposits with a massive microstructure characteristic of overbank silt deposit. F10 corresponds to floodplain or piedmont palaeosols confirmed by micromorphological analyses. The palaeosols are often prismatic and the microstructure is subangular blocky. Bioturbation and pedogenic features are numerous. They correspond mainly to channels and chambers with limpid illuvial clay coating. These observations indicate the long-lasting development of illuvial horizon (Bt) of reddish brown to dark luvisol with vertic evolution. Holocene sedimentation is dominated by shallow lake deposits in core FC4. The variability of the fluvial input is noticeable (F3 to F8) and fluvial deposits (F1 and F2) are intercalated. The amounts of carbonate increase to the top of the sedimentation. During the last centuries, the complete silting of the Lower Strymon and Angitis valley by overbank and channel deposits (F1, F2 and F9) is observed on all cores (Fig. 3).

Table 2
Sediment groups determined by grain size analyses and interpretation.

Group	Median (M)	Coarsest one percentile (P)	Description	Inferred mode of transportation
1	160–2200 μm	1000–5300 μm	Medium to coarse sand	Saltation and rolling
2a	60–160 μm	800–3000 μm	Heterometric fine sand	Saltation and suspension
2b	60–200 μm	250–600 μm	Fine sand	Saltation
3	20–60 μm	250–800 μm	Silt	Suspension
4	30–80 μm	85–200 μm	Silt	Suspension
5	7–20 μm	80–300 μm	Fine silt	Decantation and suspension
6	4–30 μm	25–120 μm	Clay to fine silt	Mainly decantation

Architecture and environmental interpretation of the Middle Holocene deposits

Holocene deposits vary from 6 m on the edge on the floodplain to 14 m along the channel of the Angitis River. The radiocarbon ages show that Holocene sedimentation began in the middle Holocene, with sedimentation rates changing from 23.6 mm·yr^{-1} from 6500 to 5200 cal yr BP, 11.5 mm·yr^{-1} from 5200 to 3200 cal yr BP to 17.5 mm·yr^{-1} from 3200 to 2400 cal yr BP (Fig. 5). Four stages of sedimentation are apparent:

1) Stage 1 (7500–6000 cal yr BP, U2–U3) with incised valley bottom and wetland development. The base of the Holocene deposits is formed by Neogene outcrops, such as the Fidokoryphi hillock, and by Pleistocene alluvial fans (U1). During this first stage, alluvial sedimentation was limited to the narrow and incised Angitis River, probably <20 m wide, and into the Strymon valley bottom to the west. The lower parts of the slopes underwent Holocene pedogenesis that resulted in the development of a mature palaeosol (U2), observed at the bottom of cores FC2 and FC3. This soil, characterized by a polyhedric to prismatic structure and significant bioturbation and splits (facies F10), shows that a large part of the Lower Angitis Valley was outside the influence of flood flows. The soil comprises an archaeological layer (potsherds, bones, burnt clay) attributed to the Middle and Late Neolithic by the radiocarbon ages obtained on charcoal samples collected from core FC2 (Fig. 6). The alluvial sedimentation observed from 7500 cal yr BP corresponds to massive fine dark grey silt in core FC1 (U3, facies F8) and laminated dark grey silt and fine sand with some fragments of Neogene formations in core FC4 (U3, facies F5). This indicates a marshy environment restricted to the east along the narrow water course of the Angitis and at the edge of a shallow lake with minor fluvial input west of the Fidokoryphi hillock. The low value of magnetic susceptibility confirms the weakness of the fluvial input from the erosion of the river basin.
2) Stage 2 (6000–5600 cal yr BP, U4a) is characterized by alluvial sedimentation that is apparent in cores FC1, FC2 and FC4. The contact between the palaeosol and the marshy deposits, and the upper unit is

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Table 3
Sedimentary facies, description and interpretation.

Facies assemblage code	Description	Lithofacies assemblage (Miall, 1996)	M	C99	Grain size group	Interpretation
F1	Horizontal to cross-bedded coarse sand with gravels	Sp, Sh, Sl	500–2200 μm	1000–5300 μm	1	Midchannel, lateral sand bars and bedforms
F2	Laminated fine to medium sand	Sh	160–500 μm	1000–2000 μm	1	Sand sheet deposited out of main channel
F3	Laminated fine sand with coarser grain, abundant amorphous organic matter, organic remains (leaf, branch…) in subhorizontal position and charcoal	Fl	60–160 μm	600–3000 μm	2a	Shallow Lake with significant fluvial input
F4	Laminated fine sand with abundant amorphous organic matter, organic remains (leaf, branch…) in subhorizontal position and charcoal	Fl	60–160 μm	200–600 μm	2b	Shallow Lake with moderate fluvial input
F5	Alternation of fine micaceous sand and silt layers	Fl	20–80 μm	80–600 μm	4	Shallow Lake with weak fluvial input
F6	Laminated (rhythmic) greyish organic fine silt and white carbonated fine silt layers	Fl	2–30 μm	20–140 μm	6	Shallow lake and its margin
F7	Massive light brown carbonated fine silts with organic remains	Fsm	2–30 μm	20–140 μm	6	Shallow lake
F8	Grey massive silt	Fsm	20–60 μm	200–800 μm	3	Shallow lake to swampy floodplain
F9	Massive light brown silt	Fm	20–80 μm	80–800 μm	3, 4, 5	Overbank deposits in floodplain
F10	Dark grey organic silt with numerous pedogenic features	P	6–60 μm	80–800 μm	3, 4, 5	Floodplain palaeosol

erosional, indicating a phase of incision before the deposition of coarser alluvial deposits. During the beginning of this stage, alluvial sedimentation mainly corresponds to sandy deposits of mid-channel and lateral bars at the bottom of cores FC1 and FC2 (U4a; facies F1, F2). The alluvial architecture, grain-size analyses and the increase in magnetic susceptibility of facies F4 in core FC4 indicate that a shallow lake existed with moderate fluvial input. These observations reveal the instability of the course of the Angitis River with flood flows running on the both sides of the Fidokoryphi hillock.

3) Stage 3 (5600–4900 cal yr BP, U4b) represents a shallow lake and marshy environment that occurred after the establishment of the fluvial environment, resulting in a rapid rise of the water table, leading to an extension of the wetlands. The marshy environments reach the eastern part of the floodplain as far as core FC2 whereas the main part of the Lower Strymon and Angitis Valley was still occupied by a shallow lake. The sandy fraction of the deposits and the recurrent deposits of medium to coarse sandy layers is apparent from the fluvial sediments in cores FC1, FC2 and FC4 (Fig. 3). This indicates that the lake was regularly reached by the flood flows of the Angitis and Strymon rivers in the east and west, respectively. On the edge of the shallow lake, marshy environment developed depositing peat that is now present in core FC2. This landscape persisted for more than a millennium with the hillock of Fidokoryphi forming an island.
4) Stage 4 (4900–2500 cal yr BP, U5) represents a shallow lake and marshy environment. The contact of these units with the underlying units is erosional. Sedimentation is firstly characterized by an alluvial layer on both sides of the hillock (U5a). Then, at the bottom of the eastern side, the alternation of shallow lake deposits and coarser fluvial deposits is evident. In contrast, to the centre of the Angitis valley and towards the Strymon River, the deposits are predominance of fine silt to fine sand indicating a shallow lake environment (U5b). The grain size and magnetic susceptibility decrease observed in core FC4, suggest a low fluvial input originating from Rhodope bedrock. The wetlands reached their maximum extension and the position of the Angitis River was probably close to its position during stage 1. The Fidokoryphi hillock remained an island even if the magnitude of the coarse deposits could indicate the building of levees along the course of the Angitis River. During this period, an increase in carbonate deposition is clearly evident in core FC4 and probably indicates a relative increase in suspended load resulting from a local erosion of the soil developed in the Neogene carbonate formations. This increase of carbonate led to the development of rhythmic deposits with lamination of fine carbonated silt at the top of the U5 unit in core FC4 and even more in the following sedimentary units (U6 and U7). This explained the records of fresh water snails (*V. viviparus*) more than mussels (*U. tumidus*) from U7.

Pollen, NPPs assemblage and fire signature

The pollen record in core FC1 can be divided into six palynozones including TLP, hydro-hygrophytic and NPPs taxa (Figs. 8 and 9).

1) FC1-1 (1000–870 cm, ~7100–6400 cal yr BP)
In the first palynozone (FC1-1), the palynological composition of the samples is slightly dominated by arboreal taxa, mainly deciduous *Quercus* (19–28%). A significant presence of other woodland taxa such as *Alnus*, *Ostrya/Carpinus orientalis*, evergreen *Quercus* and to a lesser extent *Salix* and *Betula*, complete the vegetation spectrum. This observation indicates the dominance of a woodland cover (50–60%). Nevertheless, the forest coexists with significant herbaceous vegetation comprising Poaceae (8–28%) and *Artemisia* and also anthropozoogenous and anthropogenic–nitrophilous taxa (Fig. 8), which could be the first indicators of local human impact. Charcoal particles are always present throughout core FC1, but in the first palynozone, the number of charcoal particles remains less than 100 per 10 g, showing a low fire signature (Fig. 10). A slight increase in the number of charcoal particles (222 to 224 $p \cdot g^{-1}$) at the end of the palynozone may be explained by fire activity related to the establishment of the Late Neolithic population around 6500 cal yr BP.
2) FC1-2 (870–775 cm; ~6400–5800 cal yr BP)
The second palynozone (FC1-2) shows an increase in woodland taxa (70%) with a corresponding decrease in upland herbaceous taxa, particularly Poaceae. Dense mixed forest dominates and the major species are deciduous: *Quercus* (20–30%), *Ostrya/C. orientalis*, evergreen *Quercus* and *Alnus*. We observe the development of *Corylus* and the appearance of *Fagus* at the end of this period. Major change in hydrologic conditions is also evidenced by changes in the NPPs and hydro-hygrophytic records (Fig. 9). The appearance of open water eu-mesotrophic NPPs, corresponds with peaks in *Ceratophyllum* sp. (van Geel et al., 1980/1981), *Pediastrum* and *Botryococcus* colonies (Bakker and van Smeerdijk, 1982a,b,c; Komarek and Jankovska, 2001; Pasztaleniec and Poniewozik, 2004). Other hydro-hygrophytic

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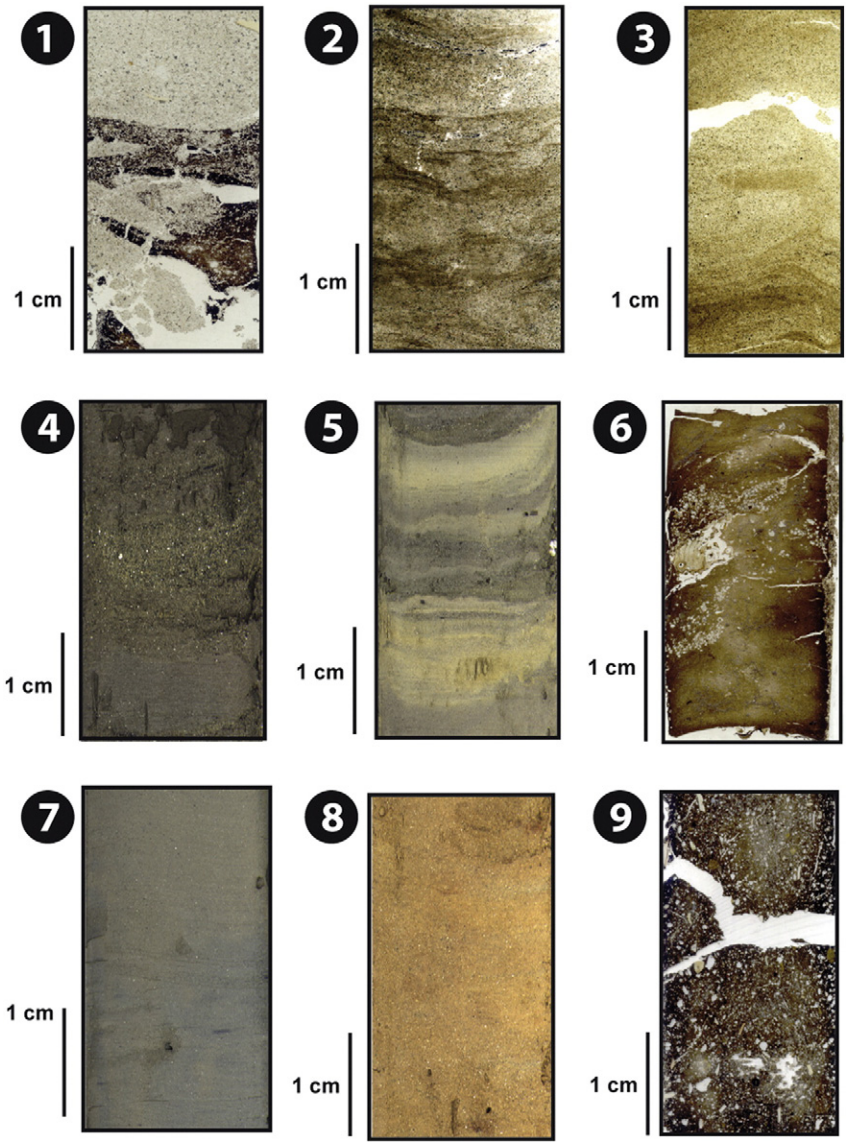


Figure 7. Thin sections showing microfacies organisation of laminated Holocene deposits. 1. Coarse to medium sand layers with reworked peat and organic remains (F1); 2. Laminations of medium to fine sandy deposits with amorphous organic matter and organic remains (leaves, twigs, etc.) in subhorizontal position (F3); 3. Laminations of medium to fine sandy deposits with amorphous organic matter, numerous microcharcoal particles and organic remains (leaves, twigs, etc.) (F4); 4. Laminations of micaceous sand and fine silt (F5); 5. Rhythmic deposits with lamination of fine carbonated silt and fine organic silt (F6); 6. Carbonated silt with organic remains (F7); 7. Grey massive silt (F8); 8. Massive light brown silt (F9); 9. Dark grey organic silt with numerous pedogenetic features (channels and chambers organised in a polyhedric structure) and archaeological artefacts (bones, fired clay, potsherds) (F10).

taxa and the two maximum percentages for *Abies* pollen at depths of 850 and 790 cm (6300 and 5900 cal yr BP), suggest wetter climatic conditions. According to the development of heliophilous and/or mesothermophilous taxa (*Corylus*, *Fagus* and evergreen *Quercus*), the wetter and likely warmer conditions were favourable for wooded cover growth on the slopes. At the same time, these conditions coincided with the start of Cerealia crop activity (0.5–5%), confirming the impact of agricultural activities in the lowland area. Weak fire activity is reflected in the low number of charcoal particles.

3) FC1-3 (775–750 cm; ~5800–5700 cal yr BP)
The third palynozone (FC1-3) corresponds to an event marked by the abrupt retreat of forest vegetation (<40%) with the exception of *Fagus*, the disappearance of almost all *Pediastrum* colonies and other hydro-hygrophytic taxa and the expansion of xerophilous NPPs, such as Type 200, indicative of temporary desiccation (van Geel et al., 1989). At the same time, we observe a significant rise in Poaceae, Cerealia, anthropogenic–nitrophilous, and anthropozoogenous taxa. The first peak of coprophilous NPPs such as *Sordaria*, *Sporormiella*, *Podospora* and *Cercophora* (van Geel, 1978; van Geel et al., 2003) suggests that the vegetation change was most likely related to grazing/browsing activities in the local surroundings. Moreover, correlation with the first major peak in charcoal particles (Fig. 10) (>1000 $p \cdot g^{-1}$) supports local human impact on the environment around 5800 cal yr BP.

4) FC1-4 (750–510 cm; ~5700–4450 cal yr BP)
The fourth palynozone (FC1-4) begins with the recovery of the landscape by arboreal taxa (*Alnus*, *Betula*, *Corylus*, *Ostrya*/*C. orientalis*, *P. sylvestris* and *Erica arborea*). The plant communities indicate a mixed-oak forest in the valley and on the lower slopes whilst a mountainous forest with coniferous (Scots pine and fir), beech and birch are recorded for the higher-elevation slopes. Wetland development is shown by an increase in *Cyperaceae* and eu-mesotrophic NPPs, such as *Tetraedron* cf. *minimum*, *Botryococcus* and *Pediastrum*, and reflects the temporary or permanent presence of open water bodies. The woodland shows shrubby patches with *E. arborea* and *Cistus*, indicating the persistence of degraded vegetation. Until 5300 cal yr BP, the number of charcoal particles remains high (500–1200 $p \cdot g^{-1}$),

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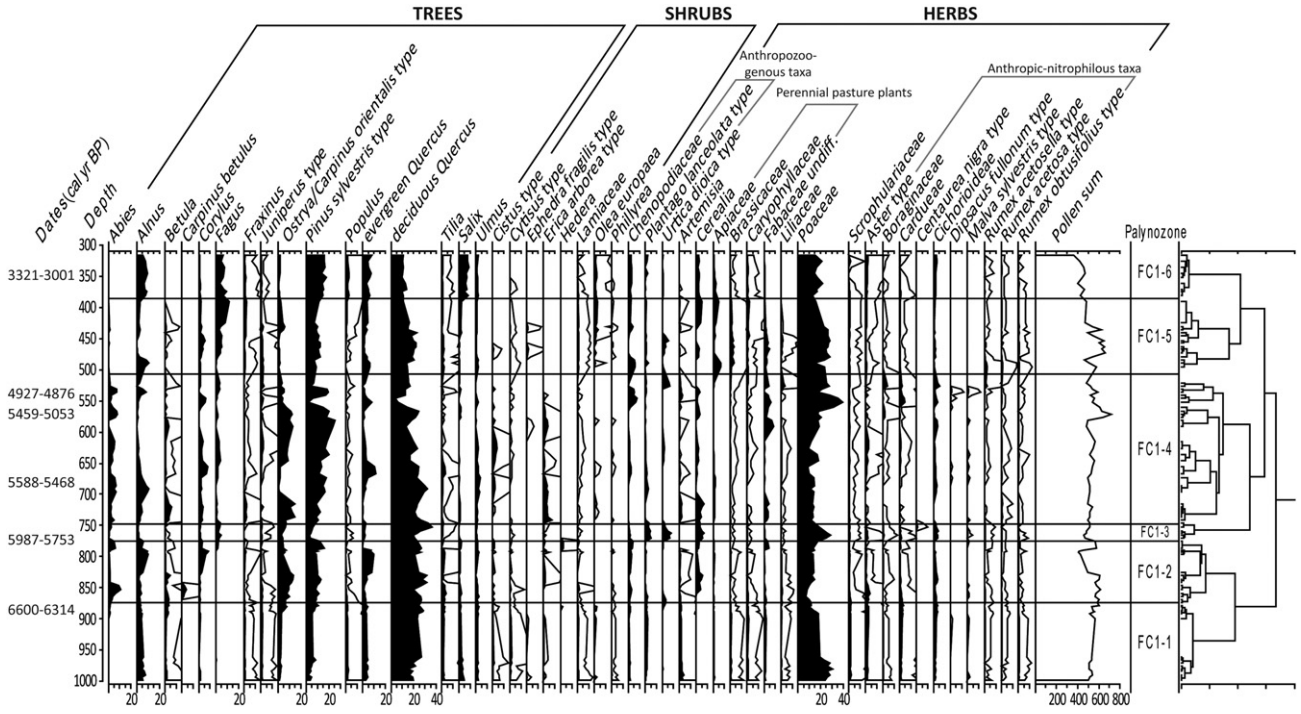


Figure 8. Percentage pollen diagram for selected trees, shrubs and herbs from core FC1 (exaggeration curves are ×10).

indicating a lasting change in the fire regime. The high number of particles even after the development of a shallow lake environment confirms that the charcoal influx in the sedimentation was mainly of local origin. After 5300 cal yr BP, the decrease in the number of charcoal particles is significant.

This palynozone was also punctuated by two similar events at around 5450 and 5000–4900 cal yr BP. These are characterized by a reduction in tree pollen with the exception of mesothermophilous and heliophilous taxa (*Corylus*, *Fagus*, evergreen *Quercus*), and a decrease in *Cyperaceae* and other hydro-hygrophytic taxa and NPPs indicative of humid environments. These changes in pollen indicate drought events. Further, for the "5450 event", this is supported by the presence of xerophilous NPPs and a charcoal peak (1439 $p \cdot g^{-1}$) that reflect dry vegetation susceptible to fire. The second event (5000–4900 cal yr BP) corresponds to a peak in NPPs indicative of erosive processes: *Glomus* cf. *fasciculatum* and *Pseudoschizaea circula* (van Geel et al., 2003). This dry period also coincides with a slight increase in *Cerealia* and anthropozoogenous taxa percentages. The consequences of these rapid climate changes may have favoured anthropogenic activities and/or their visibility in the pollen assemblage.

5) FC1-5 (510–385 cm; ~4450–3200 cal yr BP)
The fifth palynozone (FC1-5) shows a decrease in humid conditions with the disappearance of some NPPs, including *Tetraedron* cf.

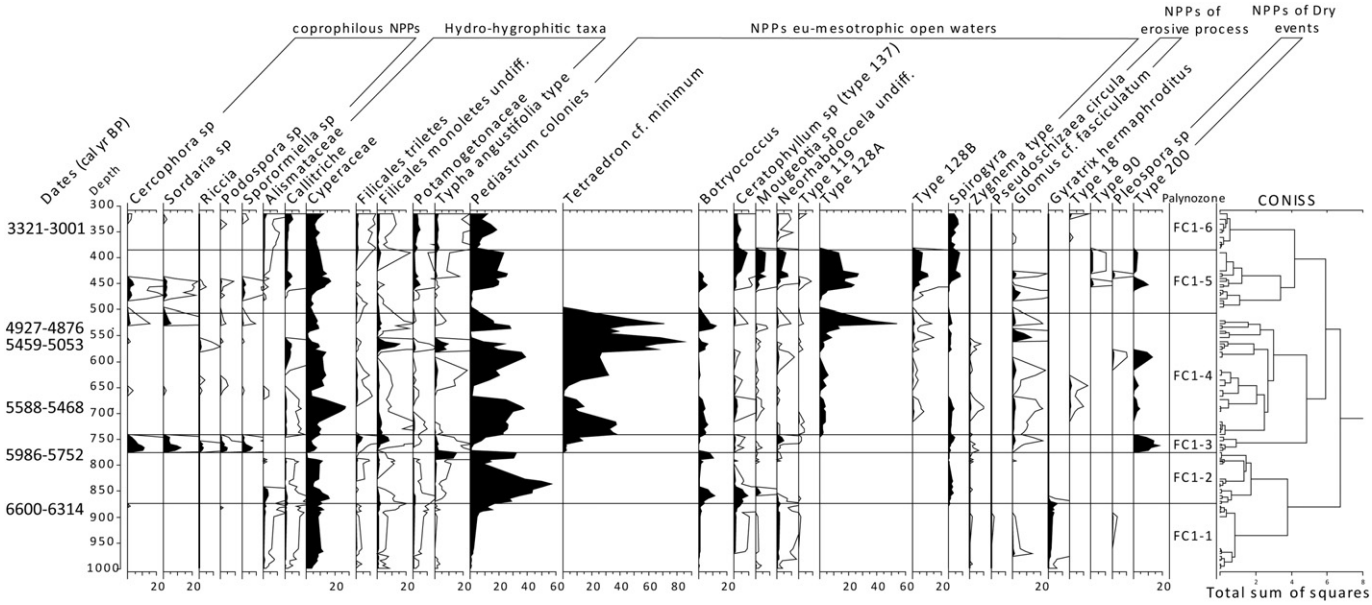


Figure 9. Percentage pollen diagram for hydro-hygrophitic taxa and NPPs from core FC1 (exaggeration curves are ×10).

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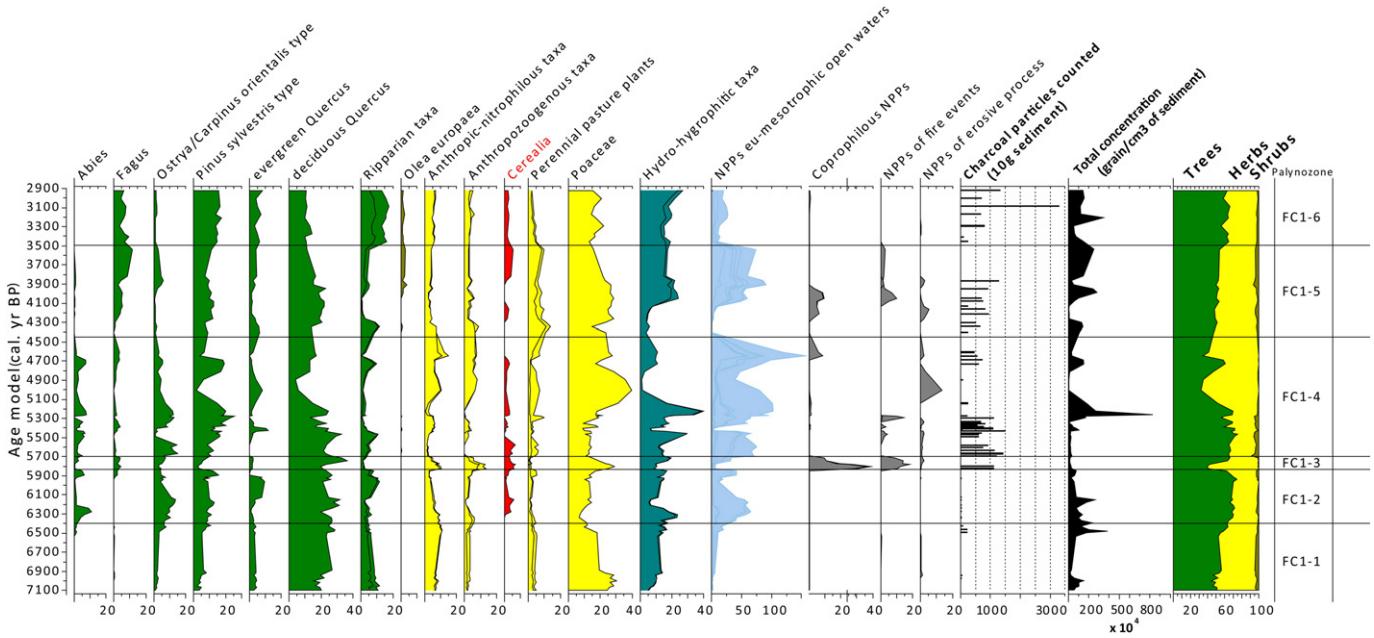


Figure 10. Pollen and NPP synthetic diagram for core FC1. Pollen and NPP groups: 1) Riparian taxa (*Alnus* and *Salix*); 2) Anthropic–nitrophilous taxa (*Aster* type, Boraginaceae, Cardueae, *Centaurea nigra* type, Cichorioideae, *Dipsacus fullonum* type, *Malva sylvestris* type, *Rumex acetosella* type, *Rumex acetosa* type, *Rumex obtusifolius* type); 3) Anthropozoogenous taxa (Chenopodiaceae, *Plantago lanceolata* type, *Urtica dioica* type,); 4) perennial pasture plants (Apiaceae, Brassicaceae, Caryophyllaceae, Fabaceae undiff.); coprophilous NPPs (*Cercophora* sp. type 112, *Podospora* sp. type 368, *Sordaria* sp. type 55A, *Sporormiella* sp. type 113, *Riccia* type); NPPs of eu-mesotrophic open water (*Pediastrum* colonies, *Ceratophyllum* sp. type 137, *Botryococcus*, *Gloeotrichia* type 146, *Spirogyra*, Neorhabdocoela undiff., type 119, type 128A, *Tetraedron* cf. *minimum*, *Zygnema* type); NPPs indicative of erosive processes (*Glomus* sp. type 207 and *Pseudoschizaea circula*); NPPs indicative of fire events or dry conditions (*Pleospora* sp. type 3B, type 200).

minimum and *Botryococcus*. Anthropogenic activities are shown by the presence of coprophilous NPPs and NPPs indicative of erosive processes, probably resulting from animal grazing. More generally, *Cerealia*, anthropozoogenous and anthropic–nitrophilous taxa indicate the development of agricultural activities. However, no significant impact on forest vegetation cover is recorded except ca. 3300 cal yr BP. The fire signature remains moderate during most of this period (500–1000 $p \cdot g^{-1}$).

6) FC1-6 (385–300 cm; ~3200–2750 cal yr BP)
The final palynozone (FC1-6) includes the persistence of Mediterranean species such as wild olive (*Olea europaea*), the gradual reduction in deciduous *Quercus* (<11%), *Ostrya/C. orientalis* (<2%), in Cyperaceae, and in most of the open water eu-mesotrophic NPPs and *Pediastrum*. This indicates a shift towards drier climatic conditions. At the same time, *P. sylvestris* recaptures the slopes whilst *Salix* and *Alnus* are present on the now drying former wetland areas. Cerealia pollen and anthropozoogenous and anthropic–nitrophilous taxa vary between 2 and 4%, reflecting a new increase in agricultural activities along the Lower Angitis. The increase in the number of charcoal particles, from 700 to 3306 $p \cdot g^{-1}$ (Fig. 9), is significant and could be related to the intensification of human activities and the overall dryness of the local environment.

Discussion

General trend of hydrological changes

The absolute level of the marshy and shallow lake environment was around 5 to 4 m below the current mean sea level (bsl) at ~6000 cal yr BP. The predicted sea level using the Lambeck and Purcell (2005) model is around 5 m bsl for this period. This modelled level is quite consistent with the estimated sea level obtained from fieldwork at the island of Lemnos in the northern Aegean for the period between 7000 and 5000 cal yr BP (Pavlopoulos et al., 2013). Thus, the rise in sea level probably explains the rise of the water table in the Lower Strymon valley and plays a key role in the long-lasting presence of the shallow lake and marshy environments from 6000 cal yr BP. This observation also confirms the relative tectonic stability since the middle Holocene. Then, a decrease in accumulation rate after 5200 cal yr BP evident along the Angitis river can be explained by the decrease in the rise of sea level predicted by the sea level curve of Lambeck and Purcell (2005), which is also observed after 5000 cal yr BP on the Alyki coastal plain at Lemnos (Pavlopoulos et al., 2013). Thus, due to their low elevation and the proximity of the sea shore, the rate of accumulation in the Lower Strymon and Angitis Valley was initially driven by sea level changes in the Aegean Sea during the middle and late Holocene.

After 6000–5600 cal yr BP, the rising of the water table and the expansion of the wetlands are supported by the sediment, pollen and NPP analyses. These show the development of a lasting shallow lake environment with some fluvial input. The rise of the water table and the maximum extension of the wetlands are explained by the large accommodation space available along the Lower Strymon Valley and the wetter conditions. They have also been recorded during the middle Holocene hydroclimatic optimum, in Central Greece, at Lake Xinias from 7000 to 5000 cal yr BP (Digerfeldt et al., 2007) and, in northern Greece, at Lake Ioannina (Lawson et al., 2004), Lake Prespa (Cvetkoska et al., 2014) and in the marine records (Triantaphyllou et al., 2009, 2014).

After 4450 cal yr BP, The pollen and NPPs data show a progressive affirmation of drier conditions after 4450 cal yr BP. This trend is widely observed in the eastern Mediterranean region and has been interpreted as the second of the major Holocene climatic oscillations recorded in the Mediterranean region, occurring ~4500–4000 cal yr BP (Magny et al., 2013). This is considered to be a non-linear response to the gradual insolation decrease (Magny et al., 2013) resulting primarily from variations in orbital parameters (Berger and Loutre, 1991, Fig. 11). Data obtained in the central Mediterranean area suggest a north–south climate partition during the Holocene (Peyron et al., 2013) whilst Triantaphyllou et al. (2014) suggest a time-transgressive gradient in

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the Aegean Sea during the middle Holocene transition. The hydrological trend of the study area follows the general pattern attributed to areas south of 40°N (Magny et al., 2013) despite its slightly northern latitude.

Impact of climatic events

The palaeoenvironmental data obtained in the Lower Angitis Valley show significant changes of centennial scale after 6000 cal yr BP. Palynological and geomorphic data indicate the high instability of the wetland environment which probably corresponds to the local response to the complex RCC identified at 6500–5000 cal yr BP (Mayewski et al., 2004; Wanner et al., 2011; Fig. 11).

Wetter conditions and hydrological response 6500–5800 cal BP

The first stage of environmental change identified corresponds the increase in fluvial sedimentation between 6000 and 5600 cal yr BP. During this period, the river was wider with alternating sandy gravel bars, bordered by a reed belt and the riparian forest. This fluvial pattern shows an increase in the sediment discharge associated to an increase in runoff in the Angitis River basin. This may be explained by increased soil erosion due to the widespread development of Late Neolithic settlement in the region. But, there is no evidence of abrupt and large opening of the landscape during this period on a regional scale (Greig and Turner, 1974; Kotthoff et al., 2008a,b; Pross et al., 2009) or more

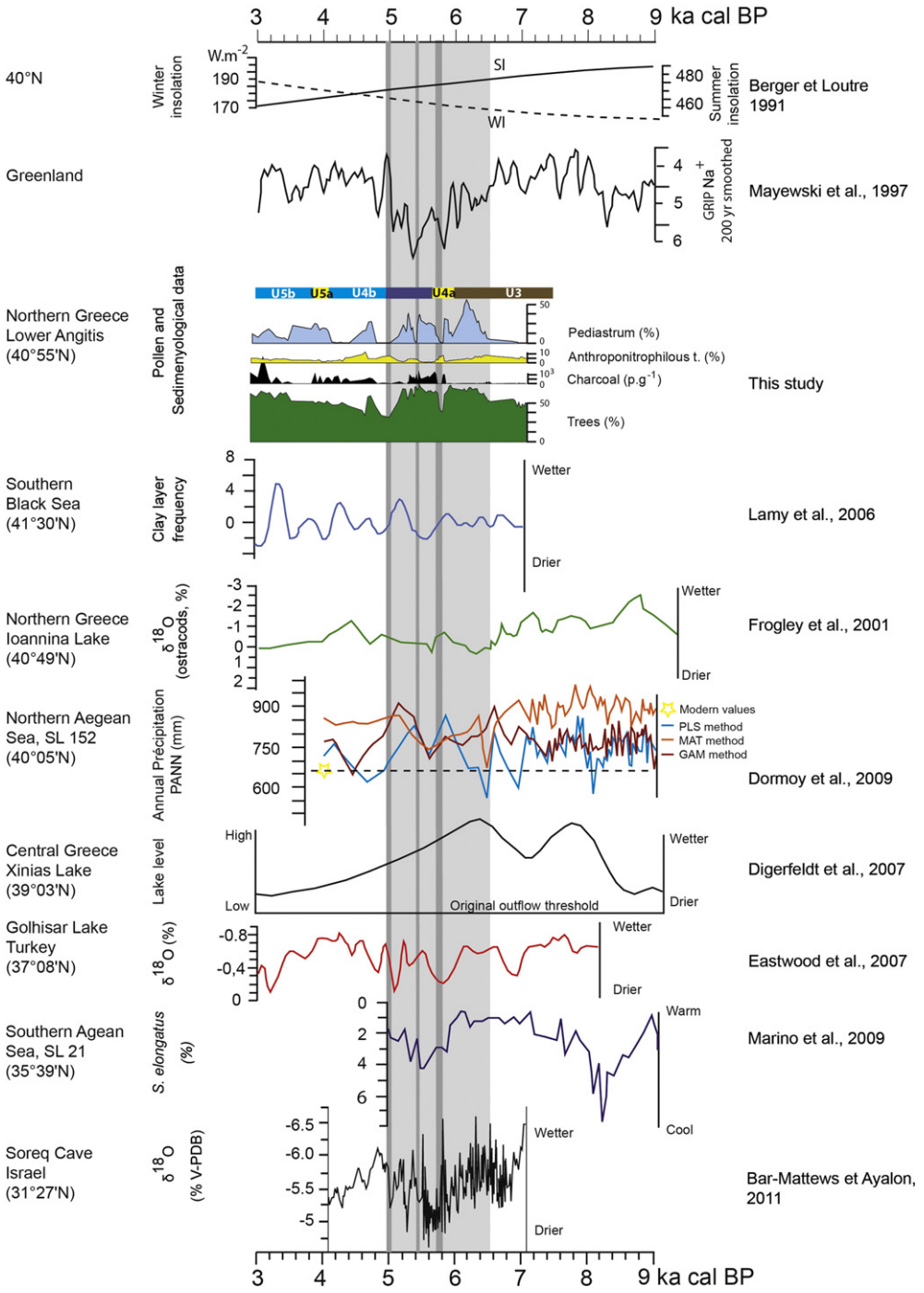


Figure 11. Comparison between environmental changes recorded by selected analyses in the Aegean and eastern Mediterranean regions. Studied period and phases of rapid climatic changes determined by Zanchetta et al., 2014 are highlighted.

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generally in northern Greece (Lawson et al., 2004). Furthermore, a soil erosion episode has not been documented in the Philippi–Drama basin before the 2nd millennium BC (Lespez, 2003, 2007). The observed fluvial input increase is thus more probably related to climate change, given that wetter conditions are more generally observed in the eastern Mediterranean region during this period (Finné et al., 2011; Triantaphyllou et al., 2014). On the southern coast of the Black Sea, such fluvial input corresponds to an increase in runoff caused by an increase in annual precipitation (Lamy et al., 2006; Fig. 11). In northern Greece (Lawson et al., 2004), the northern Aegean Sea (Dormoy et al., 2009; Kouli et al., 2012), and the eastern Mediterranean Sea (Bar-Matthews and Ayalon, 2011), this period corresponds to an increase in precipitation (Fig. 11). This increase in precipitation is associated with the onset of a cooler period well-recorded in the Peloponnesus (Heymann et al., 2013) and the southern Aegean Sea (Marino et al., 2009). Increased fluvial activity is also observed for large north African rivers and for several rivers in southern Italy and Mediterranean Spain (Faust et al., 2004; Benito et al., 2015) and suggests a widespread hydrological response to the climate change.

Climate instability and succession of three dry and cold events: 5800–4900 cal BP

This wet phase ends around 5800 cal yr BP. The pollen and NPP data then show a strong decline for all hydro-hygrophytic taxa and the disappearance of nearly all *Pediastrum* colonies. At the same time, the abrupt decline in arboreal pollen for riparian, mixed oak and altitudinal forests is not counterbalanced by the minor development of evergreen oak and beech tree. This reflects a first dry event around 5800 to 5700 cal yr BP. Kotthoff et al. (2008a,b) identify a short-term minimum in non-saccate arboreal pollen percentages accompanied by increased percentages of *Chenopodiaceae* in the northern Aegean Sea. These changes in pollen composition are interpreted as a drought climatic event that affected the vegetation across the entire northern Aegean region around 5600 cal yr BP. The development of dry conditions has also been observed more generally in eastern Mediterranean regions (Lawson et al., 2004; Lamy et al., 2006; Eastwood et al., 2007; Kotthoff et al., 2008a,b; Dormoy et al., 2009; Bar-Matthews and Ayalon, 2011; Zanchetta et al., 2014; Fig. 11). The timing of the onset of this drought event is not yet well established. The onset of this drought varies from 6100 to 5800 cal yr BP whilst the acme of dry conditions is observed from 5800 to 5600 cal yr BP according to the available data in northeastern Mediterranean areas (Fig. 11). This event corresponds to the start of cooler conditions in the southern Aegean Sea, interpreted as the incursion of cold mass air from northern latitudes to eastern Mediterranean regions (Rohling et al., 2002; Marino et al., 2009; Fig. 11). This winter pattern may have encouraged the development of drier winters in a context of more pronounced zonal flow (Zanchetta et al., 2014) related to positive NAO circulation (Magny et al., 2013). The observations made in the eastern Mediterranean area, show that this pattern was active from the southern Black Sea to the southeastern Mediterranean Sea, including the northern Aegean area studied.

Two other short events, at around 5450 and 5000–4900 cal yr BP, show the same drought conditions with a decrease of *Cyperaceae*, other hydro-hygrophytic taxa and a reduction of arboreal pollen with the exception of mesothermophilous and heliophilous taxa. These events have also been identified in marine cores from the Aegean Sea (Geraga et al., 2010). Zanchetta et al. (2014) state that two speleothem records available for the central (Corchia) and eastern Mediterranean areas (Soreq) reveal three periods of drought (Fig. 11), which can be compared to climate instability recorded in Central Europe (Magny et al., 2006). The first lasted from 5700 to 5500 cal yr BP and probably corresponds to that observed in the Lower Angitis Valley around 5800–5700 cal yr BP. The second is around 5200 cal yr BP and is also well-known in the eastern Mediterranean (e.g., Bar-Matthews and Ayalon, 2011; Kuzucuoğlu et al., 2011; Roberts et al., 2011). The third, less marked, is observed around 5000 cal yr BP in southeastern Aegean (Kouli et al., 2012). This suggests that northern Greece underwent the same pattern of climatic instability with three dry cold events than central and eastern Mediterranean areas (Zanchetta et al., 2014). The incursion of cold mass air from northern latitudes and a positive NAO circulation proposed for the first dry event can also be invoked for the others (Zanchetta et al., 2014). The data obtained in the Lower Angitis Valley points out the ability of the fluvial environment to record centennial-scale climatic events during the middle Holocene. Nevertheless, the timing and the nature of theses climatic events remain to be refined. The discrepancies between data could reflect both the uncertainties of the dating control of the palaeoclimatic data used and the relative sensitivity of each site to climate change (Peyron et al., 2013). In fact, the geographical pattern probably plays a significant role in northern Greece, given the complexity of the hydrological systems, the complex land–sea geography and the regular pulses of northern continental influences on the climate of this region.

Vegetation change and impact of agropastoral activities

The landscape was dominated by woodland cover during the initial phase (~7100–6500 cal yr BP). Mixed oak forest resulting from diversification of the forest cover is widely observed in northern Greece and the southern Balkans during thee Holocene and the start of the middle Holocene (Willis, 1994). This change in vegetation corresponds to wet mild conditions which favoured internal competitive and autogenic ecological changes (e.g., Willis, 1994; Lawson et al., 2005). The development of evergreen oak can be explained by the location of the study area near the Aegean Sea and the north–south orientation of the Strymon Valley facilitating the northward expansion of Mediterranean influences. The development of such forest cover does not mask a significant herbaceous pollen presence which indicates a more open landscape alternating with the riparian forest (alder, poplar, willow). This supports the view of Kotthoff et al. (2008a,b) who argue that the forest cover was not as dense during the middle Holocene in the northern borderlands of the Aegean Sea. Indicators of anthropogenic activity are rare although the first Neolithic settlements had been established in the broader region since 8500 cal yr BP (Lespez et al., 2013). The development of Late Neolithic settlement testifies to an increase in the intensity of farming and livestock activities occurred from 7400 to 5900 cal yr BP (Lespez, 2008). Human impact is only suggested by a continuous curve for anthropozoogenous and anthropic–nitrophilous taxa with the continuous development of *Plantago lanceolata* which could indicate pasture activities leading to a patchier forest cover. So, it appears that the large wetland studied was not suitable for crop cultivation during the first phases of Neolithic and/or the density of the forest cover was not favourable to record the impact of small-scale agricultural development.

The first environmental impact of human activities

An increase in anthropogenic taxa is observed after 6500 cal yr BP. The development of crop cultivation is demonstrated by the continuous curve for Cerealia pollen from 6300 to 5600 cal yr BP with two maximum peaks around 6300–6100 and 5 800–5600 cal yr BP. The first peak corresponds to the first occupation of Fidokoryphi (Grammenos and Fotiadis, 1980) and more generally to the occupation of numerous archaeological sites in eastern Macedonia. In the Angitis river basin, 27 stratified archaeological sites of the tell type have been inventoried indeed (Koukouli-Chrysanthaki et al., 2008), many of which seem to start around 6800 cal yr BP (Late Neolithic II). The Lower Strymon Valley includes several other archaeological sites (Grammenos and Fotiadis, 1980). The archaeological excavations conducted at Dimitra and Kryoneri address the development of a flourishing farming society during the second half of the 5th millennium BC (Grammenos, 1997; Malamidou, 2007), similar to neighbouring settlements in the Strymon Valley and the Philippi–Drama plain and the broader Balkan region

https://doi.org/10.1016/j.yqres.2016.02.002 Published online by Cambridge University Press

(Papadimitriou and Tsirtsoni, 2010). The cultivation of cereals (wheat and barley) as well as legumes (lentil and grass pea) is documented at many of them (Treuil et al., 2008). These changes are related to the establishment of cultivated fields and the development of grazing in parallel with an increase in collecting fruits, fodder and firewood as demonstrated at Dikili Tash (Valamoti, 2015). Thus the human impact on the vegetation cover is explained by an increase in settlement in the study area and at a regional scale.

None of archaeological sites of the lower Strymon valley and Angitis river basin sites seems to be occupied after ca. 6000 cal yr BP (Tsirtsoni, in press). However, in the Lower Angitis valley, the persistence of Cerealia pollen after 6000 cal BP and a second peak for anthropogenic indicators recorded around 5800–5700 cal yr BP are therefore particularly noteworthy. This is probably highlighted by tree thinning in the riparian, mixed oak and mountainous forest cover due to the drought conditions and demonstrates that farming activities continued to be practiced on the edge of the wetlands and the foothills despite the lack of archaeological evidence.

A second phase of increased anthropogenic indicators is observed from 5100 to 4700 cal yr BP, corresponding to a continuous curve for Cerealia and an increase in all anthropozoogenous and anthropic–nithrophilous taxa which reach percentages never attained during the previous period. As a consequence, the forest cover decreases (<40% of tree pollen) with the exception of evergreen oak and hazel. These latter are light-demanding trees and evergreen oak is thermophilous. Their relative increase can be explained by the clearance of the mixed oak forest and the development of dry conditions from 5000 cal yr BP. This period corresponds to the renewal of human settlement in the region. The major sites of the Late and Final Neolithic period, such as Dikili Tash and Sitagroi, are once again inhabited from 5300 to 5000 cal yr BP and the site of Kryoneri somewhat later (Maniatis et al, 2014; Tsirtsoni, in press). Agropastoral activities are also evidenced by numerous archaeological studies and the anthropogenic landscape changes correspond to lasting land use changes during the Bronze Age (Lespez, 2008). In addition, we observe the development of olive trees, possibly cultivated, from 4000 cal yr BP.

Regional comparison

The comparison with the regional data shows that landscape changes driven by human activities are also recorded during the Neolithic and the Bronze Age in northern Greece. On the edge of the Philippi marsh, close to the site of Dikili Tash, the effect of agropastoral activities is evident from around 8500 cal yr BP (Glais et al., 2016) and on the shore of Lake Kastoria, at the base of the Neolithic site of Dispilio, from 7500 cal BP (Kouli, 2015). But apart from this pollen site adjacent to a well-established archaeological context, the first evidence of landscape changes due to human activities is found later. It is recorded by pollen studies around 5000 cal yr BP at Nisi fen (Lawson et al., 2005), 4500 cal yr BP at Ioannina (Bottema, 1974; Lawson et al., 2004) and Giannitsa (Bottema, 1974), and around 3500–3000 cal yr BP in Doirani (Athanasiadis et al., 2000), Gramousti and Rezina (Willis, 1994) and Edessa (Bottema, 1974). In southern Albania, the impact of human activities has been also detected around 4500 cal yr BP (Denèfle et al., 2000). In all cases, this occurs well after the arrival of agriculture in these areas. For most of the pollen sites, their location in mountainous areas often far away from the lowlands with their dense Neolithic settlement is suggested as an explanation. In contrast, the timing of the impact of agropastoral practices on vegetation cover is more similar to that observed at several sites in central Greece and south-western Bulgaria. Human impact on vegetation cover has been recorded at Lake Voulkaria, around 5500 cal yr BP (Jahns, 2005) and at Lake Kopais from 6200 to 5500 cal yr BP (Greig and Turner, 1974) even if such changes are observed only ca. 4000 cal yr BP at Lake Xinias (Bottema, 1979; Digerfeldt et al., 2007). Similarly, the many studies conducted in south-western Bulgaria show initial sporadic evidence for cereal crops and grazing activities from 7500 to 7000 cal yr BP associated with the increase in the number of settlements during the Late Neolithic (Marinova et al., 2012). The timing of initial clearing and human impact is recorded in the same-time interval in southern Greece (7600–6000 cal yr BP, Atherden et al., 1993) and in Crete (after 6500 cal BP, Bottema and Sarpaki, 2003). The effects of agropastoral activities were probably widespread in the southeastern Balkan regions during the Late Neolithic.

The results obtained in the Lower Angitis Valley suggest that either: the heart of the large wetlands and the mountain lakes and peat bogs were too far from the cultivated and grazing areas prior to the Bronze Age; or the pollen recruitment area was probably too large and diluted the indicators of anthropogenic transformation of the vegetation cover, as is the case for the Philippi marsh (Greig and Turner, 1974). Until now, most of the pollen sites used in northern Greece are probably more favourable for detecting the effects of climate change on the environment than to track human impact, because they are not located near archaeological sites or areas disturbed by human activities.

Environmental changes and local human adaptations

The environmental research shows significant changes in the deposits from 6400 to 5800 cal yr BP. The marshy environments are replaced by fluvio-lacustrine environments. The alluvial and shallow lake deposits cover the lower part of the once inhabited foothills, as shown by the fossilisation of an occupation level attributed to the end of the Middle Neolithic/start of the Late Neolithic (FC2; Fig. 6). From then on, the expansion and nature of the wetlands does not fundamentally change until the onset of Antiquity. It is thus probable that the hill of Fidokoryphi, surrounded by an expanding marshy lake, was abandoned, at the latest, after 5600 cal yr BP. Besides, the archaeological research at Dimitra and Kryoneri, respectively located along the Angitis and the Strymon Rivers, 7 to 8 km from Fidokoryphi, shows that they were abandoned since the beginning of the 4th millennium BC (Grammenos, 1997; Malamidou, 2007, in press)

The pollen data evidence two periods of human modification of the landscape due to agropastoral activities (6300–5600 and 5100–4700 cal yr BP) corresponding respectively to the end of the Late–Final Neolithic and the Early Bronze Age periods. During the Neolithic, despite the succession of a wetter period (6400–5800 cal yr BP) and a dry event (5800–5700 cal yr BP) documented locally and in the eastern Mediterranean region in general, the effects on the landscape by human activities have been detected continuously. During the Early Bronze Age, the pollen data show that the edge of the marsh was cultivated and used for grazing whilst re-occupation of the archaeological sites within a radius of 10 km took place (Grammenos, 1997; Malamidou, 2007, in press).

The intermediary period (5600–5300 cal yr BP) is marked by a decrease in indicators of cultivation and grazing activities. Nevertheless, the continuous occurrence of cereal pollen, anthropozoogenous and anthropic–nitrophilous taxa, the development of *Cistus*, *Ericaeae*, and *Fabaceae*, and the constancy of the fire signature suggest the persistence of agropastoral activities not far from core FC1. Fire may have been used for temporary clearance for pasture purposes and probably encouraged the development of Mediterranean shrubs on the edge of the wetlands and the foothills. Nevertheless, abandonment of the sites occupied during the Late Neolithic is assessed by the excavations and settlement displacement is indisputable. The populations moved to cope with environmental change, but although they moved away from areas most affected by the rising water table, they probably settled in the foothills. In contrast to what has been observed in southwestern Bulgaria, where there is almost no indication of human impact on the vegetation from 5800 to 5200 cal yr BP (Marinova et al., 2012), the permanence, even slightly diminished, of anthropogenic indicators confirms continuity of settlement in the Lower Angitis and Strymon Valley. The abrupt succession of wet (6400–5800 cal yr BP) and dry periods

https://doi.org/10.1016/j.yqres.2016.02.002 Published online by Cambridge University Press

(5800–5700 cal yr BP) could have affected the population of eastern Macedonia, but it is unlikely that the dry and cool conditions of the short-time climate events would have led to the abandonment of settlements located around the large wetlands in the lowlands of the region. Willcox (2005) states that climate change in the Near East at the start of the Neolithic transition, in physically very contrasting environments, is often sufficient to move over very little distances to find different environmental conditions.

The lack of archaeological sites dated to this intermediate period and the weakness of archaeological evidence of such continuity raise the question of changes in settlement patterns. New archaeological and palaeoenvironmental data highlight the complexity of settlement pattern during this transitional period. As previously noted, there are no sites in northern Greece and more largely in the southeastern Balkans for which the sequence shows uninterrupted occupation from the Late–Final Neolithic to the Early Bronze Age (Tsirtsoni, 2014, in press). In eastern Macedonia, all types of settlements were abandoned in coastal (e.g., Thasos Island), lowland (e.g., Kryonery and Dikili Tash) and mountainous areas (e.g., Sidirokastro Cave), although not at the same time (Maniatis et al., 2014). This indicates that there is no geographical patterning that could suggest withdrawal to more favourable areas or spatial progression of a cultural process (Tsirtsoni, 2014, in press). Nevertheless, as suggested for Bulgaria (Leshtakov, 2006), it is possible that subsistence change supported the development of fairly mobile groups practising pastoral activities. This could also explain the increase in fire events and the development of shrublands.

To conclude, the data for the Lower Angitis Valley show that climatic instability would have necessarily affected human practices and agropastoral activities, but also indicate that change in the geographical context and in climate was not sufficient to prevent the sustainability of the human activities. The persistence of farming and herding activities during the transitional phase indicates the adaptability of the population to cope with environmental changes and points towards the role of social factors rather than environmental factors alone in triggering cultural changes. One must therefore look elsewhere for the causes of cultural transformations that affected societies at the end of the Neolithic in the Balkans. As suggested by Tsirtsoni (2014), based on the archaeological data, what appeared to be an effect of depopulation is probably the expression of a change in settlement patterns, and likely of subsistence patterns, for which the cultural, and possibly economic, factors remain to be understood.

Conclusions

Research undertaken in the Lower Angitis Valley shows that the environmental changes that occurred in the southern Balkans during the Neolithic–Bronze Age transition were complex. Paleoecological data show a succession of dry events at 5800–5700, 5450 and 5000–4900 cal yr BP confirming the climatic instability of the middle Holocene climate transition. Two periods with farming and pastural activities (6300–5600 and 5100–4700 cal BP) are evident corresponding to an increase in settlement at the regional scale. The intervening period is marked by environmental changes, but the continuous occurrence of anthropogenic taxa suggests the persistence of human activities despite the absence of archaeological evidence. The results obtained suggest that environmental factors alone were not sufficient to trigger the observed societal changes and that one should be wary of the determinist hypotheses proposed to explain the organisation and redistribution of populations affected by climate change. This raises a fundamental methodological problem and should cause us to examine with caution the results of research based on existing data sets to resolve questions about the relationship between nature and societies at supra-regional scales. Today, there is a need to go beyond the observation of co-occurrence and the hypothetical causal link between climate change and social change. For the southeastern Balkans, it is only when we have many case studies available that we may hope to identify strategies for adaptation to environmental changes and the specific dynamics of human groups in social evolution on a regional scale. The complexity of interactions reveals and limits the scope of deterministic arguments that are too simplistic. The objective is to reverse the perspective, to developing new approaches capable to describe on one hand ancient agrosystems and their resilience, and on the other hand, environmental transformations very close to human settlements as proposed in this paper, before estimating the consequences for populations on a regional or supra-regional scale.

Acknowledgments

The research presented in this paper has been conducted in the framework of two research programmes. The “Balkans 4000” project (ANR-07-JCJC-072) was coordinated by Zoï Tsirtsoni. The Archeomed-Paleomex Programme is part of the INSU-INEE MISTRALS Research project and is directed by L. Carozza and L. Lespez. Funding for the present study was also obtained from the RELICTFLORA (P11RNM-7033) project, provided by the Junta de Andalucía (Spain). Radiocarbon ages were obtained from the laboratories of Lyon (AMS measurements at Saclay), Dimokritos, Erlangen and Beta Analytic. Density and magnetic susceptibility measurements on the cores were done at the laboratory *Chrono-Environnement*-UMR CNRS 6249 in Besançon. Special thanks to Tatiana Theodoropoulou for their identification of macroscopic shells and Rebecca Miller for revising the original manuscript.

References

Ancel, J., 1930. La Macédoine, étude de colonisation contemporaine. Librairie Delagrave, Paris.
Andreou, S., Fotiadis, M., Kotsakis, K., 1996. Review of Aegean prehistory V: the Neolithic and Bronze Age of northern Greece. American Journal of Archaeology 100, 537–597.
Anthony D.W., Chi, J.Y. (Eds.) 2009. The lost world of old Europe. The Danube Valley, 5000–3500 BC. ISAW, New York University-Princeton University Press, New York and Princeton.
Athanasiadis, N., Tonkov, S., Atanassova, J., Bozilova, E., 2000. Palynological study of Holocene sediments from Lake Doirani in northern Greece. Journal of Paleolimnology 24, 331–342.
Atherden, M.A., 2000. Human impact on the vegetation of southern Greece and problems of palynological interpretation: a case study from Crete. In: Halstead, P., Frederik, C. (Eds.), Landscape and Land Use in Postglacial Greece, Sheffield Studies in Aegean Archaeology, Sheffield, pp. 62–78.
Atherden, M., Hall, J., Wright, J.C., 1993. A pollen diagram from the northeast Peloponnese, Greece: implications for vegetation history and archaeology. The Holocene 3, 351–356.
Bakker, R., van Smeerdijk, D.G., 1982a. A palaeocological study of a Late Holocene section from “Het Ilperweld” W. Netherlands. Review of Palaeobotany and Palynology 36, 95–163.
Bakker, M., Van Smeerdijk, D.G., 1982b. A palaeoecological study of a late Holocene section from “Het Ilperveld”, Western Netherlands. Review of Palaeobotany and Palynology 36, 95–163.
Bakker, R., van Smeerdijk, D.G., 1982c. A palaeocological study of a Late Holocene section from “Het Ilperweld” W. Netherlands. Review of Palaeobotany and Palynology 36, 95–163.
Bar-Matthews, M., Ayalon, A., 2011. Mid-Holocene climate variations revealed by high-resolution speleothem records from Soreq Cave, Israel and their correlation with cultural changes. The Holocene 21, 163–171.
Bellier, R.-C. Bondoux, Cheynet, J.-C., Geyer, B., Grélois, J.-P., Kravari, V., 1986. Paysages de Macédoine. Travaux et mémoires du Centre de Recherche d'Histoire et de Civilisation de Byzance du Collège de France Monographies 3. De Boccard, Paris.
Benito, G., Macklin, M.G., Zielhofer, C., Jones, A.F., Machado, M.J., 2015. Holocene flooding and climate change in the Mediterranean. CATENA 130, 13–33.
Berger, J.-F., Guilaine, J., 2009. The 8200 cal BP abrupt environmental change and the Neolithic transition: a Mediterranean perspective. Quaternary International 200, 31–49.
Berger, A., Loutre, M.-F., 1991. Insolation values for the climate of the last 10 million years. Quaternary Science Reviews 10, 297–317.
Berglund, B., 2003. Human impact and climate changes — synchronous events and a causal link? Quaternary International 105, 7–12.
Bond, G., Kromer, B., Beer, J., Muscheler, R., Evans, M.N., Showers, W., Bonani, G., 2001. Persistent solar influence on North Atlantic climate during the Holocene. Science 294, 2130–2136.
Bottema, S., 1974. Late Quaternary Vegetation History of Northwestern Greece. Groningen (Thesis).
Bottema, S., 1979. Pollen analytical investigations in Thessaly (Greece). Palaeohistoria 21, 19–40.
Bottema, S., Sarpaki, A., 2003. Environmental change in Crete: a 9000-year record of Holocene vegetation history and the effect of the Santorini eruption. The Holocene 13, 733–749.

Boyadžiev, Y., 1995. Chronology of prehistoric cultures in Bulgaria. In: Bailey, D.W., Panayotov, I. (Eds.), Prehistoric Bulgaria, Monographs in World Archaeology 22. Prehistory Press, Madison, pp. 149–191.
Boyadžiev, J., 1998. Radiocarbon dating from southeastern Europe and the cultural processes during the fourth millennium B.C. In: Stefanovich, M., Todorova, H., Hauptmann, H. (Eds.), In the Steps of James Harvey Gaul 1, Sofia, pp. 349–370.
Bozilova, E., Tonkov, S., 2000. Pollen from Lake Sedmo Rilsko reveals southeast European postglacial vegetation in the highest mountain area of the Balkans. New Phytologist 148, 315–325.
Bravard, J.P., Peiry, J.L., 1999. The CM pattern as a tool for the classification of alluvial suites and floodplains along the river continuum. Geological Society, London. Special Publications 163, 259–268.
Bronk Ramsey, C., 2013. OxCal 4.2. Web Interface Build, (78).
Broussoulis, J., Yiakkoupis, P., Arapoyannis, E., Anastasiadis, J., 1991. Drama lignite deposit geology, exploration, resources. IGME Report 1, Athens (in Greek with English Abstr.).
Brown, A.G., 1999. Biodiversity and pollen analysis: modern pollen studies and the recent history of a floodplain woodland in SW Ireland. Journal of Biogeography 26 (1), 19–32.
Brown, A.G., 2008. Geoarchaeology, the four dimensional (4D) fluvial matrix and climatic causality. Geomorphology 101, 278–297.
Büntgen, U., Tegel, W., Nicolussi, K., McCormick, M., Frank, D., Trouet, V., Kaplan, J.O., Herzig, F., Heussner, K.-U., Wanner, H., Luterbacher, J., Esper, J., 2011. 2500 years of European climate variability and human susceptibility. Science 331, 578–582.
Butzer, K.W., 2012. Collapse, environment, and society. Proceedings of the National Academy of Sciences 109, 3632–3639.
Carcaillet, C., Bouvier, M., Larouche, A.C., Richard, P.J.H., 2001. Comparison of pollen-slide and sieving methods in lacustrine charcoal analyses for local and regional fire history. The Holocene 11, 476–547.
Carrión, J.S., Navarro, C., 2002. Cryptogam spores and other non-pollen microfossils as sources of palaeoecological information: case-studies from Spain. Annales Botanic Fennici 39, 1–14.
Clark, J.S., 1988. Particle motion and the theory of stratigraphic charcoal analysis: source area, transport, deposition, and sampling. Quaternary Research 30, 67–80.
Cvetkoska, A., Levkov, Z., Reed, J.M., Wagner, B., 2014. Late Glacial to Holocene climate change and human impact in the Mediterranean: the last ca. 17 ka diatom record of Lake Prespa (Macedonia/Albania/Greece). Palaeogeography, Palaeoclimatology, Palaeoecology 406, 22–32.
Darcque, P., Tsirtsoni, Z., 2010. Evidence from Dikili Tash (Eastern Macedonia, Greece) and the tell issue. In: Hansen, S. (Ed.), Leben auf dem Tell als soziale Praxis, Beiträge des Internationalen Symposiums, Rudolf Habelt., Bonn, pp. 55–69.
Dearing, J., 1999. Magnetic susceptibility. Environmental Magnetism: A Practical Guide 6, Quaternary Research Association, London, pp. 35–62.
Demakopoulou, K., 1996. The transition to the Bronze Age: the Neolithic heritage. In: Papathanasopoulos, G.A. (Ed.), Neolithic Culture in Greece. N.P. Goulandris Foundation, Museum of Cycladic Art, Athens, pp. 191–197.
DeMenocal, P., 2001. Cultural responses to climate change during the Late Holocene. Science 292, 667–673.
Denèfle, M., Lézine, A.M., Fouache, E., Dufaure, J.J., 2000. A 12,000-year pollen record from Lake Maliq, Albania. Quaternary Research 54, 423–432.
Digerfeldt, G., Sandgren, P., Olsson, S., 2007. Reconstruction of Holocene lake-level changes in Lake Xinias, central Greece. The Holocene 17, 361–367.
Dinter, D., Royden, L., 1993. Late Cenozoic extension in North-eastern Greece: Strymon Valley detachment system and Rhodope metamorphic core complex. Geology 21, 45–48.
Dormoy, I., Peyron, O., Combourieu-Nebout, N., Goring, S., Kotthoff, U., Magny, M., Pross, J., 2009. Terrestrial climate variability and seasonality changes in the Mediterranean region between 15,000 and 4,000 years BP deduced from marine pollen records. Climate of the Past 5, 615–632.
Drake, B.L., 2012. The influence of climatic change on the Late Bronze Age collapse and the Greek Dark Ages. Journal of Archaeological Science 39, 1862–1870.
Eastwood, W.J., Leng, M.J., Roberts, N., Davis, B., 2007. Holocene climate change in the eastern Mediterranean region: a comparison of stable isotope and pollen data from Lake Gölhisar, southwest Turkey. Journal of Quaternary Science 22, 327–341.
Faegri, K., Iversen, J., 1989. Textbook of Pollen Analysis. Wiley, Chichester.
Faust, D., Zielhofer, C., Escudero, R.B., del Olmo, F.D., 2004. High-resolution fluvial record of late Holocene geomorphic change in northern Tunisia: climatic or human impact? Quaternary Science Reviews 23, 1757–1775.
Finné, M., Holmgren, K., Sundqvist, H.S., Weiberg, E., Lindblom, M., 2011. Climate in the eastern Mediterranean, and adjacent regions, during the past 6000 years—a review. Journal of Archaeological Science 38, 3153–3173.
Geraga, M., Ioakim, C., Lykousis, V., Tsaila-Monopolis, S., Mylona, G., 2010. The highresolution palaeoclimatic and palaeoceanographic history of the last 24,000 years in the central Aegean Sea, Greece. Palaeogeography, Palaeoclimatology, Palaeoecology 287, 101–115.
Gerasimidis, A., 2000. Palynological evidence for human influence on the vegetation of Mountain Regions in Northern Greece: the case of Lailias, Serres. In: Halstead, P. (Ed.), 2000, Landscape and Land Use in Postglacial Greece. Sheffield Studies in Aegean Archaeology, Sheffield, pp. 28–37.
Glais, A., Lopez-Saez, J.-A., Lespez, L., Davidson, R., 2016. Climate and human–environment relationships on the edge of the Tenaghi–Philippon marsh (Northern Greece) during the Neolithization process. Quaternary International http://dx.doi.org/10.1016/j.quaint.2015.07.032.
Görsdorf, J., Bojadžiev, J., 1996. Zur absoluten Chronologie der bulgarischen Urgeschichte. Berliner 14C-Datierungen von bulgarischen archäologischen Fundplätzen. Eurasia Antiqua 2, 105–173.
Grammenos, D., 1997. Neolithic Macedonia, Athens (in Greek with English Abstr.).
Grammenos, D., Fotiadis, M., 1980. Sur les habitats préhistoriques de la Macédoine orientale. Anthrôpologika 1, 15–53 (in Greek with English Abstr.).
Greig, J.R.A., Turner, J., 1974. Some pollen diagrams from Greece and their archaeological significance. Journal of Archaeological Science 1, 177–194.
Grimm, E.C., 1992. Tilia Version 2. Illinois State Museum. Research and Collection Center, Springfield.
Heymann, C., Nelle, O., Dörfler, W., Zagana, H., Nowaczyk, N., Xue, J., Unkel, I., 2013. Late Glacial to mid-Holocene palaeoclimate development of Southern Greece inferred from the sediment sequence of Lake Stymphalia (NE-Peloponnese). Quaternary International 302, 42–60.
Horvat, I., Glavac, V., Ellenberg, H., 1974. Vegetation Südosteuropas. Geobotanica Selecta IV. Fischer, Stuttgart.
Jahns, S., 2005. The Holocene history of vegetation and settlement at the coastal site of Lake Voulkaria in Acarnania, Western Greece. Vegetetation History Archaeobotany 14, 55–66.
Kaniewski, D., Van Campo, E., Guiot, J., Le Burel, S., Otto, T., Baeteman, C., 2013. Environmental roots of the Late Bronze Age crisis. PLoS ONE 8, e71004.
Komarek, J., Jankovska, V., 2001. Review of the green algal genus Pediastrum; implication for pollen — analytical research. Bibliotheca Phycologica 108, 1–127.
Kotthoff, U., Koutsodendris, A., Pross, J., Schmiedl, G., Bornemann, A., Kaul, C., Marino, G., Peyron, O., Schiebel, R., 2011. Impact of Lateglacial cold events on the northern Aegean region reconstructed from marine and terrestrial proxy data. Journal of Quaternary Science 26 (1), 86–96.
Kotthoff, U., Müller, U.C., Pross, J., Schmiedl, G., Lawson, I.T., van de Schootbrugge, B., Schulz, H., 2008a. Lateglacial and Holocene vegetation dynamics in the Aegean region: an integrated view based on pollen data from marine and terrestrial archives. The Holocene 18, 1019–1032.
Kotthoff, U., Pross, J., Müller, U.C., Peyron, O., Schmiedl, G., Schulz, H., Bordon, A., 2008b. Climate dynamics in the borderlands of the Aegean Sea during formation of Sapropel S1 deduced from a marine pollen record. Quaternary Science Reviews 27, 832–845.
Koukouli-Chrysanthaki, H., Malamidou, M., Lespez, L., 2008. Carte archéologique de la plaine de Philippes–Drama. In: Koukouli-Chryssanthaki, H., Treuil, R. (Eds.), Dikili Tash, village prehistorique de Macédoine orientale. Bibliothèque de la Société archéologique d'Athènes 254, pp. 395–414 (Athènes).
Kouli, K., 2015. Plant landscape and land use at the Neolithic lake settlement of Dispilió (Macedonia, northern Greece). Plant Biosystems http://dx.doi.org/10.1080/11263504.2014.992998.
Kouli, K., Gogou, A., Bouloubassi, I., Triantaphyllou, M.V., Ioakim, C., Katsouras, G., Roussakis, G., Lykousis, V., 2012. Late postglacial paleoenvironmental change in the northeastern Mediterranean region: combined palynological and molecular biomarker evidence. Quaternary International 261, 118–127.
Kuzucuoğlu, C., 2010. Climate and environment in times of cultural changes from the 4th to the 1st mill. BC in the Near and Middle East. In: Cardarelli, A., Cazzella, A., Frangipane, M., Peroni, R. (Eds.), Reasons for Changes of Societies Between the End of the IV and the Beginning of the 1st Millennium BC (Le Ragioni del Cambiamento). Scienze delle Antichità 15, pp. 141–163 (Roma).
Kuzucuoğlu, C., 2014. The Neolithic in Anatolia at the regional scale. Some issues concerning chronology and environmental contexts. In: Arnaud-Fasetta, G., Carcaud, N. (Eds.), French Geoarchaeology in the 21st Century, CNRS Editions, Paris, pp. 129–156.
Kuzucuoğlu, C., Dörfler, W., Kunesch, S., Goupille, F., 2011. Mid-to late-Holocene climate change in central Turkey: the Tecer Lake record. The Holocene 21, 173–188.
Lambeck, K., Purcell, A., 2005. Sea-level change in the Mediterranean Sea since the LGM: model predictions for tectonically stable areas. Quaternary Science Reviews 24, 1969–1988.
Lamy, F., Arz, H.W., Bond, G.C., Bahr, A., Pätzold, J., 2006. Multicentennial-scale hydrological changes in the Black Sea and northern Red Sea during the Holocene and the Arctic/North Atlantic Oscillation. Paleoceanography 21, PA1008. http://dx.doi.org/10.1029/2005PA001184.
Lawson, I., Frogley, M., Bryant, C., Preece, R., Tzedakis, P., 2004. The Lateglacial and Holocene environmental history of the Ioannina basin, north-west Greece. Quaternary Science Reviews 23, 1599–1625.
Lawson, I.T., Al-Omari, S., Tzedakis, P.C., Bryant, C.L., Christaniss, K., 2005. Lateglacial and Holocene vegetation history at Nisi Fen and the Boras mountains, northern Greece. The Holocene 15, 873–887.
Lemmen, C., Wirtz, K.W., 2014. On the sensitivity of the simulated European Neolithic transition to climate extremes. Journal of Archaeological Science 51, 65–72.
Leshtakov, K., 2006. The Bronze Age in the Upper Thracian plain. Annual of the University of Sofia, Archaeology Dept. 3 pp. 141–217 (in Bulgarian with English Abstr.).
Lespez, L., 2003. Geomorphic responses to long-term land use changes in Eastern Macedonia (Greece). CATENA 51, 181–208.
Lespez, L., 2007. Les dynamiques des systèmes fluviaux en Grèce du Nord au cours des 7 derniers millénaires: vers une approche multi-scalaire des interactions Nature/Société. Géomorphologie, Relief, processus, environnement 1, 49–66.
Lespez, L., 2008. L'évolution des paysages du Néolithique à la période ottomane dans la plaine de Philippes. Société Archéologique d'Athènes et École Française d'Athènes, Athènes.
Lespez, L., 2011. Territoires protohistoriques en Grèce du Nord, approche géographique et geoarchéologique. In: Treuil, R., Philippakis, G. (Eds.), Archéologie du territoire, de l'Egée au Sahara. Presses Universitaires de la Sorbonne, Paris, pp. 95–109.
Lespez, L., Dalongeville, R., 1998. Morphogenèse würmienne en Grèce du Nord: le piémont des montagnes de Lékani. Géomorphologie, Relief, Processus, Environnement 4, 331–350.
Lespez, L., Tsirtsoni, Z., Darcque, P., Koukouli-Chrysanthaki, H., Malamidou, D., Treuil, R., Davidson, R., Kourtessi-Philippakis, G., Oberlin, C., 2013. The lowest levels at Dikili

https://doi.org/10.1016/j.yqres.2016.02.002 Published online by Cambridge University Press

Tash, Northern Greece: a missing link in the Early Neolithic of Europe. Antiquity 87, 30–45.
Lespez, L., Tsirtsoni, Z., Lopez Saez, J.-A., Le Drezen, Y., Glais, A., 2014. Beyond determinism: for a local approach to nature/society interactions in the southern Balkans at the transition from the Neolithic to the Bronze Age. In: Arnaud-Fassetta, G., Carcaud, N. (Eds.), French Geoarchaeology in the 21st Century, Editions du CNRS, Paris, pp. 157–171.
Magny, M., de Beaulieu, J.L., Drescher-Schneider, R., Vannière, B., Walter-Simonnet, A.V., Millet, L., Bossuet, G., Peyron, O., 2006. Climatic oscillations in central Italy during the Last Glacial–Holocene transition: the record from Lake Accesa. Journal of Quaternary Science 21, 311–320.
Magny, M., Joannin, S., Galop, D., Vannière, B., Haas, J.N., Bassetti, M., Bellintanie, P., Scandolarif, R., Desmet, M., 2012. Holocene palaeohydrological changes in the northern Mediterranean borderlands as reflected by the lake-level record of Lake Ledro, northeastern Italy. Quaternary Research 77, 382–396.
Magny, M., Combourieu Nebout, N., de Beaulieu, J.L., Bout-Roumazeilles, V., Colombaroli, D., Desprat, S., Francke, A., Joannin, S., Peyron, O., Revel, M., Sadori, L., Siani, G., Sicre2, S., Samartin, M.A., Simonneau, A., Tinner, W., Vannière, B., Wagner, B., Zanchetta, G., Anselmetti, F., Brugiapaglia, E., Chapron, E., Debret, M., Desmet, M., Didier, J., Essallami, L., Galop, D., Gilli, A., Haas, J.N., Kallel, N., Millet, L., Stock, A., Turon, J.L., Wirth, S., 2013. North–south palaeohydrological contrasts in the central Mediterranean during the Holocene: tentative synthesis and working hypotheses. Climate of the Past 9, 2043–2071.
Malamidou, D., 2007. Kryoneri: a Neolithic and early Bronze Age settlement. The Lower Strymon Valley, Proceedings of the International Symposium Strymon Praehistoricus 27, pp. 297–308.
Malamidou, D., 2016. Kryoneri, Nea Kerdyllia: a settlement of the Late Neolithic and early Bronze Age on the lower Strymon valley, Eastern Macedonia. In: Tsirtsoni, Z. (Ed.), The Human Face of Radiocarbon. Reassessing Chronology in Prehistoric Greece and Bulgaria, 5000–3000 cal BC, Travaux de la Maison de l'Orient, Lyon, pp. 171–180 (in press).
Maniatis, Y., Kromer, B., 1990. Radiocarbon dating of the Neolithic and Early Bronze Age site of Mandalo, W. Macedonia. Radiocarbon 32, 149–153.
Maniatis, Y., Tsirtsoni, Z., Oberlin, C., Darcque, P., Koukouli-Chryssanthaki, C., Malamidou, D., Siros, Miteletsis M., Papadopoulos, S., Kromer, B., 2014. New ^{14}C evidence for the Late Neolithic–Early Bronze Age transition in Southeast Europe. Open Journal of Archaeometry 2, 5262. http://dx.doi.org/10.4081/arc.2014.5262.
Marino, G., Rohling, E.J., Sangiorgi, F., Hayes, A., Casford, J.L., Lotter, A.F., Kucera, M., Brinkhuis, H., 2009. Early and middle Holocene in the Aegean Sea: interplay between high and low latitude climate variability. Quaternary Science Reviews 28, 3246–3262.
Marinova, E., Tonkov, S., Bozilova, E., Vajsov, I., 2012. Holocene anthropogenic landscapes in the Balkans: the palaeobotanical evidence from southwestern Bulgaria. Vegetation history and archaeobotany 21, 413–427.
Mayewski, P.A., Rohling, E., Stager, C., Karlen, W., Maasch, K., Meeker, L.D., Meyerson, E., Gasse, F., vanKreveld, S., Holmgren, K., Lee-Thorp, J., Rosqvist, G., Rack, F., Staubwasser, M., Schneider, R., 2004. Holocene climate variability. Quaternary Research 62, 243–255.
Mercuri, A.M., Sadori, L., Ollero, P.U., 2011. Mediterranean and north-African cultural adaptations to mid-Holocene environmental and climatic changes. The Holocene 21, 189–206.
Miall, A.D., 1996. The Geology of Fluvial Deposits: Sedimentary Facies, Basin Analysis and Petroleum Geology. Springer-Verlag, Berlin.
Moore, P.D., Webb, J.-A., Collinson, M.E., 1991. Pollen Analysis. Blackwell Scientific Publications, London.
Nikolov, V., 2012. Salt, early complex society, urbanization: Provadia–Solnitsata (5500–4200BC). In: Nikolov, V., Bacvarov, K. (Eds.), Salt and Gold: The Role of Salt in Prehistoric Europe, Faber, Provadia–Veliko Tarnovo, pp. 11–65.
Papadimitriou, N., Tsirtsoni, Z., 2010. Greece in the Broader Cultural Context of the Balkans During the 5th and 4th Millennium BC, Athens (In Greek with English Abstr.).
Passega, R., 1957. Texture as characteristic of clastic deposition. AAPG Bulletin 41, 1952–1984.
Pasztaleniec, A., Poniewozik, M., 2004. Pediastrum species (Hydrodictyaceae sphaeropleales) in phytoplankton of Sumin Lake (Leczna–Wlodawa Lakeland). Acta Societatis Botanicorum Poloniae 73, 39–46.
Pavlopoulos, K., Fouache, E., Sidiropoulou, M., Triantaphyllou, M., Vouvalidis, K., Syrides, G., Gonnet, A., Greco, E., 2013. Palaeoenvironmental evolution and sea-level changes in the coastal area of NE Lemnos Island (Greece) during the Holocene. Quaternary International 308, 80–88.
Peyron, O., Goring, S., Dormoy, I., Kotthoff, U., Pross, J., de Beaulieu, J.-L., Drescher-Schneider, R., Vannière, B., Magny, M., 2011. Holocene seasonality changes in the central Mediterranean region reconstructed from the pollen sequences of Lake Accesa (Italy) and Tenaghi Philippon (Greece). The Holocene 21, 131–146.
Peyron, O., Magny, M., Goring, S., Joannin, S., de Beaulieu, J.-L., Brugiapaglia, E., Sadori, L., Garfi, G., Kouli, K., Ioakim, C., Combourieu-Nebout, N., 2013. Contrasting patterns of climatic changes during the Holocene across the Italian Peninsula reconstructed from pollen data. Climate of the Past 9, 1233–1252.
Pross, J., Kotthoff, U., Müller, U.C., Peyron, O., Dormoy, I., Schmiedl, G., Kalaitzidis, S., Smith, A.M., 2009. Massive perturbation in terrestrial ecosystems of the Eastern Mediterranean region associated with the 8.2 kyr B.P. climatic event. Geology 37, 887–890.
Psilovikos, A., 1986. Contribution to the geomorphology of the south-western part of the Rhodope Massif (Greek East Macedonia). Geologica Balcanica 16, 21–32.
Reille, M., 1992. Pollen et Spores d'Europe et d'Afrique du Nord. Laboratoire de Botanique Historique et Palynologie, Marseille.
Reimer, P., Bard, E., Bayliss, A., Beck, J., Blackwell, P., Bronk Ramsey, C., Buck, C., Cheng, H., Edwards, R., Friedrich, M., Grootes, P., Guilderson, T., Haflidason, H., Hajdas, I., Hatté, C., Heaton, T., Hoffmann, D., Hogg, A., Hughen, K., Kaiser, K., Kromer, B., Manning, S., Niu, M., Reimer, R., Richards, D., Scott, E., Southon, J., Staff, R., Turney, C., van der Plicht, J., 2013. IntCal13 and Marine13 radiocarbon age calibration curves 0–50,000 years cal BP. Radiocarbon 55, 1869–1887.
Renfrew, C., Gimbutas, M., Elster, E. (Eds.), 1986. Excavation at Sitagroi: A Prehistoric Village in Northeast Greece, T.I. University of California, Los Angeles.
Roberts, N., Brayshaw, D., Kuzucuoğlu, C., Perez, R., Sadori, L., 2011. The mid-Holocene climatic transition in the Mediterranean: causes and consequences. The Holocene 21, 3–13.
Rohling, E., Mayewski, P., Abu-Zied, R., Casford, J., Hayes, A., 2002. Holocene atmosphere–ocean interactions: records from Greenland and the Aegean Sea. Climate Dynamics 18, 587–593.
Stefanova, I., Ammann, B., 2003. Lateglacial and Holocene vegetation belts in the Pirin Mountains (southwestern Bulgaria). The Holocene 13, 97–107.
Stockmarr, J., 1971. Tablets with spores used in absolute pollen analysis. Pollen et Spores 13, 615–621.
Strid, A., Tan, K., 1997. Flora and Vegetation of North Est Greece Including Thasos and Samothraki, Copenhagen. Botanical institute, University of Copenhagen.
Tinner, W., Conedera, M., Ammann, B., Gaggeler, H.W., Gedye, S., Jones, R., Sagesser, B., 1998. Pollen and charcoal in lake sediments compared with historically documented forest fires in southern Switzerland since AD 1920. The Holocene 8, 31–42.
Todorova, H., 1978. The Eneolithic Period in Bulgaria in the 5th Millenium B.C. BAR I.S. 49. Archaeopress, Oxford.
Todorova, H., 1995. The Neolithic, Eneolithic and transitional period in Bulgarian prehistory. In: Bailey, D.W., Panayotov, I. (Eds.), Prehistoric Bulgaria, Monographs in World Archaeology 22. Prehistory Press, Madison, pp. 79–98.
Todorova, H., 2007. Die paleoklimatische Entwicklung in VII-I Jt. Vor Chr. In: Todorova, H., Stefanovich, M., Ivanov, G. (Eds.), The Struma/Strymon River Valley in Prehistory. In the Steps of James Harvey, Gerda Henkel Stiftung, Sofia, pp. 1–6.
Todorova, H., Stefanovich, M., Ivanov, G. (Eds.), 2007. The Struma/Strymon river valley in Prehistory, Proceedings of the International Symposium 'Strymon Praehistoricus'. Kjustendil-Blagoevgrad (Bulgaria) and Serres-Amphipolis (Greece, Sofia).
Treuil, R., Darcque, P., Poursat, J.C., Touchais, G. (Eds.), 2008. Les civilisations égéennes du Néolithique et de l'Âge du Bronze. PUF, Paris.
Triantaphyllou, M.V., Ziveri, P., Gogou, A., Marino, G., Lykousis, V., Bouloubassi, I., Emeis, K.-C., Kouli, K., Dimiza, M., Rosell-Melé, A., Papanikolaou, M., Katsouras, G., Nunez, N., 2009. Late Glacial–Holocene climate variability at the south-eastern margin of the Aegean Sea. Marine Geology 266, 182–197.
Triantaphyllou, M.V., Gogou, A., Bouloubassi, I., Dimiza, M., Kouli, K., Rousakis, G., Kotthoff, U., Emeis, K.-C., Papanikolaou, M., Athanasiou, M., Parinos, C., Ioakim, C., Lykousis, V., 2014. Evidence for a warm and humid Mid-Holocene episode in the Aegean and northern Levantine Seas (Greece, NE Mediterranean). Regional Environmental Change 14, 1697–1712.
Tsirtsoni, Z., 2010. The end of the Neolithic period in Greece and the Balkans. In: Papadimitriou, N., Tsirtsoni, Z. (Eds.), Greece in the Broader Cultural Context of the Balkans During the 5th and 4th Millennium BC, Athens, pp. 92–103 (In Greek with English Abstr.).
Tsirtsoni, Z., 2014. Formation or transformation? The 4th millennium BC in the Aegean and the Balkans. In: Horejs, B., Mehofer, M. (Eds.), Western Anatolia Before Troy. Proto-urbanisation in the 4th Millennium BC? Proceedings of the International Symposium Held at the Kunsthistorisches Museum Wien, Wien, pp. 275–304.
Tsirtsoni, Z. (Ed.), 2016s. The Human Face of Radiocarbon: Reassessing Chronology in Prehistoric Greece and Bulgaria, 5000–2000 cal BC, Travaux de la Maison de l'Orient et de la Méditerranée, Lyon (in press).
Valamoti, S.M., 2015. Harvesting the 'wild'? Exploring the context of fruit and nut exploitation at Neolithic Dikili Tash, with special reference to wine. Vegetation History and Archaeobotany 24, 35–46.
van Geel, B., 1978. A palaeoecological study of Holocene peat bog sections in Germany and The Netherlands, based on the analysis of pollen, spores and macro- and microscopic remains of fungi, algae, cormophytes and animals. Review Palaeobotany and Palynology 25, 1–120.
van Geel, B., 2001. Non-pollen palynomorphs. In: Smol, J.P., Birks, H.J.B., Last, W.M. (Eds.), Tracking Environmental Change Using Lake Sediments, 3: Terrestrial, Algal and Silicaceous Indicators, Kluwer, Dordrecht, pp. 99–119.
van Geel, B., Aptroot, A., 2006. Fossil ascomycetes in Quaternary deposits. Nova Hedwigia 82, 313–329.
van Geel, B., Bohncke, S.J.P., Dee, H., 1980/1981. A palaeoecological study of an upper Late Glacial and Holocene sequence from "De Borchert", The Netherlands. Review Palaeobotany and Palynology 31, 367–448.
van Geel, B., Buurman, J., Brinkkemper, O., Schelvis, J., Aptroot, A., van Reenen, G., Hakbijl, T., 2003. Environmental reconstruction of a Roman Period settlement site in Uitgeest (The Netherlands), with special reference to coprophilous fungi. Journal of Archaeological Science 30, 873–883.
Van Geel, B., Coope, G.R., Van Der Hammen, T., 1989. Palaeoecology and stratigraphy of the Lateglacial type section at Usselo (The Netherlands). Review of Palaeobotany and Palynology 60 (1), 25–129.
Wanner, H., Solomina, O., Grosjean, M., Ritz, S.P., Jetel, M., 2011. Structure and origin of Holocene cold events. Quaternary Science Reviews 30, 3109–3123.
Weiss, H., Courty, M.A., Wetterstrom, W., Guichard, F., Senoir, L., Meadow, R., Curnow, A., 1993. The genesis and collapse of third millennium North Mesopotamian civilization. Science 261, 995–1004.
Weninger, B., Clare, L., 2011. Holocene rapid climate change in the eastern Mediterranean. An emerging archaeological climate research programme. In: Krauss, R. (Ed.), Beginnings. New Research in the Appearance of the Neolithic Between Northwest Anatolia and the Carpathian Basin, Marie Leidorf, Rahden/Westf, pp. 11–22.
Weninger, B., Alram-Stern, E., Bauer, E., Clare, L., Danzeglocke, U., Jöris, C., Kubatzki, C., Rollefson, G., Todorova, H., Van Andel, T., 2006. Climate forcing due to the 8200 cal

https://doi.org/10.1016/j.yqres.2016.02.002 Published online by Cambridge University Press

BP event observed at Early Neolithic sites in the eastern Mediterranean. Quaternary Research 66, 401–420.
Weninger, B., Clare, L., Rohling, E., Bar-Yosef, O., Böhner, U., Budja, M., Bundschuh, M., Feurdean, A., Gebel, H.-G., Jöris, O., Linstädter, O., Mayewski, P., Mühlenbruch, T., Reingruber, A., Rollefson, G., Schyle, D., Thissen, D., Todorova, H., Zielhofer, C., 2009. The impact of rapid climate change on prehistoric societies during the Holocene in the eastern Mediterranean. Documenta Praehistorica 36, 7–59.
Weninger, B., Clare, L., Gerritsen, F., Horejs, B., Krauß, R., Linstädter, J., Özbal, R., Rohling, E.J., 2014. Neolithisation of the Aegean and Southeast Europe during the 6600–6000 cal BC period of rapid climate change. Documenta Praehistorica 41, 1–31.
Whitlock, C., Anderson, R.S., 2003. Methods and interpretation of fire history reconstructions based on sediment records from lakes and wetlands. In: Swetnam, T.W., Montenegro, G., Veblen, T.T. (Eds.), Fire and Climate Change in the Americas. Springer, New York, pp. 3–31.
Wiener, M.H., 2014. The interaction of climate change and agency in the collapse of civilizations c. 2300–2000 BC. Radiocarbon 56, 1–16.
Willcox, G., 2005. The distribution, natural habitats and availability of wild cereals in relation to their domestication in the Near East: multiple events, multiple centres. Vegetation History and Archaeobotany 14, 534–541.
Willis, K.J., 1994. The vegetational history of the Balkans. Quaternary Science Reviews 13, 769–788.
Zanchetta, G., Bar-Matthews, M., Drysdale, R.N., Lionello, P., Ayalon, A., Hellstrom, J.C., Isola, E., Regattieri, E., 2014. Coeval dry events in the central and eastern Mediterranean basin at 5.2 and 5.6 ka recorded in Corchia (Italy) and Soreq caves (Israel) speleothems. Global and Planetary Change 122, 130–139.

https://doi.org/10.1016/j.yqres.2016.02.002 Published online by Cambridge University Press