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The Impact of Rapid Climate Change on prehistoric societies during the Holocene in the Eastern Mediterranean

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ABSTRACT – *In this paper we explore the impact of Rapid Climate Change (RCC) on prehistoric communities in the Eastern Mediterranean during the Early and Middle Holocene. Our focus is on the social implications of the four major climate cold anomalies that have recently been identified as key time-windows for global RCC (*Mayewski et al. 2004*). These cooling anomalies are well-dated, with Greenland ice-core resolution, due to synchronicity between warm/cold foraminifera ratios in Mediterranean core LC21 as a proxy for surface water temperature, and Greenland GISP2 non sea-salt (nss) [K^+] ions as a proxy for the intensification of the Siberian High and for polar air outbreaks in the northeast Mediterranean (*Rohling et al. 2002*). Building on these synchronisms, the GISP2 age-model supplies the following precise time-intervals for archaeological RCC research: (i) 8.6–8.0 ka, (ii) 6.0–5.2 ka, (iii) 4.2–4.0 ka and (iv) 3.1–2.9 ka calBP. For each of these RCC time intervals, based on detailed ^{14}C-based chronological studies, we investigate contemporaneous cultural developments. From our studies it follows that RCC-related climatic deterioration is a major factor underlying social change, although always at work within a wide spectrum of social, cultural, economic and religious factors.*

IZVLEČEK – *V članku obravnavamo vpliv hitre klimatske spremembe (HKS) na prazgodovinske skupnosti v vzhodnem Sredozemlju v zgodnjem in srednjem holocenu. Naš fokus je usmerjen v socialne posledice, ki so jih povzročile štiri glavne klimatske anomalije. Ohladitve so bile identificirane nedavno in označene kot ključne časovne niše za globalne HKS (*Mayewski et al. 2004*). Ohladitve so dobro datirane z ledeno vrtino na Grenlandiji, s sinhronostjo razmerij toplo/hladno med foraminiferami kot indikatorji temperature morja na površini v globokomorski vrtini LC21 vzhodnem Sredozemlju in z ne-morskimi solnimi (nms) [K^+] ioni kot indikatorji intenzivnosti Sibirskega anticiklona in prodora polarnega zraka v severovzhodno Sredozemlje. GISP2 časovni model gradi na teh sinhronizmih in zagotavlja precizne časovne intervale za arheoološke raziskave HKS: (i) 8.6–8.0 ka, (ii) 6.0–5.2 ka, (iii) 4.2–4.0 ka in (iv) 3.1–2.9 ka calBP. S pomočjo ^{14}C kronoloških analiz kulturnih sekvenc smo vzpostavili kronološke korelacije z vsakim intervalom HKS in opazovali kulturne dinamike. Ugotovili smo, da so klimatske spremembe in poslabšanja povzročitelji socialnih sprememb, seveda v povezavi z drugimi kulturnimi, ekonomskimi in religijskimi dejavniki.*

KEY WORDS – *Rapid Climate Change; Holocene; GISP2; Dead Sea Level; Levantine Moist Period; Neolithic; Chalcolithic; Bronze Age; domestication*

INTRODUCTION

Definition of Rapid Climate Change (RCC)

Our understanding of natural climatic variability in the Holocene has increased considerably during recent years. One of the most remarkable discoveries is the existence of a distinctly repetitive pattern of global cooling anomalies, with major (among other cycles) 1450-year periodicity during the Glacial periods, extending through the Holocene up to modern times, *i.e.* the most recent 'Little Ice Age' (*Mayewski et al. 1994; 1997*). These Holocene cold anomalies, the focus of the present paper, are known as Rapid Climate Change (RCC) events (*Mayewski et al. 1997; 2004*).

Mayewski *et al.* (*2004*) have identified as many as six RCC periods for the Holocene, that are given as 9000–8000, 6000–5000, 4200–3800, 3500–2500, 1200–1000, and 600–150 calBP. These periods were documented by a comparison of ~50 globally distributed palaeoclimate records, carefully selected according to length (with preference given to full Holocene coverage), sampling resolution (dating resolution better than 500 yr), interpretation quality, and geographic distribution. For the purposes of the present paper, we reduce the study area to the Eastern Mediterranean, and focus on three (shortened) RCC periods (8600–8000, 6000–5200, and 3000–2930 calBP).

Previous studies

The 4200–4000 RCC period (also known as '4.2 ka calBP event') is not studied further here. Detailed studies are provided by Weiss *et al.* (*1993*) and Staubwasser and Weiss (*2006*, both with further references) on the effects of drought in northern Mesopotamia. First considerations towards the possibility of a climatic background for the collapse of Anatolian and Aegean Early Bronze Age trade networks are supplied by Şahoğlu (*2005.passim 354*). Much further work is necessary on this topic, but if confirmed this would significantly extend the already large region (northern Mesopotamia, parts of the Indian subcontinent, East Africa) for which there appear to be observable social effects of the 4.2 ka calBP event (*Weiss 2000; Staubwasser and Weiss 2006*). A useful general introduction to the topic of '*Collapse as Adaptation to Rapid Climate Change*' is provided by Weiss (*2000*).

Welcome methodological guidance on how to approach these questions is also provided by recent studies towards understanding the collapse of rainfed agricultural cultures in the western part of the Chinese Loess Plateau (*An et al. 2005*). Here, a conspicuous transition from long-established farming communities to more mobile (pastoralist) societies is observable. However, in this case, the archaeology is poorly dated.

A continuous 9000 year high-resolution (U/Th-dated; $\Delta^{14}C$-tuned) record of the Holocene Asian Monsoon is available from Dongge Cave in Southwest China (*Wang et al. 2005*). This record provides interesting structural details for the 4.2 ka calBP event, which may be of interest in archaeological studies. In this respect, it is also worth noting that the 4.2 ka calBP event is the biggest anomaly for chloride in the GISP2 Holocene record. The chloride series is interpreted as a proxy for North Atlantic sea ice extent. During the 4200–4000 calBP time interval, the GISP2 chloride values are the lowest in the entire Holocene, indicative of a Holocene sea ice minimum in the North Atlantic. During this period, it is to be expected that summer-like conditions prevailed in the North Atlantic, thus parallel to drought in the Levant (*Mayewski and White 2002*).

Archaeological RCC-catchment

In our studies, the RCC periods as defined by Mayewski *et al.* (*2004*) are first shortened according to a combination of archaeological and geographic criteria to age intervals 8600–8000, 6000–5200 calBP, and 3100–2900 calBP. These shortened RCC time windows correspond to the maximum density of high GISP2 non-sea salt (nss) [K^+] values. When approaching the site level, the RCC time windows are further shortened, with a focus on individual (annual) peak values of the GISP2 nss [K^+] proxy. This window-technique and the ^{14}C-methods used for archaeological RCC-catchment in this paper are described in more detail below.

In essence, the approach is to use the Gaussian (200 yr) smoothed GISP2 nss [K^+] data for explorative (regional) cultural studies, and the higher-resolution GISP2 nss [K^+] raw-data for fine tuning on specific sites.

Organisation of study

This study is organised as follows. Firstly, those climate records to feature in this study are introduced, after which we provide a brief recapitulation of the combined Rapid Climate Change (RCC) scenario.

In the second section, archaeological case studies are presented; these are organised in chronological order, beginning with the oldest, and are taken from our study area, which encompasses the Eastern Mediterranean (Levant, Turkey, Greece, Bulgaria, and Romania). For each of the time-intervals in which there is strong evidence for RCC impact during the Early and Middle Holocene, we have chosen a specific region for more detailed archaeological RCC research. Using this approach we hope to optimise the potential of this study.

Be this as it may, many results remain complicated due to the wide diversity in cultural, climatic and environmental phenomena involved. The diversity of research topics is itself mirrored, to some extent, in the number of participating researchers.

CLIMATE RECORDS

Overview of RCC-records

To begin, Figure 1 supplies an overview of selected records showing Holocene Rapid Climate Change (RCC) events in the Mediterranean, southern Europe, and the North Atlantic (Fig. 1, from top to bottom): the Greenland GISP2 ice-core ($\delta^{18}O$ record), the Western Mediterranean (marine core MD95–2043), the Eastern Mediterranean (marine core LC21), the North Atlantic (Bond-Events), Romania (Steregoiu), and the Greenland GISP2 ice-core (nss [K^+] Gaussian smoothed (200 yr) and nss [K^+] high-resolution record. Site-locations are shown in Figure 2, together with a schematic representation of the main climatic players, the atmospheric and oceanic circulation mechanisms during RCC periods.

Individual RCC-records

Little Ice Age

Perhaps the most prominent of the RCC events/periods is the recent Little Ice Age (LIA) when mountain glaciers expanded in both hemispheres (*Mayewski et al. 2004.Fig.4*) and there occurred a strengthening of westerlies over the North Atlantic and in Siberia (*Mayewski et al. 2004.250*). However, as emphasised by Maasch *et al.* (*2005*), a reduction in global temperature is not necessarily the best indicator of climatic deterioration. Simultaneous with the LIA, some of the most severe droughts of the entire Holocene are observed in tropical regions (*Haug et al. 2001*).

This strong regional component of Holocene RCC makes studies in climate-archaeology complicated, since observations made in one region are not necessarily valid for the next. However, as shown below, in view of recent advances in palaeoclimatology, and especially in terms of regional climatic forecasting (and the use of modern analogues), it is now possible to reduce significantly uncertainty in regional forecasting. Consequently, by combining modern regional and supra-regional modelling predictions with empirical evidence from recent marine, terrestrial and ice-core records for the Holocene, we are now well-equipped to study for the first time, and that means explore, the impact of Rapid Climate Change (RCC) on prehistoric communities in the Eastern Mediterranean.

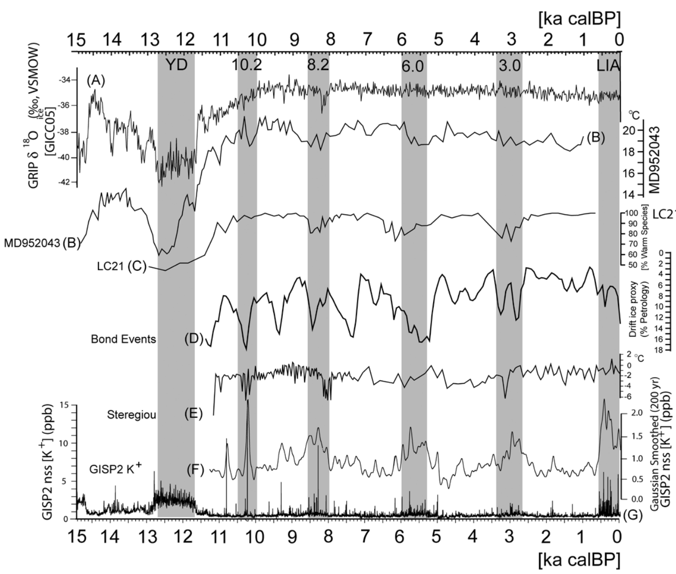

Fig. 1. Northern Hemisphere Palaeoclimate Records showing Holocene Rapid Climate Change (RCC) (site map cf. ***Fig. 2), (A) Greenland GISP2 ice-core $\delta^{18}O$ (*****Grootes et al. 1993*****), (B) Western Mediterranean (Iberian Margin) core MD95–2043, sea surface temperature (SST) C37 alkenones (*****Cacho et al. 2001; Fletcher et al. 2008*****), (C) Eastern Mediterranean core LC21 (SST) fauna (*****Rohling et al. 2002*****), (D) North Atlantic Bond-Events, stacked petrologic tracers of drift ice from cores MC52–V29191+MC21–GGC22 (*****Bond et al. 2001*****), (E) Romania (Steregoiu), Mean Annual Temperature of the Coldest Month (MTC, °C) (*****Feurdean et al. 2008*****), (F) Gaussian smoothed (200 yr) GISP2 potassium (non-sea salt [K+]; ppb) ion proxy for the Siberian High (*****Mayewski et al. 1997; Meeker and Mayewski 2002*****), (G) High-Resolution GISP2 potassium (non-sea salt [K+]; ppb) ion proxy for the Siberian High (*****Mayewski et al. 1997; Meeker and Mayewski 2002*****).***

Marine Core LC21 (35.66° N, 26.48° W, –1522 m water depth)

Due to its central position in the southeast Aegean to the east of Crete (Fig. 2), marine core LC21 (35.66° N, 26.48° W, –1522 m water depth) is of prime importance to this study. At this location, selected marine fauna have been used as a proxy for sea-surface temperature (SST), thus providing an insight into expansions and contractions of cooler Aegean waters in relation to warmer Levantine waters (*Rohling et al. 2002*). Accordingly, it has been established that the ratio of warm/cold surface living foraminifera can be used to describe a series of rapid SST variations during the Holocene. The LC21 record reveals a pattern of (presently) three major temperature drops in the SE Aegean, which can be dated to 8.6–8.0 ka calBP, 6.5–5.8 ka calBP, and 3.5–2.8 ka calBP (*Rohling et al. 2002*). Modern calibration of fauna-derived sea-surface temperature (SST) variations shows that these temperature drops have a strong seasonal component in winter and early spring (*Rohling et al. 2002*).

Although the decline in warm species in core LC21 from 90% to 80% just after 8.6 ka calBP (Fig. 1) might appear slight, this decrease nevertheless corresponds to a significant change in surface temperature (SST) of between 2 and 3° Celsius. Consequently, the wind-chill (see below) underlying such apparently small changes in water temperature fluctuation should not be underestimated. First, the temperature change (from warm to cold) is rapid; it is observed in marine core LC21 from one sample to the next, hence corresponding to a maximum interval of approximately one century. Second, the change in temperature is observed in a *c.* 300 metre deep water column, *i.e.* the habitat of the marine fauna under study. Therefore, the seemingly small temperature change corresponds to the transfer of huge amounts of energy. Similar temperature drops have also been recorded in many other marine records in the Mediterranean basin, although these can of course have resulted from various factors, *e.g.* cold water circulation from one basin to another. As mentioned above, the focus of this paper is on the SST fluctuations observed in core LC21 during RCC periods, since these are primarily caused by wind induced cooling of the water surface.

The RCC-mechanism

Perhaps the most remarkable result of LC21 studies was the recognition that the rapid SST variations observed in this core resulted from the rapid movement of extremely cold air masses over the surface of the Aegean Sea. The location of core LC21 close to Crete makes it particularly sensitive to the expansion and contraction of cooler northern Aegean waters, *i.e.* it lies at the southern point of these water masses, in a position that is especially sensitive to the cooling effects of winds sweeping down from the Balkans. Before reaching the LC21 core location, north-easterly (RCC) winds would have already traversed the sea surface over a distance of some 700km. Since the RCC winds are predominantly winter/early spring phenomena and typically only occur for a few days at a time, the energy transfer between surface water and wind must proceed quite rapidly. Therefore, there are strong indications that in certain (RCC) periods during the Holocene, large amounts of cold air must have been available in the northern Aegean, but typically only for a short time during winter and early spring. The ability of the cold north-easterly winds to induce so much energy transfer from the LC21 water column (~300m) in such a short time (max ~100 yrs) during RCC periods, at-

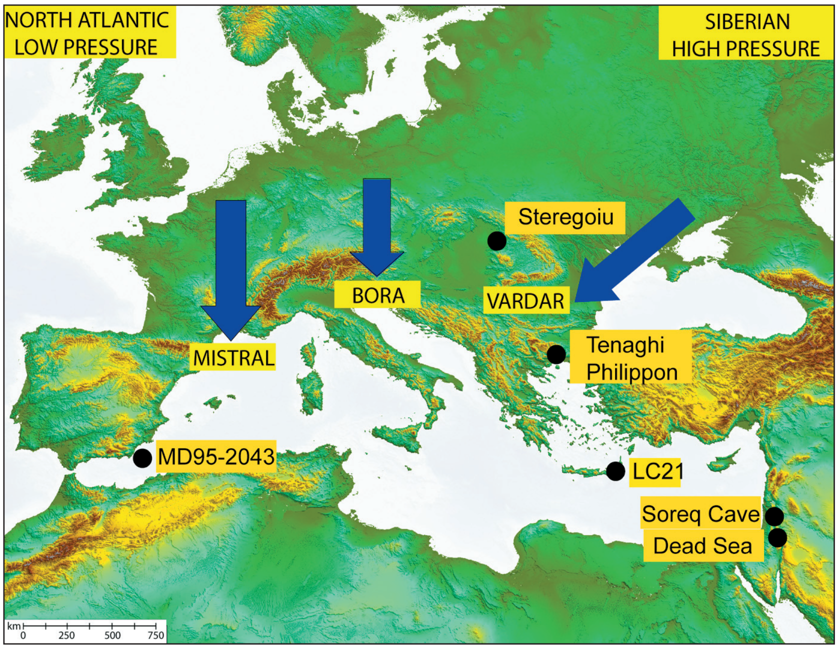

Fig. 2. Map showing locations of RCC-study sites and important RCC-winds. SRTM Global Bathymetry and Elevation Data: courtesy of* Becker et al. 2009. *Mapped using Lambert Equal-Area Projection by Globalmapper.

tests to the remarkable intensity of the cold polar/ continental airflows.

Correlation of Aegean sea surface temperature and Siberian high pressure

Now that the basics of the water cooling mechanism are understood (water evaporation caused by extremely cold and dry air flowing rapidly over a warm ocean surface), the question arises as to the source of this cold air. General meteorological considerations and modern observations indeed suggest Siberia as a likely source region. This atmospheric path (Siberia–>Aegean) has been proposed for cold air masses during the Holocene on the basis of an unusually high correlation between the LC21 SST record and the non-sea-salt (nss) [K^+] chemical ion concentration measured in the Greenland GISP2 ice-core (72.6° N, 38.4° W, +3200 m height). High [K^+] values are coincident with an intensification of the semi-permanent Siberian high pressure zone (*Mayewski et al. 1997*).

The correlation between Aegean SST and Greenland GISP2 nss [K^+] is of major importance for our studies. It provides not only a meteorological mechanism for RCC, and therefore an explanation for RCC, but also a long and continuous (~60 ka; *cf.* Fig. 4), and very precise (GISP2 ice-core based) time-scale that can be applied to all fields of RCC-research. This being the case, the next question is whether it is possible to identify the effects of RCC at terrestrial sites.

Steregoiu (Romania)

Recently published high-resolution pollen records from Steregoiu (47° 48' 48" N; 23° 22' 41" E; 790 m.a.s.l) and Preluca Tiganului, two fen-peat sites in northwest Romania, have provided the first evidence that movements of extremely cold air associated with the RCC-mechanism had a massive ecological impact in Southeastern Europe in the past (*Feurdean et al. 2008*). At these locations there are indications for rapid air temperature drops (> 4°C), at least during the 8.2 ka and the 3.0 ka calBP RCCs. Intriguingly, in the Steregoiu record there is additional evidence for the existence of a further RCC at 10.2 ka calBP that is not visible in LC21. The temperature reconstruction for Steregoiu is based on calculations performed for eight modern analogues. Figure 1 shows the estimated [°C] temperature of the coldest month (MTC). In this record, even the 3.0 ka calBP RCC is represented (if only with one data point). The 8.2 ka calBP event is unequivocal (but see below for critical discussion of what we are actually seeing here), and as previously mentioned, there is good evidence for a strong RCC period around 10.2 ka calBP.

Certainly, one might now ask why the clearly discernable GISP2 nss [K^+] peak at 10.2 ka calBP (Fig. 4) was not already defined as an RCC event by Mayewski *et al.* (*2004*). The reason for this lies in the fact that this research deliberately avoided the Early Holocene section of the GISP2 nss [K^+] record so as to minimise the risk of confusing RCC with post-Younger Dryas North Atlantic melt-water events. The mechanism underlying the GISP2 K^+ peak at 10.2 ka calBP remains unknown, and it is for precisely this reason that it is interesting to see the environmental impact of an Early Holocene cold event dating to 10.2 ka calBP in northwest Romania. The sites at Steregoiu and Preluca Tiganului are located at a considerable distance (~700km) from the North Atlantic, but equally distant (~700km) from both the Aegean coast and the Black Sea. Strictly speaking, just as for the 8.2 ka calBP cold signal at Tenaghi Philippon (*Pross et al. 2009*), the cause of the 10.2 ka calBP event in Romania remains to be established, although it has been suggested it was caused by perturbation of the North Atlantic circulation (*Feurdean et al. 2008*). According to the pollen-based temperature reconstructions, whereas a significant drop in (average) at both sites during RCC intervals a significant drop in (average) winter temperatures in the order of 4°C has been estimated for both sites during RCC intervals, summer temperatures during RCC intervals appear to have been comparable to those currently prevailing. Cold episodes around 10.2 and 7.8 ka calBP have also been recorded in $\delta^{18}O$ values in speleothems from northwest Romania (*Tamas et al. 2005*). Calculated annual (average) RCC precipitation rates are significantly higher than at present. It remains to be mentioned that from no other region of Southeastern Europe do we presently have evidence for the impact of the (expected) RCC at 3000–2930 calBP.

Hudson Bay outflow (classical 8.2 ka calBP event)

As is well-known from Greenland ice-core stable oxygen records (Fig. 1), temperatures in the North Atlantic region dropped abruptly around 8200 years ago, only to recover over the course of the subsequent *c.* 160 years (*Thomas et al. 2007*). It is now widely accepted that the observed cooling was caused by the catastrophic collapse of a remnant Laurentide ice-dome and subsequent drainage of large amounts of melt-water from the Hudson Bay (alias proglacial Lake Agassiz) into the North Atlantic (*Barber et al.*

1999). Theoretical studies (*e.g. Renssen et al. 2001; 2002; Bauer et al. 2004*) confirm that the amount of fresh water stored in Lake Agassiz would have been sufficient to lower the surface water density in the North Atlantic below the threshold value for salinity-driven (contrasting wind-driven) deep-water formation (*cf. Rahmstorf 2003*). Further, these studies demonstrate that the Hudson-Bay outflow could indeed have triggered, and upheld, a reduction of the thermohaline circulation (THC) for many hundreds of years, depending on the amount of freshwater released and the duration of the freshwater pulse. Naturally, there are still questions concerning, for example, the THC slowdown mechanism and the spatial extent of the associated supra-regional air temperature reduction.

Most importantly, however, and as pointed out by Rohling and Pälike (*2005*), the sharp peak so prominent in the Greenland $\delta^{18}O$ records is, in fact, only one specific component (dating *c.* 8.2–8.0 ka calBP) within the much broader climatic anomaly identified in many proxies on a global scale (typically dating *c.* 8.6–8.0 ka calBP). The compounded nature of these signals, and specifically the temporal overlap of the (oceanic) Hudson Bay outflow event with the (atmospheric) 8.6–8.0 ka calBP GISP2 RCC period, implies that we should be cautious with far-reaching interpretations of the Hudson Bay event until the underlying mechanisms and potential combined effects are better understood.

Tenaghi Philippon (Northern Greece)

Further terrestrial evidence for the expected massive ecological impact of the movement of extremely cold RCC air in the Northeastern Aegean during RCC periods is provided by pollen data from Tenaghi Philippon, North Greece (*Pross et al. 2009*). Here, during the 8.2 ka calBP RCC event a significant reduction in tree-pollen is observed that is representative of a decline in winter temperatures of more than 4°C. The shape of the pollen decline record has close similarities to the classical 8.2 ka calBP 'Hudson Bay' event. Although this suggests a direct southern European atmospheric response to changes in North Atlantic thermohaline circulation, here we must note the occurrence of exactly that scenario referred to above, *i.e.* that at Tenaghi Philippon the effects of the Hudson Bay outflow and of RCC may be compounded (*Rohling and Pälike 2005; Pross et al. 2009*).

MD95-2043 (west Mediterranean)

Since the Mediterranean basin is practically isolated from North Atlantic oceanic circulation, the transmission of climate signals from the North Atlantic to the Eastern Mediterranean must proceed via the atmosphere. For this reason, we expect differences between climate development in the Holocene in the east and west of the Mediterranean. Although our present focus is on the Eastern Mediterranean, a high-resolution climate record (core MD95-2043) from the Western Mediterranean is included in Figure 1 for comparison (record B). Due to the existence of anticyclonic gyres in the Alborán Sea at this location (Fig. 2), it is possible to register low-salinity surface waters that derive from the North Atlantic. Palynological studies on core MD95-2043 (*cf. Fletcher et al. 2008*) have shown the high sensitivity of this location to rapid climate variability during the last glacial period. For example, during interstadial conditions, rapid forest expansion is observed on the Iberian Peninsula, whilst forest contraction is observed during stadials. It is therefore interesting to explore whether this high-resolution also provides evidence for Holocene RCC events. As can be seen in Figure 1 (record B), there are indications in core MD95-2043 of SST decline (in the order of 2 °C) during some of the RCC time intervals (*cf.* shaded RCC events ~10.2 ka; ~8.6–8.0 ka calBP; ~6.0–4.2 ka calBP). Regarding the 3.1–2.9 ka calBP RCC in the Western Mediterranean, pollen records indicate the occurrence of short-term arid phases in the southern Iberian Peninsula (*Carrión 2002; Fletcher et al. 2007*). These correspond chronologically with enhanced flood frequencies in the Lower Moulouya Basin of northeast Morocco (*Zielhofer et al. 2009; in press*).

Bond events (north Atlantic)

Further conspicuous evidence that the generally warm and supposedly stable Holocene climate was repeatedly punctuated by a sequence of abrupt cooling events comes from the North Atlantic. First identified some 12 years ago (*Bond et al. 1997*), the existence of periods of intensified ice drifting across the North Atlantic is now well-established for the Glacial. Detailed source and material analysis of lithic grains has shown that these materials were transported on icebergs ('ice-rafting') and deposited on the ocean floor when the icebergs melted ('Heinrich events'). The icebergs originated from glaciers on the western side of the North Atlantic. Unfortunately, the corresponding Holocene drift-ice record, which uses stacked petrologic tracers from cores MC52-V29191+MC21-GGC22 (Fig. 1; *Bond et al. 2001*), is not sufficiently well-dated for application per se in archaeological high-resolution climate studies. Nevertheless, it does provide additional evidence for the existence of cooling anomalies in the Holocene, most notably around 9.5 ka calBP (perhaps the 9.4 ka calBP GISP2 nss [K+] peak) and again around 7.5 ka calBP, (without convincing GISP2 nss [K+] peak). In the Bond event sequence, the 3.1–2.9 ka calBP GISP2 nss [K+] -defined RCC has the curious appearance of a double peak; this requires further study.

Frozen Bosporus (northwest Turkey)

A modern climate analogue record for our study area is supplied by the historical eye-witness documentation of winter-freezing events in the Bosporus region (*Yavuz et al. 2007*). The Frozen Bosporus record builds on the observed freezing over of the narrow Bosporus/Marmara waterway caused by ice masses pushed into the Bosporus from the Black Sea by strong, cold and dry winds blowing from the northeast. Since it is no easy matter to freeze salt water, we have here a vivid illustration of the intensity of the cold winds needed to produce the observed masses of floating icebergs, and transport them downwind (although supported by strong surface currents) from the Black Sea through the Bosporus and the Marmara Sea, and even as far as the Dardanelles (the location of Troy).

What we observe in the historical Bosporus record is a strong clustering of freezing events between 1600 and 1929 AD, quite in line with the GISP2 nss [K+] peak cluster during the Little Ice Age (LIA). Due to the likely bias in the historical documentation towards younger events, this record cannot be applied directly to instrumental calibration. A further disadvantage is the non-linearity of this record, since salt water freezing has a threshold value depending on salinity, *i.e.* around –2 °C lower than freshwater. Nevertheless, the Bosporus record does supply a useful illustration of climatic effects to be expected in this region during RRC times.

During the LIA, it appears that the most severe winters were regularly accompanied by the often complete freezing over of the Bosporus, the Golden Horn, and parts of the Black Sea. Such freezing events were observed in the years 1621, 1669, 1755, 1779, 1823, 1849, 1857, 1862, 1878, 1893, 1928, 1929, and – most recently – in 1954. The 1954 freezing originated not directly from local RCC winds, but from the dynamiting of the ice-blocked Danube, with icebergs subsequently drifting into the Bosporus (*pers comm, Mehmet Özdoğan 2008*). Interestingly, again early in 1954, the Prehistoric Department at Istanbul University was difficult to access for many weeks due to metre-deep snow (*pers comm, Mehmet Özdoğan 2009*). Regardless of whether or not we count 1954 as a RCC-year, these observations provide a glimpse of the widespread effects of extreme cooling to be expected in the Eastern Mediterranean during RCC periods.

Transferred to prehistoric RCC periods, the Bosporus event sequence suggests an average of at least one catastrophically cold winter per generation (~25 yrs). Interestingly, the intensity of the cold spells appears to have gradually diminished during the last three centuries (*Yavuz et al. 2007.646*). These observations are of immediate interest for our understanding of the abandonment of Troy (northwest Anatolia) during the 3.0 ka calBP RCC, as well as for the general timing of the Aegean Dark Ages, should this indeed be the result of RCC (*cf.* discussion below). For the sake of completeness, we finally note that the frequency analysis of historical eye-witness accounts of the freezing of the River Thames during the last 1000 years (*Currie 1996*) shows a similar density maximum during the LIA period 1600–1928 AD (Fig. 3). Again, we cannot exclude a bias towards younger observations.

The Glacial GISP non-sea salt (nss) potassium [K+] concentration record

It is informative to extend discussion of the GISP2 nss [K+] record further back in time into the glacial periods. Over its entire extent, the GISP2 record shows a clear anti-correlation between the stadial-interstadial sequence defined by stable $\delta^{18}O$ oxygen isotopes and the nss [K+] series. Detailed examination of the GISP2 chemical ion series (*Mayewski et al. 1997*) has shown that not only [K+], but the ma-

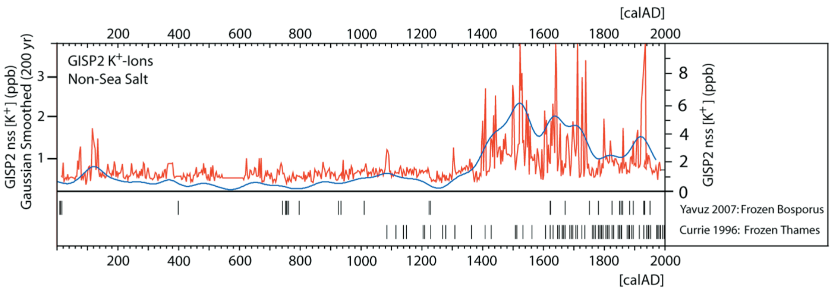

Fig. 3. Freezing Events during the last 2000 years in the Bosporus, the southern Black Sea and Marmara region, derived from historical documents (**Yavuz et al. 2007*****), compared to the GISP2 nss [K+] ion record (*****Mayewski et al. 1997; 2004*****). Also shown is the historical record (1000–2000 AD) of the Thames freezing (*****Currie et al. 1996*****).***

jority of measured chemical species (Ca_2^+, Mg_2^+, Na^+, Cl^-) rise and fall in concert with the Greenland stadials and interstadials, respectively, with the exception of NH_4 and NO_3. Each species has its own environmental signature, but in combination they map an intensification of the atmospheric dust flux (*i.e.* polar circulation) during Greenland Stadials, and a reduction in polar circulation during Interstadials (*Mayewski et al. 2004*). Prior to the Holocene, the coldest and windiest periods in high-latitudes (including North America, Europe, and the Northeastern Mediterranean) are those with high $[K^+]$ values.

One of most conspicuous and most often studied time-intervals covered by the GISP2 record is the cold and dry Younger Dryas (YD). It is characterised, like other stadial periods, by high GISP2 nss $[K^+]$ values (Fig. 4). However, due to the dominant role of North Atlantic Ocean circulation in its formation, the YD is not rated by Mayewski *et al.* (*2004*) as an RCC event *sensu strictu*. Instead, the RCC designation is reserved solely for atmospheric circulation patterns. For the pre-Holocene periods this is most notably the case for Greenland stadials, although continuously high GISP2 nss $[K^+]$ values are also observable during the Late Glacial Maximum (LGM) (Fig. 4). Due to the RCC definition (*Mayewski et al. 2004*), with its clear focus on atmospheric circulation (contrasting oceanic circulation), the GISP2 nss $[K^+]$ record (Fig. 4 lower) is probably even more useful for archaeological applications than the presently most frequently referenced GISP2 stable oxygen isotope record.

For example, during the LGM the landscapes of much of Central Europe comprised inhospitable steppe and were open-forested. Not unexpectedly, therefore, during this period a major population decline is observed in Central Europe. In terms of human tolerance towards extreme cold, the climate modelling studies by the Cambridge Stage 3 Project have identified wind-chill, along with snow cover, as the two most important hominid-related climatic variables underlying Palaeolithic landscape use and migration patterns (*van Andel et al. 2004*).

Modelling studies: glacial rapid climate change

Evidence that the RCC mechanism is at work – not only during the Holocene (as is presently best shown by LC21) – but also during Glacial periods, is obtained from reconstructions of glacier ablation line displacements. These show that atmospheric configurations similar to the LIA were manifest in intensified form during the Last Glacial Maximum (LGM), some 19–23 000 years ago (*Kuhlemann et al. 2008*). In this work, which is of immediate relevance to archaeological studies, it is shown for the LGM that the cooling associated with enhanced GISP2 nss $[K^+]$ values was accompanied by a lowering of the equilibrium line altitude (ELA) for glacier formation by up to 1500m in the circum-Mediterranean mountain chains.

Furthermore, during glacial RCC periods, due to funnelling effects between the Alps and the Pyrenees, an invasion of polar air masses into the Western Mediterranean is to be expected, particularly down the Rhône valley into the Gulf of Lyons, just as for the Eastern Mediterranean (*Kuhlemann et al. 2008*). Although derived for glacial conditions, which would have been more extreme than today due to the more southerly position of the LGM polar front, similar conditions can be expected for the Holocene RCC time intervals.

The 10.2 ka calBP RCC event

What can also be deduced from Figure 4 is the exceptional amplitude of the GISP2 nss $[K^+]$ record at ~10 277 calBP (GISP2). We associate this peak with a new RCC not previously defined by Mayewski *et al.* (*2004, cf. above*). The 10.2 ka calBP nss $[K^+]$ peak is sufficiently removed from the nearest SO_4-peak in terms of GISP2 ages, as well as in GISP2 core depth, to exclude influence from neighbouring strong volcanic SO_4 activity dating to ~10 325 calBP (GISP2). Hence we can state with some confidence that the 10.2 ka calBP $[K^+]$ peak is unlikely to have resul-

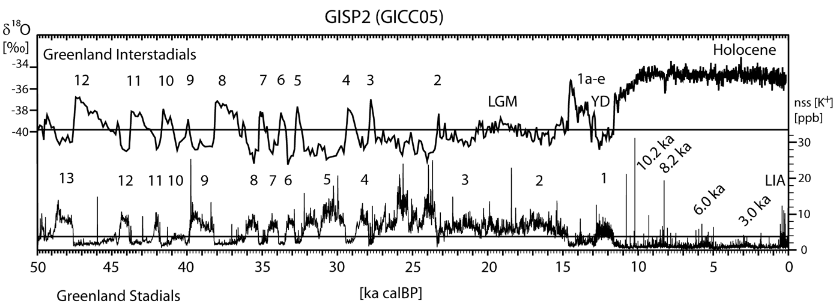

Fig. 4. Glacial GISP2 nss [K⁺] chemical ion record in the time-window 0–50 ka calBP (*Mayewski et al. 1997; 2004*). GI – Greenland Interstadial (GI numbers* cf. Johnsen et al. 1992*); LGM – Last Glacial Maximum, YD– Younger Dryas. Holocene RCC-periods are indicated at ~10.2 ka, ~8.2 ka, ~6.0 ka, ~3.0 ka and Little Ice Age (LIA). Age. GISP2 records are presented on U/Th-Hulu age-model (*Weninger and Jöris 2008*). Greenland stadials are defined by δ18O minima (*cf. Johnsen et al. 1992*).

ted from volcanic activity. The possibility that this peak is related to biomass burning is also unlikely, since there are no unusual amounts of NH_4 in the corresponding GISP2 ice-sample. It is important to note that all GISP2 ion measurements stem from the same ice sample. For this reason, we infer that the source of the 10.2 ka calBP GISP2 nss [K^+] deposit – as is the case with all other RCC events – must lie in atmospheric crustal dust transported from Asia to Greenland. This is the dominant atmospheric path underlying [K^+] in all sections of the GISP2 record. Further, judging from its intensity (Fig. 4), the 10.2 ka calBP [K^+] represents one of the most intense cold events to have occurred during the last 50 kyr. Indeed, this deposit appears even stronger than the GISP2 nss [K^+] event dating to 40 ka calBP (GISP2). Interestingly, the 40 ka calBP GISP2 nss [K^+] peak is distinct in time (by ~50 years) from the Campagnian Ignimbrite Eruption. The time difference of 50 ice-yrs corresponds to 2–4 samples at given GISP2 depths.

Sapropel S1 (Eastern Mediterranean)

Sapropel S1 is yet another important RCC record that stems from the marine domain in the Eastern Mediterranean, but which has strong supra-regional climate connections to the lower latitude Monsoon regime. Sapropels are dark, organic-rich sedimentary deposits that can be found throughout the Mediterranean basin. The formation of sapropels occurs when the ventilation of the ocean floor is interrupted, *i.e.* when the ocean surface is diluted with buoyant fresh water. Accordingly, fresh water inhibits the formation of deep-water, thus starving the benthic fauna (ocean-bottom species) of oxygen. Beyond their formal identification as thick black layers in sediment cores, sapropels are characterised by a reduced salinity (salt concentration) of surface water at the time of deposition, and by their stable oxygen isotope composition. The latter can be measured in the varying frequency of selected planktonic (surface-living) foraminifera. Sapropels are common throughout the Mediterranean basin, and are among the most important marine indicators for enhanced precipitation/runoff.

The formation of sapropels in the Eastern Mediterranean during the Early Holocene is related to a strong increase in summer rainfall (*e.g. Rohling and Hilgen 1991; Rohling 1994; Ariztegui et al. 2000*). Since any change from dry to humid conditions can be expected to have a considerable influence on the development of vegetation, thereby affecting practically all kinds of human food resources, they may be used in archaeological studies as important general indicators for (terrestrial) rainfall variation. However, prior to the consultation of sapropels for the purpose of archaeological RCC studies in the Holocene, it is essential that three specific requirements are met: (i) there must be an accurate and precise chronology of Eastern Mediterranean Sapropel S1 formation; (ii) the predicted precipitation changes must be substantiated by terrestrial climate data; and (iii) the combined precipitation record must be placed alongside the precise GISP2 nss [K^+] chronology and in relation to the archaeological events under study. Only then can we confidently forecast climatically-induced social responses and processes.

The LC21 core record has recently been integrated into a supra-regional multiproxy chronostratigraphic framework (*Casford et al. 2007*). Within this framework special attention has been placed on the derivation of reliable (statistically robust) ages for the beginning and end of Sapropel S1. Accordingly, the most reliable age for the onset of Sapropel S1 is 9920±240 calBP; the end of Sapropel S1 is dated to 6806±240 calBP. Both ages are noted here at the 2σ level (95% variance) and have been derived using standardised depths of 174.5 cm (for the base) and of 131.0 cm (for the top) of the Sapropel S1 dark layer in core LC21 (*Casford et al. 2007; ebda., Tab. 4*, Number 1 & equation in Fig. 5).

Complementary climate records: precipitation (Dead Sea levels)

The Holocene Dead Sea lake level record (Fig. 5) recently published by Migowski *et al.* (*2006*) provides a rain gauge with tremendous predictive capabilities for Near Eastern archaeology, and especially for the Jordan valley, with its rich cultural heritage. In combination with other lower latitude climate proxies, the Dead Sea record is given a central position in the present study. Notwithstanding, there are several points that need to be made regarding this proxy. Firstly, the Dead Sea level responds primarily to precipitation changes in the northern Jordan Valley which are channelled down-valley from the Lake Kinneret basin. Secondly, due to its high salinity, the Dead Sea itself does not provide the fresh-water necessary to support farming communities.

Thirdly, there is a pronounced non-linearity in the relation between (hypothetical) Levantine precipitation and (measured) Dead Sea lake level. This non-linearity is due the fact that the Dead Sea comprises two closely connected sub-basins separated by a sill at ~402–403m bmsl (*Migowski et al. 2006.422*).

The deep northern basin is fed mainly by the Jordan and to a lesser extent by local runoff. When the waters of the northern basin rise to levels above the sill, overflowing waters flood the shallower southern basin. In this case the combined lake area, and therefore total evaporation, rises significantly. Therefore, very high precipitation is required to simultaneously raise the water level of the northern basin above the sill and to maintain this high level against enhanced evaporation. Conversely, when the northern basin drops significantly below the sill during extreme arid periods, salt is deposited in the centre of the lake. This important process is not evident in the level graph (Fig. 5).

To support the interpretation of the Dead Sea record, particularly with respect to this non-linearity, we have drawn a dashed horizontal line in Figure 5 at the sill height of ~402.5m. Allowing for such scaling complications, the Dead Sea level represents an invaluable document for climate-archaeological research in the Levant. It remains to be mentioned that the Dead Sea record is derived from multiple cores with an age model based on a large set (N = 38) of precise AMS ^{14}C-ages measured on 'organic relics' (*Migowski et al. 2006. 428*, Appendix A) at the Kiel laboratory.

Of outstanding interest for RCC studies is the very abrupt rise in lake level at approximately 10.1 ka calBP, which sees water rise from a level below *c.* 430 bmsl to a height of ~380 bmsl (Fig. 5). This level is maintained for about 500 years before it drops by approximately 10m to around 370 mbsl at ~9.4 ka calBP. Migowski *et al.* (*2006*) attach a number of question marks to the (oscillating?) heights measured between 9.4 ka and 8.6 ka calBP; however, water levels are still clearly higher than the sill. At around 8.6 ka calBP, the water level drops significantly to a level some 10m below the sill, followed at *c.* 8.1 ka calBP by a further drastic decrease, when the level plummets by a further 15m to approx. 428 bmsl, the lowest ever recorded value in the Holocene. After recovering slightly to ~405 mbsl at around 7.5 ka calBP, relatively low level conditions continue until 5.6 ka calBP. Thereafter, several fluctuations are observed until a second conspicuous maximum at 370 mbsl is reached. This maximum is maintained for ~400 yrs, between 4.0 ka and 3.6 ka calBP. Then, once again, at around 3.2 ka calBP there occurs a significant drop, by 60m, to a lake level well below the sill (Fig. 5, *Migowski et al. 2006*).

Regional predictions using combined RCC-precipitation data (Near East)

Comparisons with other climate records (Fig. 5) show that the abrupt rise in Dead Sea level at 10.0 ka calBP corresponds well (within error limits of ± 100 yrs) with the onset of Sapropel S1. The extremely large Dead Sea level drop to ~428 mbsl, dating between 8.1 ka and 7.5 ka calBP, is to some large extent synchronous with the Sapropel S1a-b interruption. This is indicative of a major arid period in the Jordan Valley, and appears to run parallel to supra-regional aridity as indicated by the synchronicity with the Sapropel S1a-b interruption. Most im-

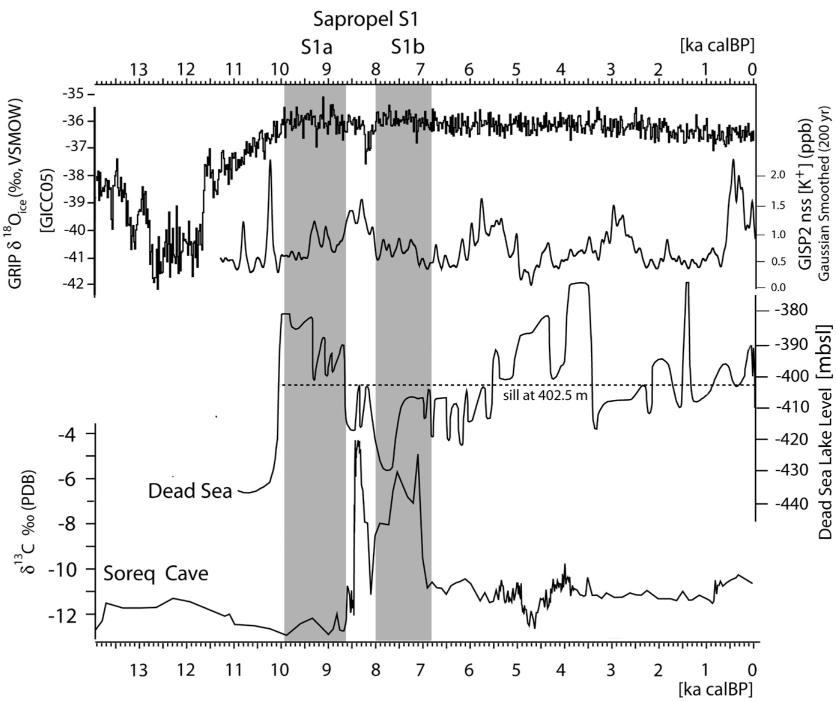

Fig. 5. Dead Sea (Jordan) Lake Levels as proxy for Holocene precipitation (**Migowski et al. 2006*****) in comparison to Greenland GRIP (GICC05-age model) ice-core stable oxygen isotopes δ^{18}O (*****Grootes et al. 1993*****), Greenland GISP2 ice-core nss [K$^+$] chemical ions as proxy for Rapid Climate Change, (*****Mayewski et al. 1997*****), and Soreq Cave (Israel) δ^{13}C record as proxy for flash-flood intensity (*****Bar-Matthews et al. 2003*****). Shaded area indicates Sapropel S1 with onset ~9.9 ka calBP and end ~6.8 ka calBP) according to Casford et al. (*****2007*****), and interruption between S1a and S1b assumed *****c.***** 8.6–8.0 ka calBP (see text).***

portantly, the drought conditions in the Levant coincide with the 8.6–8.0 ka calBP RCC (Fig. 5).

Together, these records provide tantalising evidence for an extended period (10.1–8.6 ka calBP) with enhanced rainfall in southern Jordan and, by implication, perhaps even in the entire Levant. This wet period started abruptly, shortly after the 10.2 ka calBP cold-event, and came to an abrupt end at the onset of the next younger RCC at 8.6 ka calBP. A further GISP2 nss [K^+] peak at 9.5 ka calBP might also be related to Dead Sea low stands, and North Atlantic impact is suggested by its age-correlation with a Bond event of similar age (Fig. 1). However, caution is advised in the interpretation of all such correlations, particularly as the Monsoon-related Q5 cave record from Oman (*Fleitmann et al. 2003*) also shows a marked signal at around 9.5 ka calBP.

Early Holocene climate in the Near East

At this point, we recapitulate our general understanding of the climate system in the wider Near East, and provide a set of regional predictions for Early Holocene Rapid Climate Change in the Levant. By comparative study of climate records from the Jordan Valley (Dead Sea Lake Levels), the Aegean Sea (marine core LC21), the Red Sea (core GeoB 5844-2) and Greenland GISP2 ice-core records (Fig. 1) the following key messages can be formulated:

● The Jordan Valley was extremely wet from *c.* 10.0–8.6 ka calBP. We use the term 'Levantine Moist Period' (LMP) to characterise the high levels of precipitation in this time-interval. The LMP is presently best-documented in Dead Sea lake levels (*Migowski et al. 2006*) and low Red Sea salinity (*Arz et al. 2003*). In the Dead Sea record the LMP is recognised as an approx. 1400-year period, with high lake levels that resided continuously above the sill separating the northern and southern basins. During the LMP, it appears that both basins were filled.

● Following a brief (~200 yrs), but extremely cold RCC event at 10.2 ka calBP, the LMP commences abruptly at 10.0 ka calBP, and wet conditions are maintained for the following 1400 yrs.

● The LMP ends abruptly and immediately prior to the onset of the next RCC (8.6–8.0 ka calBP) interval. During both RCC events (10.2 ka and 8.6–8.0 ka calBP) the Eastern Mediterranean was punctuated by regular winter/spring outbreaks of extremely cold polar air masses. During these RCC periods the region would have been regularly 'bathed' – perhaps for days on end and maybe even for weeks in winter and early spring – with air masses directly from Siberia.

● Consistent with meteorological expectations, and independently confirmed by the major drop observed in Dead Sea Lake Levels (*Migowski et al. 2006*), during the entire 8.6–8.0 ka calBP GISP2 RCC event the Jordan Valley experienced an extended drought. On the basis of the Soreq Cave record (*Bar-Matthews et al. 2003*) it is likely that this drought period may have been interrupted by major episodic torrential rainfall events.

ARCHAEOBIOLOGICAL RECORDS

Early domestication of cereals in the Near East

The cultivation of wild cereals began during the very late Younger Dryas (YD), continuing during the Pre-Pottery Neolithic A (PPNA) period (*Willcox et al. 2009*). In correlation to the slow increase of precipitation following the end of YD, annual harvesting would have become increasingly successful, and, as known from experimental studies, the process of steady cultivation ended with the appearance of the cultigens. Therefore, it is not surprising that the rapid onset of the Dead Sea moist period at ~10.1 ka calBP displays a highly positive temporal correlation to an almost simultaneous appearance at many sites in the Near East of domesticated cereals (see below). These sites could represent budding-off communities, in line with a related demographic increase due to the success in this early phase of farming (*cf.* Neolithic Demographic Transition: *Bouquet-Appel and Bar-Yosef 2008*).

This trend is clearly visible in Figure 6 where archaeobotanical findings from Near Eastern sites are arranged according to age (calibrated ^{14}C-ages) and cultural period; sites are classified into three different categories: (i) use of wild cereals (green); (ii) use of domesticated cereals (blue); and (iii) unclear crop status (black). The archaeobotanical data are taken from Nesbitt (*2002.Tab. 1*), with conventional ^{14}C-ages replaced here (Fig. 6) by calibrated ^{14}C-ages. The crop status-coded sites are shown in context with the Dead Sea level record of Migowski *et al.* (*2006*). Featured sites are located in Southeastern Turkey, Syria, Israel, and Jordan. Within dating errors, the earliest use of genetically changed cereals coincides everywhere in these regions (within *c.* ± 100 yrs, 68%) with the abrupt increase in precipitation as documented in Dead Sea levels. As discussed in the next section of this paper, further correlations should follow from this, and indeed do; for example, the contemporaneous onset of large villages that marks the beginning of the Middle Pre-Pottery Neolithic B (MPPNB) tradition.

Early domestication of goats in the Near East

Following Zeder and Hesse (*2000*), the earliest (culturally) domesticated goats in the Near East are presently known from the site of Ganj Dareh in the Zagros Mountains. This claim is based on a set of twelve AMS ^{14}C-ages on goat bones (Capra hircus aegagrus). As already pointed out by the authors, these ages fall within a remarkably narrow time-window, especially considering that the dated bone samples were collected from five different stratigraphic levels (A to E) of the 7-metre-deep tell settlement.

According to the accumulative ^{14}C-age calibration diagram (Fig. 7), the Ganj Dareh ^{14}C-ages lie in such temporal proximity that it is difficult to further differentiate between the different bone ages on the basis of the given ^{14}C-values. There is good agreement of these ^{14}C-ages with previous AMS-measurements on seeds (hordeum) from the same layers (B, C, D, and E) (Tab. 1). We therefore support the proposal of Zeder and Hesse (*2000*) that site occupation at Danj Dareh must have been brief, probably no more than one or two centuries. As can be deduced from Figure 7, ^{14}C-ages correspond closely with the onset of moist conditions around 10.1 ka calBP, *i.e.* the beginning of the Levantine Moist Period. However, we realise that the existence of a close correlation between any two variables does not prove the existence of a causal relation between them.

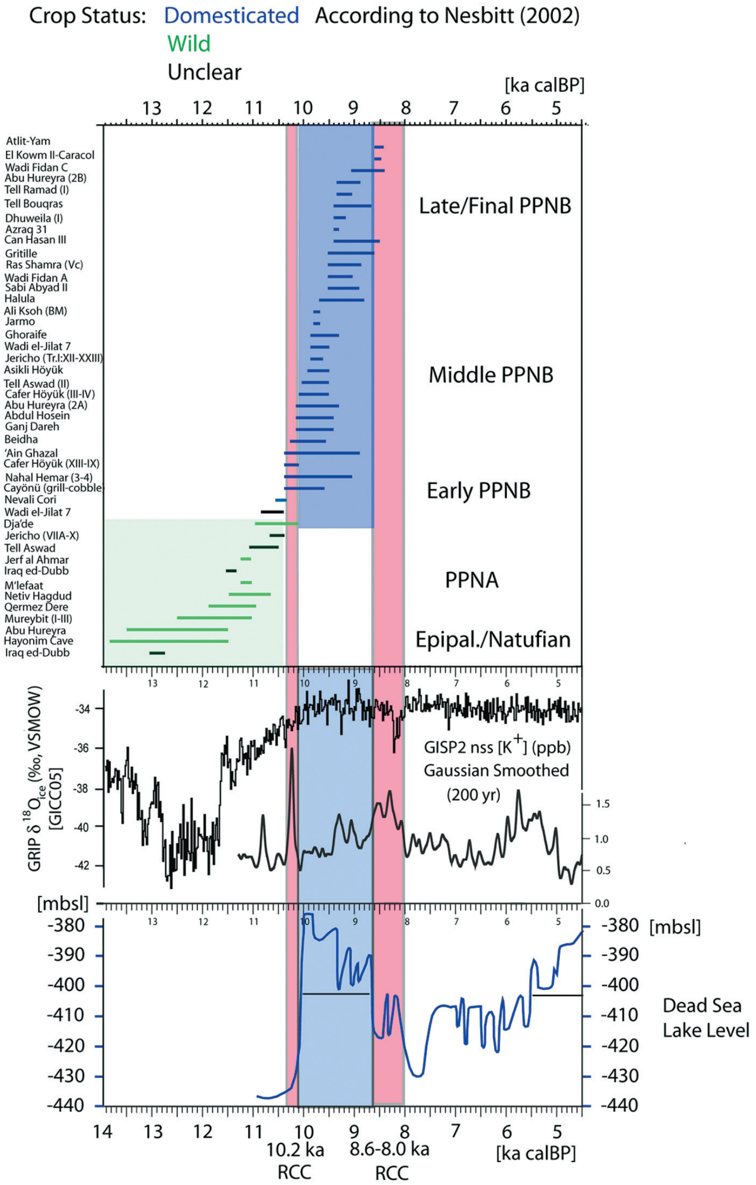

*Fig. 6. Archaeobotanical records for cereals (crop status: wild, domesticated, or unclear) arranged according to site age and cultural periods after Nesbitt (*2002*) compared with Greenland GRIP stable oxygen isotopes (*Grootes et al. 1993*), Greenland GISP2 nss [K$^+$] values (*Mayewski et al. 1997; 2004*) and Dead Sea Lake Levels (*Migowski et al. 2006*). Note: the archaeobotanical data shown here are from Nesbitt (*2002: ebda. Tab. 1*), with the replacement of conventional ^{14}C age values by tree-ring calibrated ^{14}C dates.*

SOCIAL RESPONSES TO RAPID CLIMATE CHANGE

There are good (ethnographically documented) reasons to link (archaeologists seldom say: correlate) the beginning of farming and herding in the Early Holocene in the Near East with major changes in social organisation (*Cauvin 2000; Bar-Yosef 1998; 2001; Kuijt and Goring Morris 2002; Nesbitt 2002*). To date, however, researchers have been reluctant to add the next link, *i.e.* that between social organisation, based on domesticated animals and plants, and the supporting climate conditions. According to contemporary archaeobiological modelling, significant social changes are to be expected when mobile and semi-sedentary lifestyles based on hunting and gathering are replaced by farming and herding in permanent settlements. Since plant domesticates have nutritional advantages, and these advantages can be optimised in combination with animal husbandry, it is further to be expected that the transition from gathering to cultivating will be accompanied by local population growth.

It is significant that once domesticated cereals and animals have become available, farming communities can literally take these resources (plants, animals) and carry them into regions far beyond those parts in which their wild forms occur. In theory, all of these factors acting together, *i.e.* the adaptation of agriculture and active animal management, *should* lead to major demographic growth on a supra-regional scale. There are, of course, questions that remain unanswered. Did this envisaged population growth really occur, and – if so – where and under which cultural, economic and religious circumstances; and how can we best measure prehistoric population size?

A review of contemporary studies on these major issues of prehistoric research in the Near East confirms the above expectations to some extent, but only to first-order and with varying degrees of uncertainty and ambiguity. For example, according to recent studies on animal domestication in SE Turkey (*Ilgezdi 2008*), there is evidence from Çayönü, as well as from Nevali Çori and Göbekli Tepe, that the establishment of these early permanent villages did not depend on animal domestication, nor on crop cultivation. For an extended time period the economies of these sites were based on hunting wild animals and gathering wild crops. We may also expect major site-specific differences, depending on site function. For example, at religious centres an extended use of hunted game would be understandable, given that people tend to keep to old traditions. There are presently only a few sites which have supplied sufficient ^{14}C-data to study such questions. We take a closer look at the site chronology of Çayönü below.

Strongly effecting our present RCC-forecasting is the fact that it is impossible to separate the 10.2 ka calBP GISP2 nss [K$^+$] RCC peak from the onset of LMP. In addition to the statistical (^{14}C-measurement) as well as ^{14}C-age calibration errors for the LMP-onset, we must allow for errors in the GISP2-age model. To simplify the discussion, in the following we define the RCC/LMP time slot as an error-prone (±100 years, 68%) combined age marker of ~10.1±0.1 ka calBP. This does not imply that both processes are synchronous. It is simply not yet possible to separate them in time. Strictly speaking, we do not even know their order.

NEAR EASTERN EARLY HOLOCENE CULTURAL DEVELOPMENT

Having completed the presentation and discussion of the RCC proxies, in the second section of this paper we turn to archaeological case studies, in chronological order, from old to young. The case studies are further assembled geographically and cover selected study areas; we begin in the Levant (Jordan, Syria, SE-Turkey, Cyprus) where our first focus is the 10.2 ka calBP RCC event. Subsequently, for the younger RCC-events we move ever westwards, through Turkey, Greece, Bulgaria, and finally to Romania.

Near Eastern Early Holocene chronology

All the studies in this paper are based on a large archaeological radiocarbon database for the Epipalaeo-

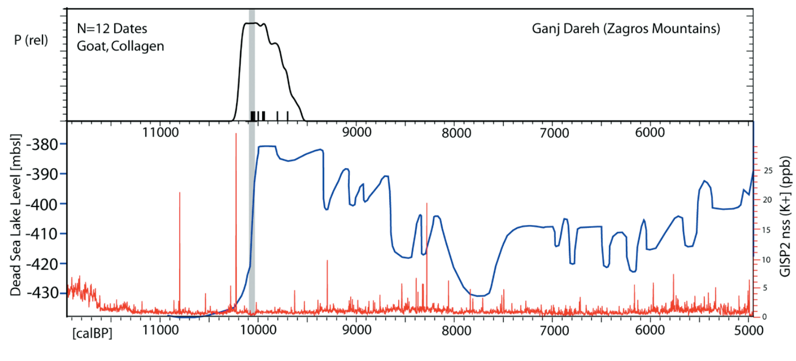

Fig. 7. Radiocarbon Data from Ganj Dareh (Zagros Mountains, NW-Iran) for the earliest (known) domesticated goats (*Zeder and Hesse 2000*), shown in comparison to Dead Sea (Jordan) Lake Level record (*Migowski et al. 2006*) and Greenland GISP2 ice-core nss [K$^+$] chemical ions (*Mayewski et al. 1997*). The shaded area indicates good temporal agreement between the first appearance of domesticated goats in NW-Iran and the onset of the Levantine Moist Period (see text). Additional ^{14}C-ages on charcoal and short-lived seed samples from Ganj Dareh (not shown in this figure) are given in Tab. 1. Note the extreme depth (more than 7m) of the Ganj Dareh stratigraphy in comparison to the small spread of ^{14}C-ages.

lithic and Neolithic in the Near East and SE-Europe that currently includes 14 627 ^{14}C-ages of which 65% are georeferenced (*cf.* Appendix). The ^{14}C-database contains N = 1856 different (usually multi-period) georeferenced sites. Databases of this kind are never complete. However, due to large-scale collection by a number of researchers working independently (*Housley 1994; Görsdorf and Bojadžiev 1996; Gérard 2001; Bischoff 2004; Bischoff et al. 2004; 2005; Rollefson pers comm 2002; Reingruber et al. 2004; 2005; Thissen 2004; Thissen et al. 2004; Weninger et al. 2006; Böhner and Schyle 2009*) we may now, for all practical purposes, uphold a claim of relative completeness.

Figure 8 provides a chronological overview of the contents of this database with respect to the Early Holocene in the Levant. The ^{14}C-ages are arranged according to country (Jordan, Israel and Palestine), with further grouping after currently defined cultural periods (Natufian, PPNA, EPPNB, MPPNB, LPPNB, and PPNC/Yarmoukian).

Since the Natufian is always found below PPNA accumulations in archaeological stratigraphies, the apparent temporal overlap of Natufian and PPNA is caused by dating errors.

Figure 9 provides a set of maps showing the geographical distribution of major sites assigned to these various cultural units. The majority of these sites have supplied either large or (mainly) small sets of ^{14}C-ages. For historical reasons (*i.e.* early excavation), however, many of these archaeological ^{14}C-data sets are characterised by unsatisfactory properties, *e.g.* in terms of limited dating precision, frequent selection of long-lived (charcoal) samples, inadequate chemical pre-treatment of bone, and the often incomplete – and in some cases even entirely absent – archaeological and archaeobiological sample documentation. Nevertheless, as is indicated by Figure 8, it is possible to construct a reasonably well- constrained regional and temporal-cultural periodisation for the early Holocene in the Near East via larger-scale archaeological, cartographic, and statistical processing of ^{14}C-dating probability (Methods: Appendix). In archaeology, as in palaeoclimatological research, questions of dating are inevitably often the most crucial. Some of the more specific dating problems will be discussed in the course of the following RCC case studies.

Lab Code	^{14}C-Age (BP)	Material	Species	Level	Depth (cm)+	Reference
Beta–108238	8780 ± 50	bone collagen	goat	A	180–200	Zander and Hesse (2000.*Tab. 1*)
Beta–108239	8930 ± 60	bone collagen	goat	B	165–180	Zander and Hesse (2000.*Tab. 1*)
Beta–108240	8780 ± 50	bone collagen	goat	B	220–240	Zander and Hesse (2000.*Tab. 1*)
Beta–108241	8720 ± 50	bone collagen	goat	B	240–260	Zander and Hesse (2000.*Tab. 1*)
Beta–108242	8940 ± 50	bone collagen	goat	B	280–300	Zander and Hesse (2000.*Tab. 1*)
Beta–108243	8920 ± 50	bone collagen	goat	C	460–480	Zander and Hesse (2000.*Tab. 1*)
Beta–108244	8840 ± 50	bone collagen	goat	D	430–460	Zander and Hesse (2000.*Tab. 1*)
Beta–108245	8940 ± 50	bone collagen	goat	D	580–600	Zander and Hesse (2000.*Tab. 1*)
Beta–108246	8870 ± 50	bone collagen	goat	E	580–585	Zander and Hesse (2000.*Tab. 1*)
Beta–108247	8830 ± 50	bone collagen	goat	E	665–675	Zander and Hesse (2000.*Tab. 1*)
Beta–108248	8900 ± 50	bone collagen	goat	E	700–710	Zander and Hesse (2000.*Tab. 1*)
Beta–108249	8840 ± 50	bone collagen	goat	E	765–770	Zander and Hesse (2000.*Tab. 1*)
OxA–2102	8690 ± 110	charred seeds	hordeum	E	GD.F1.136	*Housley 1994*
OxA–2099	8840 ± 110	charred seeds	hordeum	B	GD.F1.70	*Housley 1994*
OxA–2101	8850 ± 100	charred seeds	hordeum	D	GD.F1.70	*Housley 1994*
P–1488	8888 ± 98	Charcoal	n.d.	B	–2,10 to –2,40 m	*Lawn 1970*
P–1484	8968 ± 100	Charcoal	n.d.	D	–6,20 m	*Lawn 1970*
OxA–2100	9010 ± 110	charred seeds	hordeum	C–D	GD.F1.110	*Housley 1994*
P–1485	9239 ± 196	Charcoal	n.d.	C	–4,50 m	*Lawn 1970*

* This list does not include the (clearly aberrant) measurements of the SI- and GaK-laboratories. The complete set of Ganj Dareh ^{14}C-ages is given in Böhner and Schyle (2009).
+ In Zander and Hesse (2000.*Tab. 1*) the depth scale is erroneously given as 'mm'.

Tab. 1. Radiocarbon Dates on animal bones from Ganj Dareh, NW-Iran (34°27' N, 48°07' E), shown by metrical analysis to be from domesticated goat (**Capra Hircus Aegagrus*****), (*****Zander and Hesse 2000*****). This list includes complementary* ^{14}C-data from Ganj Dareh, (not shown in Figure 7). Note the good agreement between ^{14}C-ages on short-lived seed samples and on short-lived animal bones for all phases (B, C, D, E).***

Natufian

In the Near East, the transition from a Palaeolithic mobile hunter-gatherer to more sedentary forms of settlement with horticulture can be traced back to the late Pleistocene and the pre-agricultural villages of the Early Natufian. This is a pan-Levantine cultural and economic complex that is generally characterised by the occurrence of well-established sedentary communities in the moister zones of modern-day Israel, with seasonal camps in the Negev, in the Jordan Valley and the Damascus basin. Natufian sites are also known from Syria. Important Late Natufian deposits, rich in plant remains, have been excavated at Abu Hureyra and Mureybet in the Middle Euphrates region. Otherwise, the preservation in most Natufian sites, and in spite of the practice of floatation, did not provide botanical remains, but a considerable amount of fauna. The great paucity of plant remains from these sites explains why we have so few ^{14}C-AMS dates for the Natufian. The dependence of present dating on bulk charcoal (that may contain clay with a certain amount of old carbon), as well as on bone samples (that are often contaminated by carbonates) may explain the apparent overlap between the Natufian and the PPNA (Fig. 8). Quite remarkably, the Natufian is unknown in Southeastern Turkey.

Researchers have often noted that the Early Natufian evolved under the favourable (warm, moist) conditions of the Last Interstadial (Bölling-Alleröd, *c.* 14 500–12 900 calBP). In comparison, the Late Natufian is very much contemporaneous with the colder and drier conditions of the *Younger Dryas* (*e.g. Bar-Yosef 1998*). Regarding these questions, however, caution is advised, particularly as the periods known as Bölling, Alleröd, and *Younger Dryas* are primarily defined with reference to Northern European vegetation patterns. Given the lack of high-resolution palynological proxies in the Near East, it remains questionable whether similar definitions can be applied. Notwithstanding, palynological studies do suggest a significant decrease of rainfall over the entire region during the (Levantine) *Younger Dryas* (*Bar-Yosef 1998.161*, with references; *Willcox et al. 2009*).

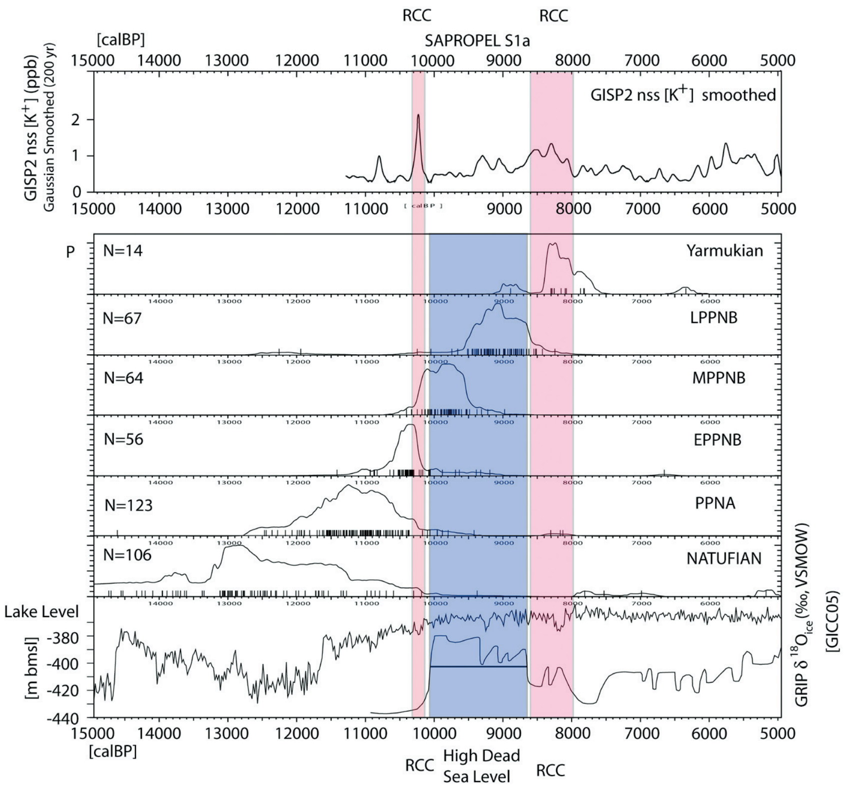

Fig. 8. Upper: Greenland GISP2 nss [K+] values (*Mayewski et al. 1997; 2004*). Middle: Schematic Early Holocene Cultural Chronology in West Asia based on grouped calibrated ^{14}C-ages (*cf. *Appendix I, Radiocarbon Database). Abbreviations: (PPNA): Pre-Pottery Neolithic A, (E-M-L PPNB): Early-Middle-Late Pre-Pottery Neolithic B. Lower: NGRIP stable oxygen isotopes with GICC05 age model (*Rasmussen et al. 2006*); Dead Sea Levels (*Migowski et al. 2006*). Blue shading shows high Dead Sea Levels (called Levantine Moist Period, LMP, *cf. *text); red shading shows 10.2 ka and 8.6–8.0 ka calBP RCC.

During this period, many of the observed changes in subsistence patterns do appear to be under climatic control, albeit with strong regional components. For example, towards the end of the Natufian, there is a generally downward trend in settlement density, but which (i) in the Levantine corridor is associated with a notable increase in gazelle hunting; and (ii) in the Negev is accompanied by evidence for newly emerging foraging groups, known as the Harifian culture (*Goring-Morris 1991*), specialising in plant collection in combination with a broad spectrum of hunting activities.

Pre-pottery Neolithic A (PPNA)

Following the Natufian, and prior to the onset of the Pre-Pottery-Neolithic (PPN) *sensu strictu*, the existence of a transitional phase linking these

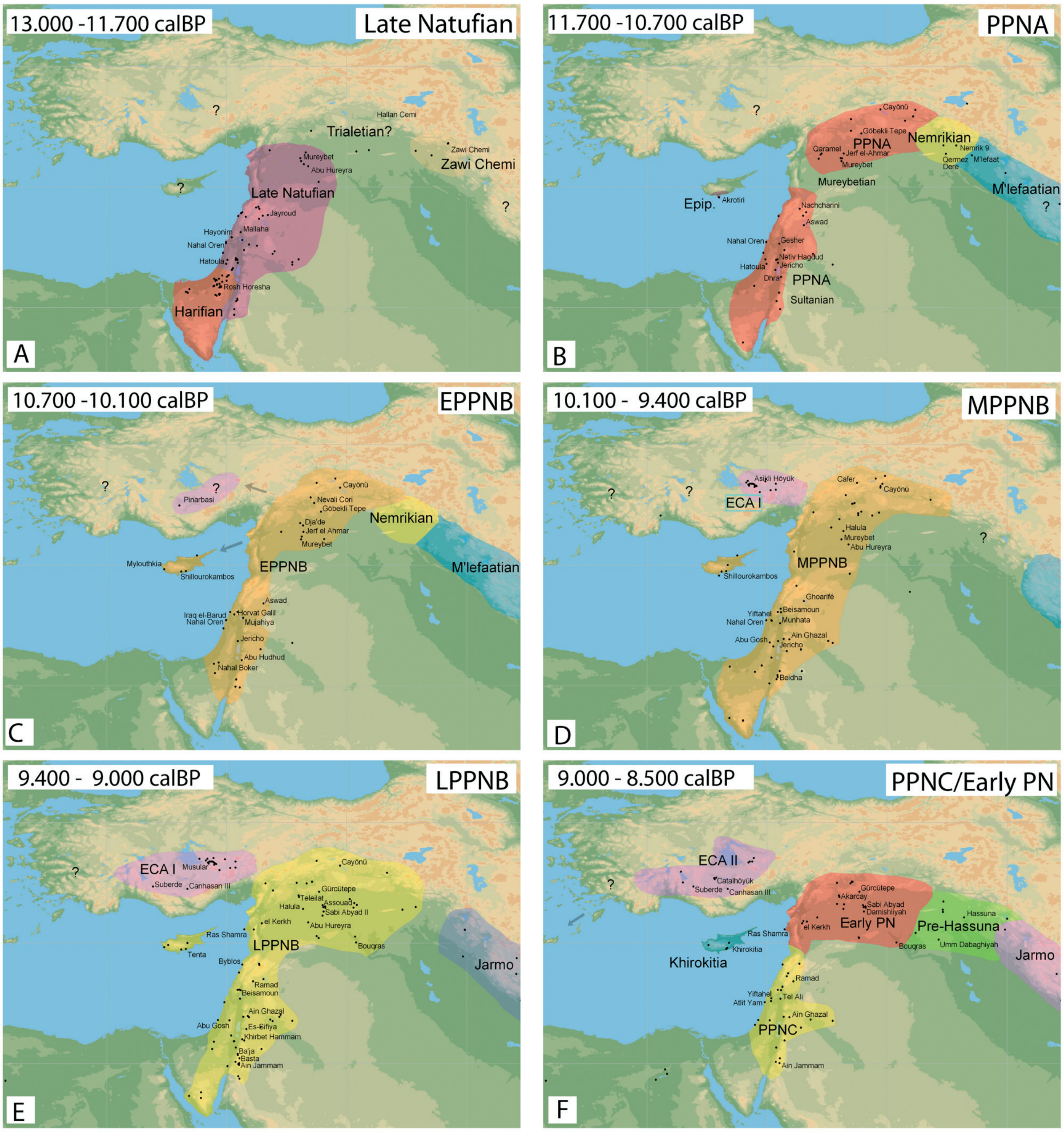

Fig. 9. Geographic distribution of cultural units and archaeological sites referenced in the text: (A): Late Natufian, (B): PPNA = Pre-Pottery Neolithic A, (C): EPPNB = Early Pre-Pottery Neolithic B, (D): MPPNB = Middle Pre-Pottery Neolithic B, (E): LPPNB = Late Pre-Pottery Neolithic B, (F): PPNC = Pre-Pottery Neolithic C, Early PN = Early Pottery Neolithic. Further acrynms: Epip = Epipalaeolithic, ECA = Early Central Anatolian.

two cultural entities has been postulated, the so-called Khiamian. It is considered a short term phenomenon that, together with the ensuing Sultanien, is incorporated under the term PPNA. In the northern Levant the two are more clearly separated in the Mureybet excavations, and are therefore not included under the general term of PPNA (*Ibanez 2008*). As recommended twenty years ago (*Bar-Yosef 1989*), the underlying problems are even today best resolved by subsuming both entities under the term PPNA. When applied to the ^{14}C-database (Appendix), this approach culminates in a prolonged PPNA period with a rather diffuse inception around 12 ka calBP, although with an extended overlap with available Natufian ^{14}C-ages. However, any requested precise dating of the Natufian and Natufian/PPNA transition is immediately confronted with the high standard deviations of available ^{14}C-ages, prevailing doubts as to the chemical integrity of the samples dated, and poor archaeological sampling strategies. Clearly, there is still room for more precise cultural and regional differentiation of the Natufian and PPNA data.

This will be achieved when Natufian sites with good preservation of charred botanical remains are found and excavated.

The long PPNA, as defined here, is found in two distinct regions: in the northern Levant (as 'Khiamian' and Mureybetian) and in the southern Levant (as 'Khiamian' and 'Sultanien'). Major sites in the Middle Euphrates region are Mureybet (with basal layers IB and II), Jericho and Salabiyah IX in the Jordan Valley, and Hatoula in the Judean Hills.

In both regions the PPNA is associated with a decline in Natufian-type microlithic assemblages and the pan-Levantine introduction of new projectile types, so called 'el-Khiam points'. Although they upheld earlier building traditions (*i.e.* round or oval structures) from the Natufian and Khiamian, PPNA communities certainly invested more energy and materials than their forefathers in house building. Circular and oval stone foundations continued to be the standard shape of the domestic unit, but quarrying clay and hand moulding plano-convex bricks for the walls, as well as mounting flat roofs that required supporting posts, represent increased investment in creating a human space (*Bar-Yosef 1989*). Some settlements show a clear subdivision of settlement space, including storage facilities. In addition to these staples of PPNA architecture, there occur some very significant developments: for example, the appearance of rectangular shaped buildings at Mureybetian sites, the development of monumental religious architecture in SE Anatolia (*Schmidt 2006*), and the construction of the massive encircling wall and tower at Jericho.

In contrast to its ill-defined beginnings, the PPNA has a distinctly defined termination at *c.* 10.3 ka calBP (Fig. 8). This is conspicuous, since it correlates with the 10.2 ka calBP RCC cold event. Now, with this preliminary result, as is typical of our explorative approach, we must immediately switch from the given level of cultural study to a more detailed site analysis. The next step would be to identify, for as many sites as possible with given cultural identification, the exact site-position (layer, stratum, phase, architecture) for which further archaeo-climatic studies would appear rewarding. This approach is applied, immediately below, at the sites of Jericho and Çayönü.

Site study: Jericho (Israel)

The tower at Jericho provides our first archaeological RCC study. Measuring 10m in diameter at its base, constructed of unshaped stones to a (preserved) height of *c.* 8.5m, and with an internal staircase, already from the technical aspect this structure was a major feat of Neolithic architectural expertise (Fig. 11). Nevertheless, debate continues concerning its exact function. Whereas its excavator Kathleen Kenyon (*Kenyon 1981.6–8*) believed it to have been part of a defence system, following Bar-Yosef (*1986. 158*) this is unlikely; it was erected against the interior of Jericho's perimeter wall and would have projected inwards, thus resulting in the partial loss of any defensive advantage. Instead, Bar-Yosef proposes that the perimeter wall protected the domestic infrastructure of Jericho against mud flows and flash floods emanating from the cliffs to the west of the site (*Bar-Yosef 1986.161*).

A new look at the available ^{14}C-data (Tab. 2) shows that the transition from PPNA to PPNB at Jericho falls close to the 10.2 ka calBP RCC (Fig. 10). Building on this result, we have applied a more detailed analysis of the ^{14}C-series to identify the exact position of the 10.2 ka calBP RCC within the Jericho site stratigraphy. A subset (Tab. 3) of the Jericho data supplies a stratified series of ^{14}C-ages, as is necessary for the application of the wiggle matching technique. As shown in Figure 12, using a simple linear growth (equidistant 50-year phase length) model to describe the architectural sequence, the seriated ^{14}C-ages are seen to fit well to the ^{14}C-age calibration curve for PPNA Levels IV–IX. Immediately following (*i.e.* prior to PPNB Levels XI–XIV), there appears to be a hiatus in the stratigraphy. At this time – during Level X and dating to ~10.2 ka calBP – the tower finally becomes embedded within the growing settlement debris. Level X, which directly covers the tower, is described by Kenyon (*1981*) as consisting of soft, grey powdery soil. The position of this layer, which is the first layer to completely cover the tower, is indicated in Figure 12.

We conclude that there may be a climatic background to the Level X mud flows that, according to Bar-Yosef (*1986*) gave reason for the construction of a protection wall. Specifically, the mud flows may result from flash-floods in causal connection with the 10.2 ka calBP RCC (*cf.* below; discussion of rubble slides in S Jordan during 8.2 ka calBP RCC). Furthermore, according to the ^{14}C-ages, following Level IX there appears to be a hiatus in the order of ~300 yrs between the PPNA and the PNNB. This is indicated by the fact that the ^{14}C-ages of layers XI–XIV disagree with the above (continuous) linear growth model. They fit the calibration curve better, and then also agree with the 50-year Level model if a ~300 gap is assumed between Levels IX and XI (Fig. 12). Although it is clearly not advisable to over-interpret the precision of these dates from early excavations, the PPNA-PPNB transition at Jericho is an interesting candidate for future geo-archaeological RCC studies.

Pre-Pottery Neolithic B (PPNB)

In general terms, the EPPNB is believed to have evolved in a continuous line of development from the final Mureybetian in parts of northern Syria, whence it dispersed, spreading into southeastern parts of Anatolia (*e.g.* Boytepe, Cafer Höyük, Çayönü, Nevalı Çori, and Göbeli Tepe) in a first expansion phase. At present, Dja'de in northern Syria, and Çayönü in the foothills of the Eastern Taurus feature some of the best investigated EPPNB settlement deposits. Architecture now encompasses rectangular plan buildings, first seen in late PPNA (late Mureybetian) contexts, and which at Çayönü are eponymous for the so-called 'grill plan' phase of the settlement (*Özdoğan 2007*). At Çayönü the stone foundations of these N–S oriented structures are indicative of a clear internal organisation of the buildings in three sections. In their northern part they are characterised workshop for leather working and the production of jewellery. The central part of this area features a room with a hearth which is thought to have been domestic. At their southern end are found three smaller adjacent rooms, possibly used for storage. Stone assemblages are now characterised by the appearance of what are to become typical PPNB tool types. Among the projectiles to appear in this phase are, for example, archaic forms of so-called Byblos points, which in the course of the PPNB take on supra-regional significance; leaf-shaped points; and points with a truncated base. Generally speaking, these projectiles are now larger than earlier pieces, their bases and points thinned by long, flat, parallel removals known as 'lamellar retouch' (*cf. Cauvin 2007.Fig. 25*).

Site study: Çayönü (PPNA-PPNB, southeast Turkey)

As mentioned above, according to recent research in the Near East, the establishment of permanent villages did not necessarily depend on animal domestication nor on crop cultivation. Since at Çayönü there is a long series of ^{14}C-ages available, which not only covers the PPNA-B transition but also the transition from hunting to herd management, it is interesting to take a closer look at the chronology of this site in terms of potential RCC or LMP influence.

For comparison purposes, in Figure 13 we have arranged the radiocarbon data from Çayönü. The data are grouped according to architectural period, and are shown against the GISP2 nss [K^+] RCC proxy and the Dead Sea Lake Levels. For each period the status of animal management (wild, domesticated) and animal species (sheep, goat, pig, cattle) identified by faunal analysis is indicated. From a chronological perspective it is disappointing that no clear separation of the different architectural periods appears. Nei-

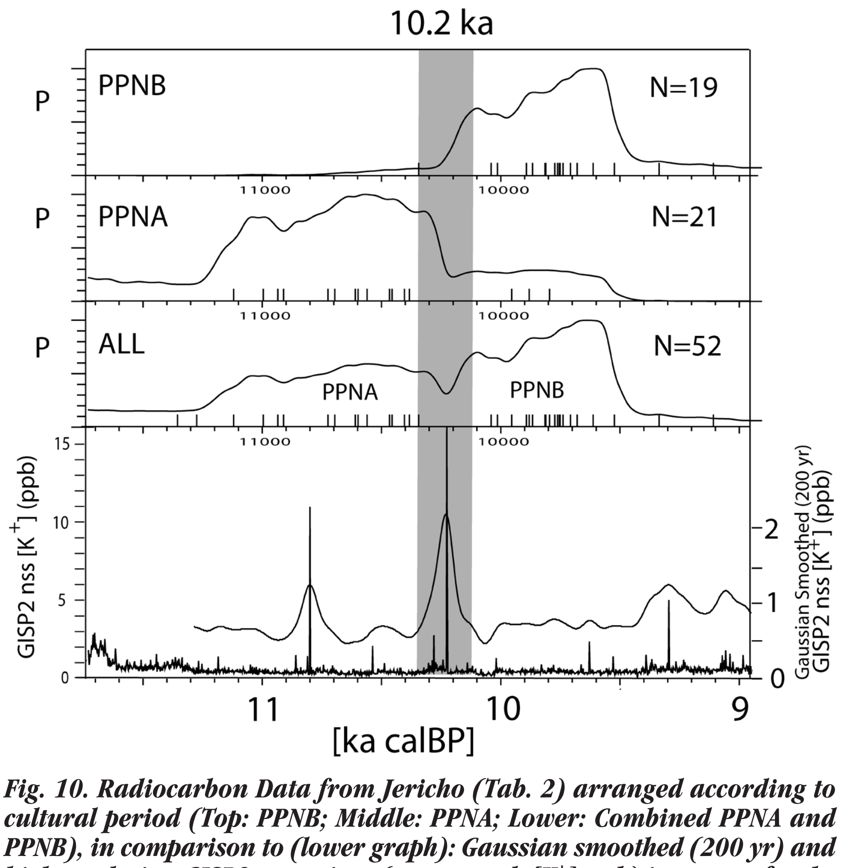

Fig. 10. Radiocarbon Data from Jericho (Tab. 2) arranged according to cultural period (Top: PPNB; Middle: PPNA; Lower: Combined PPNA and PPNB), in comparison to (lower graph): Gaussian smoothed (200 yr) and high-resolution GISP2 potassium (non-sea salt [K^+]; ppb) ion proxy for the Siberian High (*Mayewski et al. 1997; Meeker and Mayewski 2002*). The GISP2 nss [K^+] RCC event at 10.2 ka calBP falls exactly between the PPNA and PPNB layers. The calibrated ^{14}C-age distribution gives reason to assume a hiatus between PPNA and PPNB. Radiocarbon periodisation according to Böhner and Schyle (*2009*), with references for individual ^{14}C-ages given in Tab. 2.

ther do the radiocarbon ages for the earlier architecture (Basal Pits, Round -, Grill-, Channelled Building) respond to the assigned cultural units (PPNA, EPPNB). These architectural changes follow each other so rapidly, within a span of some 400 years, that the available ^{14}C-data do not support their separation. The settlement at Çayönü begins at ~10.6 ka calBP, with no evident connection to given climate data. Following the drop in dating probability around 10.2 ka calBP, the sequence continues with a group of MPPNB ^{14}C-ages centred on the rising Dead Sea Lake Levels at ~10.0 ka calBP. For the younger

Lab Code	^{14}C-Age (BP)	Material	Period	Level-Locus	Reference
BM–105	10 250 ± 200	Charcoal	PPNA	Level IV. iiib	(1),(2),(4),(5)
BM–106	10 300 ± 200	Charcoal	PPNA	Level VI A. x–xi	(1),(2),(4),(5)
BM–110	10 180 ± 200	Charcoal	PPNA	Level IX. xxii–xxiii	(1),(2),(4),(5)
BM–115	9170 ± 200	Charcoal	PPNB	level XII.xlviia	(2),(4)
BM–1320	8539 ± 64	Charcoal	PPNB	level XI. lv	(2),(4)
BM–1321	9226 ± 76	Charcoal	PPNA	level VIII A. xvib	(2),(4),(5)
BM–1322	9376 ± 85	Charcoal	PPNA	level IV A iiib	(2),(4),(5)
BM–1323	9382 ± 83	Charcoal	PPNA	level VI A x–xi	(2),(4),(5)
BM–1324	9427 ± 83	Charcoal	PPNA	level VI xxvii	(2),(4),(5)
BM–1326	9225 ± 217	Charcoal	PPNA	level VIII A. xvib	(2),(4),(5)
BM–1327	9551 ± 63	Charcoal	PPNA	level IV A. iiib	(2),(4),(5)
BM–1401	11 086 ± 90	Charcoal	Late Natufian	level I. ii	(2),(5),(11)
BM–1769	8700 ± 110	Charcoal	PPNB	level XI. lvia	(2),(3),(4)
BM–1770	8680 ± 70	Charcoal	PPNB	level XI. lxa	(2),(3),(4)
BM–1771	8660 ± 260	Charcoal	PPNB	level XIII. lxxxa	(2),(3),(4)
BM–1772	8810 ± 100	Charcoal	PPNB	level XIII. xiv	(2),(3),(4)
BM–1773	8730 ± 80	charcoal	PPNB	level XIV. lxxxvi	(2),(3),(4)
BM–1787	9280 ± 100	charcoal	PPNA	level VIII A. xv	(2),(3),(4),(5),(13)
BM–1789	9200 ± 70	charcoal	PPNA	level IX. xx–xxia	(2),(3),(4),(5),(13)
BM–1793	8660 ± 130	charcoal	PPNB	level XIV. xxxvii	(2),(3),(4)
BM–250	10 300 ± 500	charcoal	PPNA	area D I	–
BM–251	9390 ± 150	charcoal	PPNA	area D II	(6)
BM–252	9320 ± 150	charcoal	PPNA	area D I	(6)
BM–253	8710 ± 150	charcoal	PPNB	area E I, II, V	(6)
GrN–	8900 ± 70	charcoal	PPNB	area F I	(14)
GrN–	8785 ± 100	charcoal	PPNB	area F I	(14)
P–376	11 166 ± 107	charcoal	Late Natufian	level I. ii	(2),(5),(10),(11)
P–377	9582 ± 89	charcoal	PPNA	area E I, II, V	(10)
P–378	9775 ± 110	charcoal	PPNA	area F I	(10)
P–379	9655 ± 84	charcoal	PPNA	area D I	(10)
P–380	8610 ± 85	charcoal	PPNB	area D I	(10)
P–381	8658 ± 101	charcoal	PPNB	area E I, II, V	(10)
P–382	8956 ± 103	charcoal	PPNB	area E I, II, V	(10)

References:

(1) *Barker and Makkey 1963*
(2) *Burleigh 1981*
(3) *Burleigh 1982*
(4) *Burleigh 1983*
(5) *Schyle 1996*
(6) *Barker && 1969*
(7) *Vogel and Waterbolk 1972*
(8) *Kenyon 1959*
(9) *Deevey 1967*
(10) *Stuckenrath 1963*
(11) *Weinstein 1984*
(12) *Zeuner 1956*
(13) *Bar-Yosef 1981*
(14) *Science 128, 1958, 1555*
(15) *BASOR 225, 1977, 1–16*

* This list does not include the (clearly aberrant) measurements of the GL-laboratory.

Tab. 2. Radiocarbon Dates from Jericho, Jordan (31°52'16" N, 35°26'38" E). Data source: Böhner and Schyle (2009).

MPPNB cell building period, only one ^{14}C-age is available. Naturally this value appears isolated. The ^{14}C-sequence ends with another limited number for ^{14}C-ages for the LPPNB Cell/Large Room period.

As mentioned, we must be cautious in our analysis of the Çayönü dates. The stratigraphy at Çayönü is only 2–3m deep. The stratigraphic sequence of (superimposed) building phases is well-established. However, due to the thin deposits the finds taken from the buildings (including ^{14}C-samples) may not in all cases be correctly associated with the building phases. We must allow for this in the radiocarbon analysis. The method is to construct a summed probability distribution for all phases. As shown in Figure 13, by adding the ^{14}C-ages for all phases the effect of any potentially wrong assignments between dated samples and architectural periods is neutralised. The corresponding calibrated ^{14}C-age graph for total (N = 32) samples is named 'Çayönü All Dates'. Similar to Jericho (Fig. 12), the accumulated sequence of ^{14}C-ages from Çayönü shows signs of a short break between the EPPNB (Channelled Building) and initial MPPNB phases (Cobble Paved Building).

What is more interesting, however, is that a consistent set of N = 7 ^{14}C-ages from the EPPNB-channelled building period offers strong indications of the introduction of (culturally) domesticated animals around 200 years before the 10.2 ka calBP RCC event. This is also prior to the onset of moist conditions during the LMP. The distance of channelled building ^{14}C-ages to the onset of the LMP at 10.0 ka calBP is even larger. We therefore conclude from the data arranged in Figure 13 that at Çayönü the earliest appearance of (culturally) domesticated animals (sheep, goat pig, cattle) occurs some 200 years prior to the RCC/LMP marker. As a reminder, since the sharp 10.2 ka calBP RCC-peak and the onset of LMP around 10.0 ka calBP are difficult to separate with any confidence, we have assigned a date of ~10.1 ka calBP to the combined RCC/LPM marker (see above). As shown in the following, similar results are obtained on Cyprus.

Site study: Mylouthkia (Cyprus)

Although the presence of Epipalaeolithic hunters on Cyprus is clearly attested at Akrotiri Aetokremnos (*Simmons 1991*), this first colonisation of the island has proven extremely difficult to date by the radiocarbon method. As shown by detailed statistical analysis (*Manning 1991*), the large majority of ^{14}C-dated bone samples from this site are contaminated to such an extent that it is impossible to provide more than an educated guess as to the correct age of the samples (*Simmons 1991*). Nevertheless, the excavations at Aetokremnos are important, even without secure site chronology, since the faunal assemblage at this site includes dwarf hippopotamus and pygmy elephant. These animals are not found at later Neolithic sites. Conversely, Aetokremnos contains none of the animal species (cattle, goats, sheep, pig) later attested for the Neolithic occupation *e.g.* at Shillourokambos and Mylouthkia. This lends support to the notion that all domesticates were brought to the island on boats from the mainland.

It is of immediate interest for RCC-research to establish whether the earliest communities on Cyprus reached the island before or after the onset of RCC/

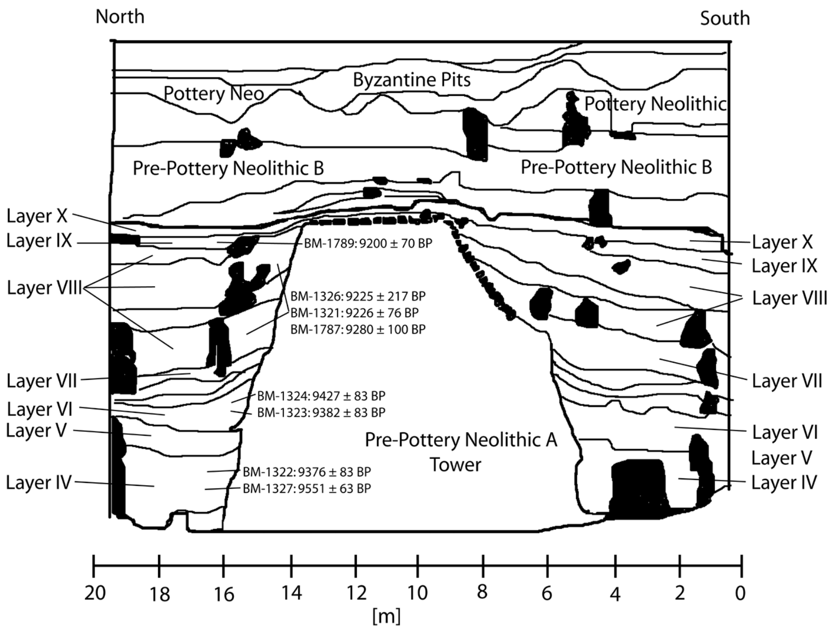

Fig. 11. Schematic Representation of Pre-Pottery Neolithic B Tower at Jericho, redrawn and simplified from Kenyon (*1981.Pl. 238*), with projection of ^{14}C-ages by stratigraphic layer, as provided in Table 2. This diagram is used as the basis for applying a simple linear growth (equidistant 50-yr phase length) model to the stratified ^{14}C-ages, with wiggle matching results shown in Figure 12. In Layer X, the PPNA tower is covered by soft, grey powdery soil (*Kenyon 1981.Pl. 238*), which may have been deposited by mudflows (*Bar-Yosef 1986*) during the 10.2 ka calBP RCC (see text).

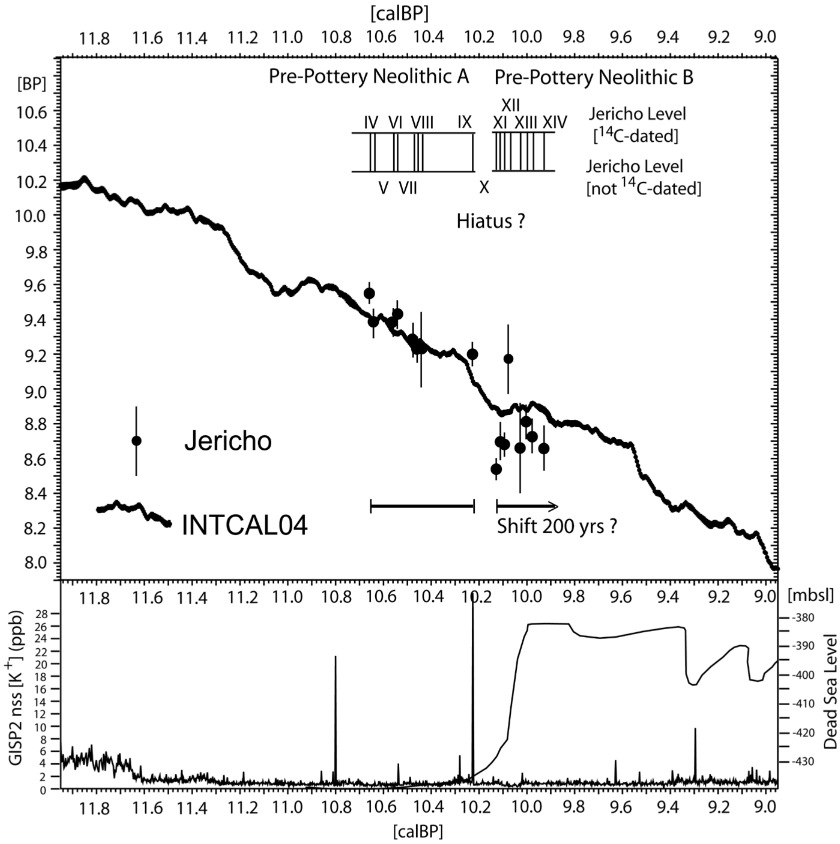

Fig. 12. Upper: Stratigraphic Wiggle Matching Radiocarbon Data from Jericho based on linear continuous growth model with Phase length of 50 yrs. This model is confirmed in terms of group for older Levels IV–IX (PPNA), and for younger Levels XI– XIV (PPNB), but with stratigraphic hiatus at Level X. The younger data group for Levels XI–XIV (PPNB) fits better to the calibration curve, when shifted en bloc younger by ~300 yrs. Lower: Greenland GISP2 nss [K+] values (**Mayewski et al. 1997; 2004*****) and Dead Sea Lake Levels (*****Migowski et al. 2006*****). Note that the hiatus in Level X is synchronous, within error limits of ~ ± 100 yrs (95%), with the 10.2 ka calBP RCC event. The PPNB site re-occupation following the hiatus is synchronous with the onset (or early part) of the Levantine Moist Period.***

LMP. Archaeological data relevant to this question are provided by excavations at Kissonerga-Mylouthkia and Parekklisha-Shillourokambos (*Peltenburg et al. 2000; Peltenburg 2004*). Both sites show features that are typical of sedentary (farmer-herding) communities (*e.g.* post hole alignments, palisade trenches), and – at Mylouthkia – the construction of two wells. According to the available ^{14}C-ages (Fig. 14; Tabs. 5, 6) processed on short-lived plant remains, the two wells at Mylouthkia (well Nr. 116 and well Nr. 133) are of very different age. Interestingly, well Nr. 116 appears to have been in use prior to the 10.2 ka calBP RCC event, whilst well Nr. 133 post-dates this RCC. Whether the emerging gap (>200 yrs?) between the two wells has any relation to the 10.2 ka calBP RCC event remains to be established. According to Peltenburg *et al.* (*2000*), the well Nr. 116 at Mylouthkia is contemporary with the Early A phase at Shillourokambos. Well Nr. 133 is expected to be contemporary with the Shillourokambos Late Phase.

The establishment of sedentary Neolithic communities on Cyprus at such an early time has aroused considerable interest in the archaeological community. We conclude that the appearance of (culturally) domesticated animals and cereals at Mylouthkia and Parekklisha occurred at least 100 years prior to the combined ~10.1 ka calBP RCC/LMP marker, and are therefore probably not intrinsically related to RCC-conditions.

Site study: 'Ain Ghazal (Jordan)

'Ain Ghazal ('Spring of the Gazelles') lies on the northeastern outskirts of Amman, Jordan. It is one of the largest prehistoric sites in the Near East and was excavated extensively between 1982 and 1989, and again from 1993 to 1998 (*Rollefson et al. 1992; Rollefson and Kafafi 2000*). The settlement lies at the intersection of several major ecological zones, including galleria forests of the Zarqa River valley, open woodland and forest, steppe, and desert; the modern isohyet at the site is *c.* 250mm, which places it at the limit of rain-fed agriculture, although in the early Neolithic, annual rainfall was probably significantly higher. The main settlement is located on a weakly inclined Pleistocene slope on the west bank of the river. This terrace-like position marks a geomorphologic exception to the generally steep slopes of the Zarqa River valley; it would have been favourable to an agrarian/pastoralist economy, especially due to the strong eponymous spring provided a year-round water supply for the residents.

The sequence of ^{14}C-ages from 'Ain Ghazal (Fig. 15) indicates that the settlement was founded around 10 200 years ago, at the beginning of the MPPNB (*cf.*

Fig. 8). Based on full-fledged cereal and pulse agriculture and goat herding (*von den Driesch und Wodtke 1997; von den Driesch 1999*), the site grew in terms of size and population during the MPPNB by up to around five hectares by the end of the period. But at around 9500 calBP the settlement size suddenly doubled (within a few generations), and the succeeding LPPNB population grew to around 3000 people or more, and covered between 14–15 hectares on both banks of the river. The LPPNB subsistence economy expanded to include domesticated sheep (*von den Driesch und Wodtke 1997; von den Driesch 1999; Wasse 1997*). At some time around 9000 calBP the site decreased in size as dramatically as it had grown only 400–500 years earlier, reduced to around 5 hectares during the PPNC period. During the following Yarmoukian culture of the Pottery Neolithic period the village continued to decrease in size and population, and eventually the site no longer supported a permanent farming population of any size, replaced instead by periodic visits to the spring by Yarmoukian pastoralists.

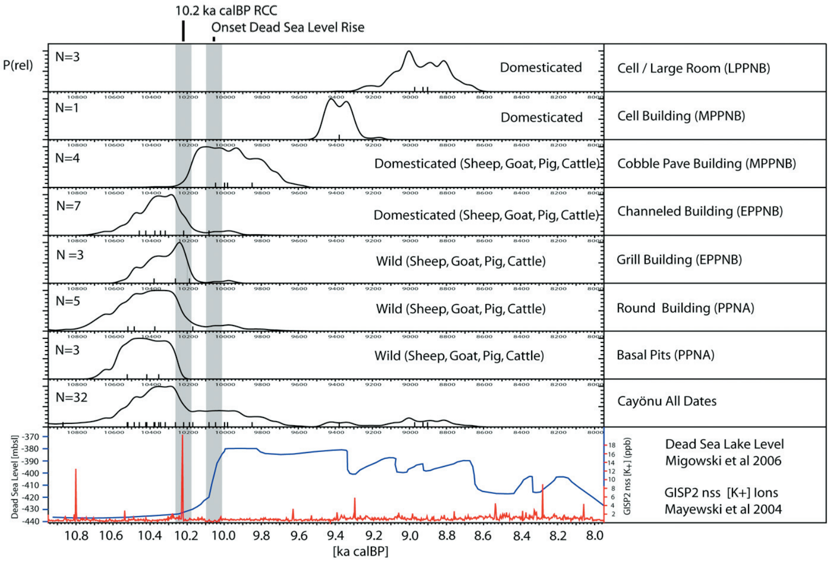

Fig. 13. Upper: Radiocarbon Data from Çayönü, arranged according to architectural periods, from old to young: Basal Pits, Round Building, Grill Building, Channelled Building, Cobble Paved Building, Cell Building, Cell/Large Room, with indication of animal management status (wild or domesticated) according to Ilgezdi (2008). Lower: Greenland GISP2 nss [K⁺] values (**Mayewski et al. 1997; 2004*****) and Dead Sea Lake Levels (*****Migowski et al. 2006*****).***

After the Yarmoukian, the site was completely deserted until the Byzantine period, when a field house was built on the slope of the west bank.

From Figure 15 it becomes apparent that permanent settlement at 'Ain Ghazal became established immediately following the onset of high Dead Sea Water Levels (~10.0 ka calBP). Following some 1700 years of continuous occupation, the site was deserted; it

Lab Code	^{14}C-Age (BP)	Material	Level	Distance (yrs)	Results: Age (calBP}
BM–1793	8660 ± 130	charcoal	XIV	0	9978
BM–1773	8730 ± 100	charcoal	XIV	50	10 028
BM–1772	8810 ± 100	charcoal	XIII	25	10 053
BM–1771	8660 ± 260	charcoal	XIII	25	10 078
BM–115	9170 ± 200	charcoal	XII	50	10 128
BM–1770	8680 ± 70	charcoal	XI	16	10 144
BM–1769	8700 ± 110	charcoal	XI	17	10 161
BM–1320–	8539 ± 64	charcoal	XI	17	10 178
not dated		**Hiatus**	**Level X**	**300 yr gap**	**continuous –> 300 yr gap**
BM–1789	9200 ± 70	charcoal	IX	100	10 278 –> 9978
BM–1326	9225 ± 217	charcoal	VIII	16	10 492 –> 10 192
BM–1321	9226 ± 76	charcoal	VIII	17	10 509 –> 10 209
BM–1787	9280 ±100	charcoal	VIII	17	10 526 –> 10 226
BM–1324	9427 ± 83	charcoal	VI	66	10 592 –> 10 292
BM–1323	9382 ± 83	charcoal	VI	17	13 609 –> 10 309
BM–1322	9376 ± 85	charcoal	IV	83	10 692 –> 10 392
BM–1327	9551 ± 63	charcoal	IV	17	10 709 –> 10 409

Tab. 3. Jericho. Stratigraphic Age Model used for ¹⁴C Wiggle Matching (Fig. 12). Linear 50 yr Levels. Outliers BM-206-205-210 (Tab. 2) excluded. A hiatus may exist between Levels IX and XI. Levels XI–XIV is likely to date ~300 yrs younger than calculated for a continuous occupation model.

Lab Code	^{14}C-Age	Material	Period	Cöyönü Phase	Locus	Ref.
GrN–10358	9180± 80	charcoal	PPNA	Round Building Phase	building RB, KE 6–1	(1)
GrN–10359	9050 ± 140	charcoal	PPNA	Round Building Phase	building RB, KE 6–5	(1)
GrN–10360	9300 ± 140	charcoal	PPNA	Round Building Phase	level r?, KW 8–1	(1)
GrN–10361	9290 ± 110	charcoal	PPNA	Round Building Phase	building RA, floor KW 6–5	(1)
GrN–13947	9240 ± 90	charcoal	EPPNB	Channelled Building Phase	ch1–4	(2)
GrN–13948	8910 ± 50	charcoal	MPPNB	Cobble-Paved Building Phase:	square 19M, hearth	(2)
GrN–13949	9205 ± 45	charcoal	EPPNB	Channelled Building Phase	ch1–4	(2)
GrN–14857	9155 ± 35	charcoal	EPPNB	Channelled Building Phase	square 27L, fire pit	(2)
GrN–14859	9170 ± 50	charcoal	EPPNB	Channelled Building Phase	building DG	(2)
GrN–14860	9040 ± 35	charcoal	EPPNB	Channelled Building Phase	square 20N, fire pit	(2)
GrN–14861	9090 ± 50	charcoal	EPPBN	Grill Building Phase	building GH, outdoor area	(2)
GrN–14862	8920 ± 130	charcoal	MPPNB	Cobble-Paved Building Phase	building BM	(3)
GrN–16462	9040 ± 65	charcoal	EPPNB	Grill Building Phase	building GTc	(3)
GrN–16463	8040 ± 60	charcoal	LPPNB	Cell/Large Room Building Phase:	building EA floor	(2)
GrN–19481	10020 ± 240	charcoal	PPNA	Round Building Phase	square 30M	(2)
GrN–19482	10230 ± 200	charcoal	PPNA	Round Building Phase	square 29M	(2)
GrN–4458	9520 ± 100	charcoal	PPN	–	K–12. unit 12	(4)
GrN–4459	9200 ± 60	charcoal	EPPNB	Grill Building Phase	K 6–9	(4)
GrN–5827	5815 ± 65	charcoal	Chalc.	Dark-Faced Burnished Ware	trench BN (NS)	(5)
GrN–5952	6100 ± 80	charcoal	Chalc.	Dark-Faced Burnished Ware	trench BN (NS)	(5)
GrN–5953	9795 ± 260	soil	PPNA	Round Building Phase	SB 1–3	(5)
GrN–5954	8055 ± 75	charcoal	LPPNB	Cell/Large Room Building Phase:	QC 5,4, fill	(5)
GrN–6241	9275 ± 95	charcoal	EPPNB	Channelled Building Phase	R, 14–0	(5)
GrN–6242	8795 ± 50	charcoal	MPPNB	Cobble-Paved Building Phase	R, 8–2.	(5)
GrN–6243	9320 ± 55	charcoal	EPPNB	Basal Pits	R, 18–1., pit	(7)
GrN–6244	8980 ± 80	charcoal	EPPNB	Channeled Building Phase	EF, 2/1	(5)
GrN–8078	8355 ± 50	charcoal	LPPNB	Cell Building Phase	Hearth, SA 14–17	(5)
GrN–8079	9250 ± 60	charcoal	EPPNB	Basal Pits	Hearth, HA, 24–1	(5)
GrN–8103	10430 ± 80	charcoal	PPNA	Round Building Phase	S, 3–1.	(5)
GrN–8819	8080 ± 90	charcoal	LPPNB	Cell/Large Room Building Phase	Hearth, SE, 12–2	(5)
GrN–8820	8865 ± 45	charcoal	MPPNB	Cobble-Paved Building Phase	BG, hearth, HG, 14–0	(5)
GrN–8821	9175 ± 55	charcoal	EPPNB	Basal Pits	hearth, HA, 25/–1/1	(5)
M–1609 *	8790 ± 250	charcoal	EPPNB	Grill Building Phase	unit K9	(8)
M–1610 *	8570 ± 250	charcoal	EPPNB	Grill Building Phase	K 6–9.	(8)
METU–10 *	9510 ± 100	soil	PPN	–	R–3/4–0.51	(6)
METU–11 *	10480 ± 100	soil	PPN	–	R–5/11/1.10	(6)
METU–13 *	5940 ± 150	soil	–	–	R–3/4–0.51	(6)
UCLA–1703B*	8340 ± 250	human	LPPNB	Large Room Phase	–	(7)
UCLA–1703C*	7620 ± 250	bone	LPPNB	Large Room Building Phase	Ir1–6	(7)

References

(1) *Braidwood 1982*
(2) *Bıçakçı 1998*
(3) *Özdoğan 1999*
(4) *Vogel and Waterbolk 1967*
(5) *Çambel 1981*
(6) *Özbakan 1988*
(7) *Çambel and Braidwood 1980*
(8) *Barker and Mackey 1968*

* Dates not used due to lack of quality control

Tab. 4. Radiocarbon Dates from Çayönü, SE-Turkey (38°13'N, 39°43'E) (*Böhner and Schyle 2009*) with site-phases related to cultural periods as follows: Basal Pits: PPNA, Round Building Subphase: PPNA; Grill Building Subphase: EPPNB; Channeled Building Subphase: EPPNB; Cobble-Paved Building Subphase: MPPNB; Cell Building Subphase: MPPNB; Cell/Large Room Building Subphase: LPPNB; Large Room Subphase: LPPNB; Dark-Faced Burnished Ware horizon: PN.

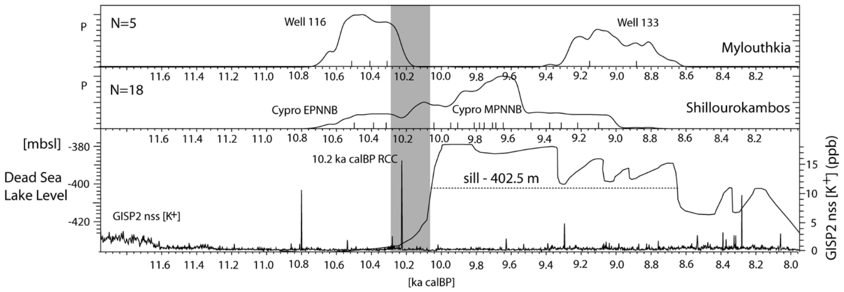

*Fig. 14. Upper: Radiocarbon Dates from Mylouthkia (Tab. 4) and Shillourokambos (Tab. 5), Cyprus. Lower: Greenland GISP2 nss [K$^+$] values (*Mayewski et al. 1997; 2004*) and Dead Sea Lake Levels (*Migowski et al. 2006*). The shaded area covers 10.2 ka calBP RCC and the initial rise in Dead Sea Levels around ~10.1 ka calBP, which are difficult to separate (*cf. *text).*

appears again in direct causal connection with the fall in Dead Sea Levels (~8.6 ka calBP).

In the following, we address the question of whether the abandonment of 'Ain Ghazal at the end of its long settlement may be explained by variability in LMP-levels, or perhaps by the dramatic environmental deterioration that can be recognised in this very period.

ENVIRONMENTAL IMPACT OF RAPID CLIMATE CHANGE ON THE NEAR EAST

Rubble slides in Jordan

In Jordan, a large number of archaeological sites are covered by massive rubble and gravel slides, often to extreme depths (several metres). Although the existence of these slides is well known to Jordanian researchers (see site description, below), their true extent and widespread occurrence in Jordan has only really become clear with the recently published review by Rollefson (*2009*). The list of Neolithic sites with rubble slides known from Jordan is impressive: 'Ain Ghazal, Abu Suwwan, es-Sifiya, Ba'ja, Basta, Wadi Shu'eib and 'Ain Jammam. The complex nature and chronology of Jordanian rubble slides will prove to be an excellent field for the study of the various interacting causes for the formation of rubble slide deposits. Current evidence already warns to concentrate exclusively on RCC explanations and to focus on certain event periods. The formation of rubble slide deposits is co-influenced by local parameters such as drainage catchments and topography, earthquakes, agricultural field clearing activity, intra-site architectural barriers (*e.g.* building terraces), *etc*., indicating the need for geo-morphological investigations accompanying rubble slide research. However, all these parameters may themselves interact with RCC-conditions (*Gebel 2009*).

List of Rubble Slides in Jordan

For reference purposes, there follows a list of sites in Jordan with Rubble Slides according to Rollefson (*2009*, with further details).

● At Wadi Shu'eib, a Yarmoukian site, some 25km to the west of 'Ain Ghazal, Simmons *et al.* (*2001.7*) reported "*a massive sorted layer of cobbles … that roughly separates portions of the Pre-Pottery and Pottery Neolithic layers*". A photo published by Rollefson (*2009*) shows that two rubble events can be discerned.

● The nearby site at Jebel Abu Thawwab also produced a substantial Late Neolithic Rubble Layer. According to Kafafi (*1988.453; cf. Kafafi 2001.17, 32, Pl. 8B*), the Early Bronze and Yarmoukian layers "*were separated by a fill containing large quantities of small stone debris*".

● At the site of 'Ain Rahub, a thick (1.0–1.5m) layer of limestone rubble contains Yarmoukian pottery, and the Yarmoukian occupation may continue below the layer (*Muheisen et al. 1988.493*). 'Ain Rahub is a good example of Yarmoukian rubble slides resulting from interacting wadi terrace formation and col-

Lab Code	^{14}C-Age [BP]	Material	Period	Feature/Locus	Reference
AA–33130	8025 ± 65	n.d.	Cypro-LPPNB	Well 133, loc. 264	*Peltenburg 2000; 2001*
OxA–7561	8185 ± 55	n.d.	Cypro-LPPNB	Well 133, loc. 264	*Peltenburg 2000; 2001*
AA–33129	9110 ± 70	n.d.	Cypro-EPPNB	Well 116 loc. 124	*Peltenburg 2000; 2001*
AA–33128	9235 ± 70	n.d.	Cypro-EPPNB	Well 116 loc. 114	*Peltenburg 2000; 2001*
OxA–7460	9315 ± 60	n.d.	Cypro-EPPNB	Well 116 loc. 124	*Peltenburg 2000; 2001*

Tab. 5. Radiocarbon Ages from Kissonerga-Mylouthkia (Cyprus).

luvial processes by an increased fluvial activity in a V-shaped valley (*Gebel 2009*).

● A further massive layer of rubble (~1m in thickness) is known from the excavations at Tell Abu Suwwan on the southern outskirts of Jerash. This layer contains Yarmoukian pottery (*an-Nahar, pers. comm. to Rollefson 2007*) and overlies some extensive PPN architecture.

● During a survey described by Cropper *et al.* (*2003. 18*) in the region south of Madaba, two sites known as Umm Meshrat I and II were located. Both show a broad distribution of Yarmoukian pottery and typical stone tools. These sites are on a terrace which includes deposits of "*fieldstones and greyish sediment, suggestive of the Yarmoukian 'debris fields' that may be associated with the 8th millennium BP climate shift … identified by Rossignol-Strick*".

● At Basta, a sediment unit up to 2m thick in places is comprised of "*tremendous amounts of detritus and mud flows*" that "*passed through and above the LPPNB layers*" (*Gebel 2003.100, cf. Tab. 1 and Pls. 2B and 2C*). Whilst awaiting further studies on these events, we must note that the excavators have not as yet ascribed the pottery finds either to the Yarmoukian or Jericho IX cultural spheres. At Basta, the slides have been responsible for the excellent architectural preservation at the site, at least in some areas (*Gebel 2003.104*).

● The situation at Ba'ja shows that we are best advised to remain cautious in all interpretations, since here the rubble slide phenomenon shows different facets. At Ba'ja, the rubble layers probably represent earthquake related debris. Earthquake damage might even stem from two separate events that occurred towards the end of occupation at the site. At a later stage, the site then experienced a thick flow (up to 1.5m in thickness) of coarse rubble and gravel with interdigitated fine gravels, all transported by water. It appears that these water-borne sediments did not result from slope collapse, but were caused by flash flooding down the narrow gorge (*Gebel and Kinzel 2007.32*). The temporal sequence of these events remains to be established and represents a major challenge due to the lack of organic materials suitable for radiometric dating.

● To complete the list, we note that evidence for the occurrence of a rubble slide is also available from the settlement at Abu Gosh, at the north-western periphery of Jerusalem. This site has produced evidence for both Pre-Pottery and Pottery Neolithic occupations. The existence of a post-PPN 'stony layer' is mentioned by Ronen (*1971*), and recent geomorphologic analysis suggests that the stony layer is confined to the habitation area itself and is not present in the nearby areas; this would suggest an anthropogenic origin for the material (*Barzilay 2003.7*).

Lab Code	^{14}C-Age [BP]	Material	Period	Feature/Locus	Reference
Ly–292	8125 ± 70	n.d	Cypro-LPPNB	Area 4, Maison 1	*Peltenburg 2000; 2001*
GifA–95032	8230 ± 90	n.d.	Cypro-MPPNB	Area 2, Level 3d	*Peltenburg 2000; 2001*
GifA–95033	8340 ±100	n.d.	Cypro-MPPNB	Area 2, Level 4a	*Peltenburg 2000; 2001*
GifA–95034	8390 ± 90	n.d.	Cypro-MPPNB	Area 2, Level 5	*Peltenburg 2000; 2001*
Ly–928	8495 ± 80	n.d.	Cypro-MPPNB	Area 1, Pit 23	*Peltenburg 2000; 2001*
Ly–1262	8670 ± 80	n.d.	Cypro-MPPNB	Area 1, Pit 23–Level D	*Peltenburg 2000; 2001*
Ly–1261	8735 ± 75	n.d.	Cypro-MPPNB	Area 1, Pit 23–Level C	*Peltenburg 2000; 2001*
Ly–291	8655 ± 65	n.d.	Cypro-MPPNB	Area 1, Level 1ž2	*Peltenburg 2000; 2001*
Ly–929	8700 ± 70	n.d.	Cypro-MPPNB	Area 1, Str. 117	*Peltenburg 2000; 2001*
Ly–6	8725 ±100	n.d.	Cypro-MPPNB	Area 1, Level 1/2	*Peltenburg 2000; 2001*
Ly–289	8760 ± 80	n.d.	Cypro-MPPNB	Sondage 2, Level 5	*Peltenburg 2000; 2001*
Ly–5	8825 ±100	n.d.	Cypro-MPPNB	Area 1, Level 1	*Peltenburg 2000; 2001*
Ly–574	8930 ± 75	n.d.	Cypro-MPPNB	Area 1, Str. 117	*Peltenburg 2000; 2001*
Ly–930	8670 ± 80	n.d.	Cypro-EPPNB	Area 1, Str. 114	*Peltenburg 2000; 2001*
Ly–931	8860 ± 90	n.d.	Cypro-EPPNB	Area 1, Str. 2	*Peltenburg 2000; 2001*
Ly–573	9110 ± 90	n.d.	Cypro-EPPNB	Area 1, F 23–Level B	*Peltenburg 2000; 2001*
Ly–572	9205 ± 75	n.d.	Cypro-EPPNB	Area 1, Str. 66	*Peltenburg 2000; 2001*
Ly–290	9310 ± 80	n.d.	Cypro-EPPNB	Area 1, Level 2, St. 45	*Peltenburg 2000; 2001*

Tab. 6. Radiocarbon Ages from Parekklisha-Shillourokambos (Cyprus).

Dating of the Yarmoukian Rubble Slides

The majority of these slides are dated by embedded Yarmoukian pottery to ~8.6–7.8 ka calBP (available ^{14}C-ages: Tab. 7). Alternatively, expressed in cultural terms, the Yarmoukian slides are dated to the transition from late Pre-Pottery Neolithic B/C (late PPNB/C) to early Pottery Neolithic (early PN). Accepting for the moment that many of these slides occurred 'simultaneously', in principle they could all have been caused by a single large earthquake. This is not even unlikely, since all the listed sites lie in close proximity (*e.g.* 'Ain Ghazal: 40km) to the active Dead Sea Fault, the seismic boundary between the African and Arabian plates. Geological observations show slip rates between these plates in the Jordan Valley in the range of 1 to 20mm per year (*Klinger et al. 2000*). Modern instrumental observations supply mean recurrence intervals for major destructive earthquakes in this region between 400 (Richter Scale Magnitude MR > 6) and 3000 years (MR > 7) (*Begin 2005*). Such earthquake magnitudes and rates of recurrence appear quite sufficient to trigger the observed slope failures, perhaps not everywhere, but surely at those sites for which Rollefson (*2009*) has documented slope declinations larger than 12 degrees. The physical character of the rubble slide at 'Ain Ghazal is illustrated in Figure 17.

Apart from earthquakes, there are other plausible explanations for the rubble slides, none of which we would like to exclude a priori. Acceptable explanations (and combinations of such) include regional environmental degradation due to over-grazing by large herds of goats/sheep, and deforestation due to factors such as Neolithic housing requirements, fuel consumption for domestic purposes, as well as lime-plaster production. Our preferred explanation is that the majority of slides were caused by slope failure due to torrential rainfall and corresponding large-scale water-lifting of slope material (*Weninger 2009*), or as Rollefson (*2009*) puts it, by "*slippery slopes*". Whether this proposal is correct or not, remains to be established, but what makes this specific hypothesis more interesting than many others is the possibility that the Yarmoukian rubble slides represent the local manifestation of broader 8.6–8.0 ka calBP RCC conditions.

Table 7 shows all available ^{14}C-ages for the Yarmoukian period, with the exception of a small number of outliers (AA-25424, AA-5204; GrN-15192). The remaining samples provide us with a small but consistent set of tree-ring calibrated ^{14}C-ages for the Yarmoukian Period, and by inference for the Yarmoukian Rubble Slides. Certainly, not all sites with Yarmoukian settlement feature a Rubble Slide (*e.g.* Sha'ar Hagolan), although it is encouraging that all Yarmoukian sites share ^{14}C-readings within the same time interval: 6300–5900 calBC (8300–7800 calBP).

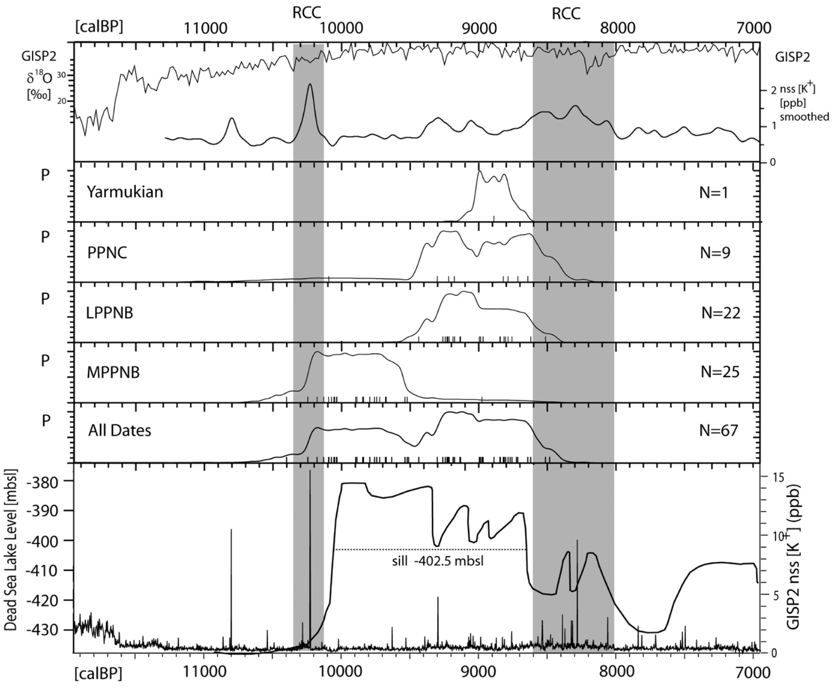

Fig. 15. Radiocarbon Dates from 'Ain Ghazal (Jordan) in comparison to selected climate records. Upper: Greenland GISP2 ice-core $\delta^{18}O$ (*Grootes et al. 1993*), Gaussian smoothed (200 yr) GISP2 potassium (non-sea salt [K$^+$]; ppb) ion proxy for the Siberian High (*Mayewski et al. 1997; Meeker and Mayewski 2002*); Middle: Early Holocene Cultural Chronology of 'Ain Ghazal based on grouped calibrated ^{14}C-ages (*cf. Appendix I, Radiocarbon Database*). Abbreviations: (MPPNB): Middle Pre-Pottery Neolithic B, (LPPNB): Late Pre-Pottery Neolithic B, (PPNC): Pre-Pottery Neolithic C. Note: The overlapping of LPPNB, PPNC and Yarmoukian ^{14}C-dates from 'Ain Ghazal does not correspond to stratigraphic observations at the site. Lower: Greenland GISP2 nss [K$^+$] values (*Mayewski et al. 1997; 2004*) and Dead Sea Lake Levels (*Migowski et al. 2006*).

Explanation for the Yarmoukian Rubble Slides

We propose the following climatic, geographical and meteorological scenarios to explain the Jordanian Rubble Slides. RCC intervals, especially times with exceptionally high GISP2 nss [K^+] values, are characterised by the high occurrence of circumpolar air pressure anomalies similar to those which prevailed in the more recent Little Ice Age. These atmospheric pressure anomalies (record: GISP2 nss [K^+]) are capable of transporting large amounts of cold and dry air from Asia into both the Balkans and adjacent parts on the northern edge of the Aegean. From here, they are channelled southwards across the Aegean Sea, where they are registered as rapid sea surface temperature (SST) variations in the LC21 marine core to the east of Crete. It follows that during this RCC interval (8.6–8.0 ka calBP), extremely cold and arid conditions, together with strong winds in the Aegean, would have prevailed in the Eastern Mediterranean. This scenario is substantiated by the period of extreme drought as documented for this period in the water level data from the Dead Sea. On the other hand, and due to the still very northerly position of the moisture-bearing Intertropical Convergence Zone, at stochastically distributed time intervals in winter or early spring (unforeseeable for the early farming communities) the cold Siberian winds interacted with the moist Mediterranean air masses to produce flashy and intensive precipitation. This is perhaps most clearly recognised in the 'flash-flood' record from the Soreq cave (*Bar-Matthews et al. 2003*). The dried out landscape in the southern Levant, perhaps in combination with widespread human-induced environmental degradation, had little to set against these flash-flood events.

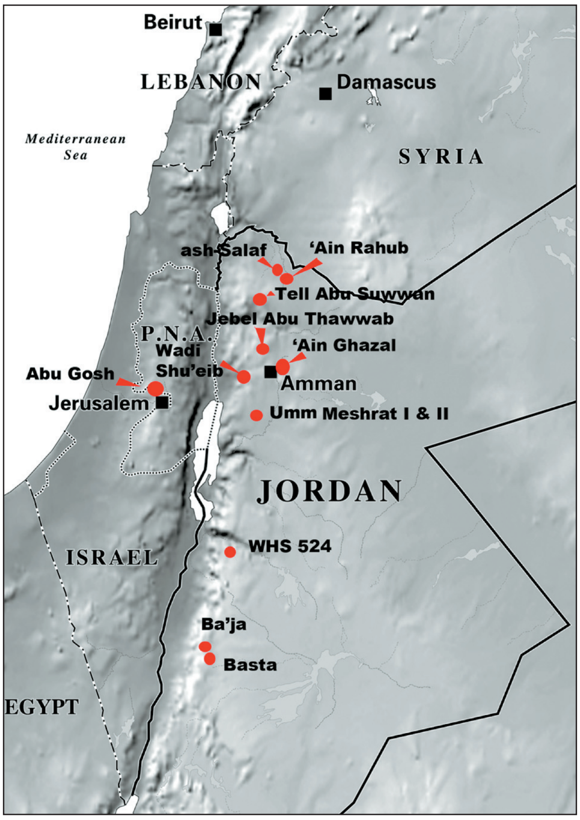

Fig. 16. Distribution of Archaeological Sites with Rubble Slides dating to the Yarmoukian Period in the Southern Levant (**Rollefson 2009*****).***

RAPID CLIMATE CHANGE IN THE KONYA PLAIN (8600–8000 calBP, CENTRAL ANATOLIA)

Site study: Çatal Höyük

In a continuation of previous studies (*Weninger et al. 2006; Clare et al. 2008*), let us now turn again to Central Anatolia to study the impact of the 8.6–8.0 ka calBP RCC at Çatalhöyük. The combined (and quite probably predisposed) extreme social and environmental sensitivity of Çatalhöyük make this site an ideal object for archaeological RCC-research. The settlement is located in a climatically quite sensitive position – in the Konya plain, on the margins of rain-fed horticulture, where even the slightest climate fluctuation could have spelled disaster for subsistence farming (*Christiansen-Weniger 1964*). Çatalhöyük looks back on a long history of research, from the first excavations by James

Lab code	^{14}C Age BP	Material	Site	Age (calBP)
Ly–4927	7330 ± 70	charcoal	Munhata	8150 ± 100
M–1792	7370 ± 400	charcoal	Munhata	8260 ± 420
RT–1544	7050 ± 78	charcoal	Qanah	7870 ± 80
RT–861D	6980 ± 180	charcoal	Qanah	7820 ± 160
OxA–7884	6980 ± 100	charcoal	Sha'ar Hagolan	7820 ± 100
OxA–7885	7270 ± 80	charcoal	Sha'ar Hagolan	8090 ± 80
OxA–7917	7410 ± 50	charcoal	Sha'ar Hagolan	8250 ± 60
OxA–7918	7465 ± 50	charcoal	Sha'ar Hagolan	8290 ± 60
OxA–7919	7495 ± 50	charcoal	Sha'ar Hagolan	8300 ± 70
OxA–7920	7245 ± 50	charcoal	Sha'ar Hagolan	8080 ± 70
OxA–9417	7285 ± 45	Seed	Sha'ar Hagolan	8100 ± 53
AA–25424	8030 ± 65	charcoal	'Ain Ghazal	8890 ± 110
AA–5204	2880 ± 95	charcoal	'Ain Ghazal	3040 ± 130
GrN–14539	7480 ± 90	charcoal	'Ain Rahub	8290 ± 80
GrN–15192	5540 ± 110	charcoal	Abu Thawwab	6340 ± 110

Tab. 7. Radiocarbon Ages for the Yarmoukian Period. Data Source:* Böhner and Schyle 2009*. Possible outliers in italics.

Fig. 17. Rubble Slide at the South Field of 'Ain Ghazal (Photo by Curt Blair).

Mellaart in the early 1960s to the new multidisciplinary project directed by Ian Hodder initiated in the 1990s. The site comprises two settlement mounds – an eastern and a western 'höyük'. Çatalhöyük East was originally settled in the late-10th millennium calBP, and following a long (~1000 yr) period of continuous occupation, was abruptly abandoned at ~8.2 ka calBP. Based on the well-constrained ^{14}C-chronology at Çatalhöyük by dendro-architectural analysis (*Newton and Kuniholm 1999*), we previously argued that the east mound abandonment was likely to have been linked to the onset of cold and dry conditions associated with climate deterioration associated with a major weakening of the North Atlantic ocean circulation (*Weninger et al. 2006*). This explanation was supported by the observation that the adjacent site of Çatalhöyük West was apparently founded ~200 yrs later, at around 8.0 ka calBP. In terms of dating, the transition from the east to the west mound corresponds very precisely to the age and duration of the classical 8.2 ka calBP Hudson Bay event.

This interpretation is substantiated by a large set of ^{14}C-ages from the two Çatalhöyük mounds. Due to the realisation that the 8.2 ka calBP North Atlantic cooling episode is actually superimposed on a globally more extended cooling period – the 8.6–8.0 ka calBP RCC interval (*Rohling and Pälike 2005*) – a re-evaluation of previous conclusions has become necessary (*Clare et al. 2008*). Even so, our findings remain unaltered. Meanwhile, new radiocarbon measurements have been put forward as evidence for continuity between the two settlements (*Higham et al. 2007; Marciniak and Czerniak 2007*). In our view, these new measurements provide yet more supporting evidence for the existence of a glaring 200-year gap that separates the two settlements (Fig. 18).

Let us return to the observation that the classical (Hudson Bay) 8.2 ka calBP event is superimposed on a wider period of climatic deterioration. The GISP2 nss [K^+] RCC record shows an abrupt switch to cooler conditions, the first time at 8.6 ka calBP. The question is whether this switch can be identified in the archaeological data from Çatalhöyük. Interestingly, the RCC-switch at 8.6 ka calBP occurs some four centuries prior to the abandonment of Çatalhöyük East. In terms of the internal architectural sequence, which is still today the best dated due to the dedicated tree-ring studies of Newton (*1993*), it occurs between settlement levels VI and V. Consequently, the evident changes in material culture at Çatalhöyük East for these levels are treated in our previous studies (*Clare et al. 2008*) as characteristic signs of the social, religious and economic impact of the 8.6–8.0 ka calBP RCC. Elsewhere, the same changes are presented as chance social markers for the transition from 'Early Pottery Neolithic' to 'Late Pottery Neolithic' in Central Anatolia (*e.g. During 2002*). Such interpretational differences are certainly not unexpected; changes in complex spheres, such as subsistence, socioeconomic systems and worldview, represent markers of climatic stress just as they do other causes of social variability.

RAPID CLIMATE CHANGE IN SOUTHEASTERN EUROPE (6000–5200 calBP)

General overview

As stated in the introduction, archaeological case studies in this paper are aimed at identifying potential settlement regions, cultural periods and archaeological sites in the Eastern Mediterranean and Southern Europe that show the possible cultural (or environmental) effects of RCC. Having studied the 8600–8000 calBP RCC in the Near East and Anatolia, we now turn to the next younger RCC period. Its time range is 6000–5200 calBP. In southern Europe, this period is associated with the transition from the Final Neolithic (FN) (or Late Copper Age/Late Eneolithic, according to region) to the Early Bronze Age (EBA).

The three main reasons we have chosen Southeastern Europe for archaeological studies on this RCC are: (i) the widely acknowledged and manifest evidence in the regional study areas (Greece, Bulgaria, Romania) for an abrupt collapse of long-standing cultural systems; (ii) this collapse dates to some time around 6 ka calBP; and (iii) this corresponds to the onset of the RCC under study (*cf.* below). We credit this evidence as manifest due to the unusually large number of breaks in the regional cultural sequences, and the quite atypical (extreme) lack of immediately (?) subsequent settlements.

In the following chapters, we analyse the above mentioned system collapse in southeast Europe from within a climatic perspective that (i) utilises high-resolution ice-core data, and (ii) provides a plausible meteorological mechanism for societal change.

6000–5200 calBP RCC-climate history

First, to the RCC-climate history. This can be deduced from a combined view of the courser-scale (200 year Gaussian smoothed nss (K^+] values) and the finer scale GISP2 nss [K^+] raw data (Fig. 1). On the courser scale the 6000–5200 calBP RCC shows a stepwise increase in [K^+] density from 6200 to 5400 calBP, a dip in density at around 5200 calBP, and an abrupt end of high density at 5000 calBP (Fig. 1). On a finer scale (Figs. 23, 24), therefore, this RCC conveys the appearance of a ramp rising continuously from 6200–5400, with a significant dip round 5150 calBP, followed by a second shorter ramp from 5200 to 5000 calBP. Sitting on the long ramp are large free-standing peaks at 6162, 5971, and 5764 calBP. The RCC finishes abruptly with its second largest peak at 4992 calBP. There are other structures in these curves (*e.g.* isolated peaks, grouped oscillations, local bumps). We refrain from further classifying these structures. They support alternative historical RCC descriptions. For example, the 6000–5200 calBP RCC may already have ended at 5200 calBP, and then had a brief renaissance at 4992 calBP. As mentioned in the introduction, the existence of such sub-structures in the GISP2 nss [K^+] record gives reason to approach the social RCC-impact on different levels of the archaeological catchment (*i.e.* regional and site-specific).

Cultural terminology

What first complicates the study of this RCC (and other studies) – and this is generally evident in Southeastern Europe – are regional differences in cultural terminology. In Greece the 6000–5200 calBP RCC interval corresponds to the transition from the Final Neolithic to the Early Bronze Age (Fig. 19). In Bulgaria the same period corresponds to the transition from the Late Eneolithic to Early Bronze Age (Fig. 22). In Romania the multilayer tell sites of the KGK VI Cultural Complex (Karanavo VI–Gumelniţa-Kodjaderman) come to an abrupt end and are replaced by single layer Cernavodã I sites (Fig. 25 a, b). What all chosen study regions have in common is that there appears to be an abrupt finale to an extended (millennial scale) period of cultural continuity and stability. This finale is most evident in widespread site abandonment. But the reasons for any such assumed settlement discontinuity are seldom clear. At many sites the crucial occupation phases are near to the modern surface, where finds are disturbed due to ploughing, and all that remains is a wide scatter of largely non-identifiable sherds.

Problems of site visibility

The poor visibility of surface pottery sherds is well-known from Thessaly, and especially for sites dating to the FN/EBA transition. In other regions, such pure visibility of pottery sherds may simply be due to lack of surveys. In Thessaly, however, thanks to the detailed analyses of settlement patterns and pottery taphonomy by Perlès (*2001*) and Johnson and Perlès (*2004*), it has recently become clear that the lack of surface finds is indeed caused by a drastic decline in population during the FN period. Further, the population decline correlates with a major move away

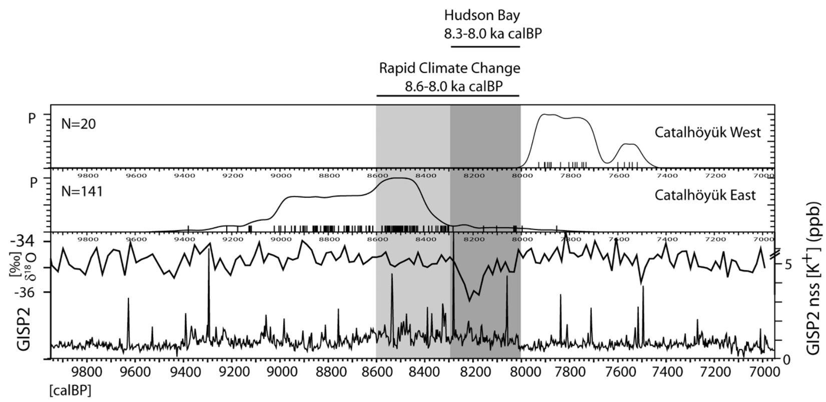

Fig. 18. Radiocarbon Dates from Çatalhöyük (Central Anatolia) in comparison to selected climate records. Upper: ^{14}C-Data from Çatalhöyük West (N = 20), ^{14}C-Data from Çatalhöyük East (N = 141) (*cf. Appendix I, Radiocarbon Database*). Lower: Greenland GISP2 ice-core δ^{18}O (*Grootes et al. 1993*); GISP2 potassium (non-sea salt [K^+]; ppb) ion proxy for the Siberian High (*Mayewski et al. 1997; Meeker and Mayewski 2002*).

from the large tell settlements. Below, we review the data in support of these statements. We find that, whereas during the EN, MN, LN–1 and LN–2 periods (Fig. 19) the large Thessalian magoules were often continuously occupied by farming communities, with the onset of the FN the majority of magoules was abandoned in favour of a distinct shift towards small upland sites. These sites are occupied mainly by pastoralists (*Perlès 2001; Johnson and Perlès 2004*). Hence, it appears that the 6000–5200 ka calBP time interval was characterised by important social change. This may be due to RCC.

Problems of site mapping

As a first test of such notions, we have reworked the Thessalian settlement maps, mainly by adding EBA site distribution data (*Hanschmann 1976.Abb. 2 with site list; van Andel, unpublished data, pers. comm.*). From the new maps (Fig. 20) it becomes even clearer how dramatic the socio-demographic shift (from Neolithic agrarian to Copper Age pastoralist economy) actually was. Quite notably, with the onset of the Early Bronze Age (EBA), there is a switch back to floodplain-based agriculture. This is followed by the next extended period of cultural flourishing – the Greek Bronze Age. Such changes become all the more evident after the application of necessary corrections to the established archaeo-radiometric age models (*cf.* below). Very similar cultural trajectories are apparent, as in Thessaly, for the same period in Bulgaria (*cf.* below) but, to some extent different, in Romania (Fig. 25 a, b).

Problems in radiocarbon dating

Before reaching further conclusions, we first identify the more precise chrono-stratigraphic position (absolute age, cultural period, site phasing) of the postulated cultural break. In terms of method, we do this by looking more closely at the ^{14}C-dating of selected archaeological sites. The criterion for site selection is the availability of larger amounts of ^{14}C-data. Clearly, the more data there are, the more precise the dating. But there are dangers in this ^{14}C-dating approach. As mentioned, over the last few decades researchers in southeast Europe have naturally been drawn into exploring the larger (multi-layer) tell-sites. Of course, this is due to a legitimate interest in their rich cultural heritage. This research interest leaves the smaller (single layer) sites often unexplored. Importantly, an amplification of given bias towards selective dating of the larger (agrarian) sites is also due to the requirements of the conventional (beta-decay counting) ^{14}C-technique. For precise measurements, in the past (prior to AMS) a typical request of conventional laboratories was that submitters provide large (5–20g) charcoal or grain samples. These came either from burnt (long-lived) wooden beams or from charred (large) grain depots. In both cases the focus is on dating *destruction events*. This focus is further amplified by the methodological necessities underlying the application of Bayesian ^{14}C-analysis (*e.g.* wiggle matching). This method works best for dates on (again: burnt) architectural sequences. In consequence, over the last decades, research on Neolithic and Bronze Age ^{14}C-chronology in SE-Europe has been systematically *overtuned* towards the omnipresent, large, multilayer (agrarian) tell settlements, and especially by those destroyed in conflagrations; on the other hand it has been *undertuned* with regard to the smaller sites with their (assumed) different economy. This bias is omnipresent in the CalPal ^{14}C-database (Appendix), despite its large size and scope, and indeed, all the more due to these very factors.

We must account for this bias. The method taken here is to produce cartographic pictures of site distributions based on pottery dating. This substantially expands the scope of the ^{14}C-database by pulling into analysis the many sites with a shortage of ^{14}C-data. But this produces new dangers that are well-known to archaeologists, and are often subsumed under headings such as *selective visibility*. Whatever limitations exist, the method is clearly most effective when the mapping is performed on a tripartite level, *i.e.* for cultural periods dating to *before, during, and after* the time interval under study. Naturally, if the landscape under study has provided neither ^{14}C-dated sites nor pottery evidence, the corresponding population will remain invisible, even if corresponding groups of people were present in large numbers. The identification of such (potentially) omnipresent and (assumed) more mobile groups that perhaps use basketry in place of pottery, and caves (or tents) instead of stone/mud brick architecture, is a vexing problem for which there is no simple solution.

Methods: key study cultures and sites (southeast Europe)

Let us turn to the site data. In Greece, our key study tell-sites are Sitagroi, Promachon, and Mandalo. In Bulgaria, a brief case study is directed at dating the Jagodina culture at its type site. Jagodina is one of the rare cases where a set of ^{14}C-ages is available for an upland archaeological site dating *within* the 6.0–5.2 ka calBP RCC-period. Together, these studies provide a preliminary *understanding* of what may have happened during this RCC-interval. We test this *understanding* – it is too early to call it a model – at the tell-settlement in Thrace, called Ezero (Tell Dipsis). Again, due to the ^{14}C-dating program, we are forced to focus on a multiply burnt-down tell site that was razed several times. This may be the chance product of enhanced ^{14}C-data visibility by way of amplified charcoal availability; however, it is perhaps not at all fortuitous that Ezero was deserted from ~6200 to 5200 calBP. In cultural terms, this corresponds to the transition from Karanovo VI to Karanovo VII. Separating these periods, the available ^{14}C-data show the existence of a major cultural hiatus. As such, as seen from within the RCC perspective, the site resettlement at Ezero at the onset of Karanovo VII dates exactly (within few decades) to the beginning of the next non-RCC period. If confirmed, this is perhaps the first time that *chronological climate determinism* is shown to allow a precise decadal-scale forecasting of periods for which major social variation may be expected. If confirmed at other sites, this would give us a viable (Greenland ice-core age-model referenced) method of forecasting exact dates at least for RCC-related social change. There will be other reasons. Turning to Romania, based on the new tell-site excavations at Pietrele (*Hansen et al. 2007; 2008*), an attempt is undertaken to derive a precise date for the collapse of the KGK VI Cultural Complex (Fig. 24). The forecasting is confirmed, but with emerging new perspectives as to the complexity of the questions under study.

To round up this introduction – although, perhaps, it is needless to state – all three study areas in southeast Europe have been carefully selected for their downwind position within the RCC corridor (Fig. 2). Here, we may expect the strongest social effects of the rapid movement of cold air masses associated with the meteorological RCC mechanism. It is beyond the scope of this paper to demonstrate whether the cultural development in neighbouring regions (*e.g.* Pannonian Basin, northwest Anatolia, and Ukrainian Steppe) was affected by RCC. Although yet lacking chronological precision, recent archaeo-botanical studies in the Troad (*Riehl and Marinova 2008*) provide further evidence for the reliability of the above mentioned forecasting.

Finally, we must again clearly emphasise our intention not to force a climate background on any of the processes under study. We rather wish to provide new data and ideas in support of further research towards the quite remarkable cultural trajectories during this period in southeast Europe. Our sole intention is to localise some of the potentially more promising regions and sites for future climate-archaeological studies.

Greece

Chronology

Beginning in Greece, Figure 19 shows the total available ^{14}C-data for the Neolithic and Early Bronze Age periods from the CalPal database (Appendix). The data are plotted in context with Greenland GISP2 ice-core stable oxygen isotope and nss [K^+] chemical series. This figure provides an overview of the main chrono-cultural subdivisions for the Greek Early Neolithic (EN), Middle Neolithic (MN), Late Neolithic 1 (LN–1), Late Neolithic 2 (LN–2) Final Neolithic (FN), and Early Bronze Age (EBA). Also given are the names of representative sites and ceramic phases (Proto-Sesklo, Sesklo, Arapi/Otzaki, Classical Dimini, and Rachmani) for the Thessalian sequence as initially defined by Gallis (*1992*). In the following, special attention is given to the cultural development of the (Chalcolithic) Rachmani period which is (i) archaeologically not well-known, and (ii) ends according to ^{14}C-ages from Mandalo (Tab. 8) with the onset of the 6.0–5.2 ka calBP RCC interval.

The existence of an ~800 yr hiatus (or change in economy, *cf.* below) that separates the Greek FN from the Greek EBA is immediately evident from the complete lack of ^{14}C-ages for this millennium in Greece (Fig. 19). As will be discussed below, the same hiatus appears in Bulgaria (Fig. 22).

According to recent reviews of the Greek Neolithic provided by Johnson and Perlès (*2004, with further references*), and in general agreement with other authors (*Coleman 1992; Johnson 1999; Perlès 2001; Alram-Stern 2004; Demoule and Perlès 2004*), the Greek FN period is expected to date between 4500 and 3500 calBC (6450–5500 calBP). In our view this dating is not supported by available ^{14}C-data. Notwithstanding, we agree with Johnson and Perlès (*2004*) that the FN period is still not known in sufficient detail to be subdivided with confidence. But the critical question concerns the dating of this very period *i.e.* the FN (Final Neolithic or Greek Chalcolithic, depending on author). The point at stake is, notably, the subdivision of the FN into three phases (Rachmani I–III). These were defined earlier by stylistic variations (*e.g.* painted spirals, incised decoration, and white incrustation) of pottery known from the synonymous Thessalian site. Today, there is agreement that the different types of Rachmani (I, II, III) pottery, as defined at Pevkakia, were found in mixed stratified contexts (*Hauptmann 1981; Weisshaar 1989; Parzinger 1991*). This is the only site where the FN in Thessaly has been excavated by modern methods and the results published (*Weisshaar 1989*).

Rachmani I has further similarities to the pottery from Sitagroi III (*e.g. Parzinger 1991; Manning 1995*). Awaiting further studies on the dating of Rachmani, it would appear parsimonious to reference the Rachmani style to available ^{14}C-ages from Mandalo Phases Ib-II (*Maniatis and Kromer 1990*; Fig. 19: 6350-6100 calBP (4400–4150 calBC). Similar dating results are achieved by using ^{14}C-ages from Sitagroi III (or other reference styles).

As a result, a large hiatus between the Greek FN and EBA becomes apparent, both in Northern Greece as well as in Thessaly (Fig. 19). Ever since the pioneering studies of Petrasch (*1991*), the existence of such a gap in the tell-settlements of southern Europe has been well known. But, with the end of Rachmani dating to ~6100 calBP, and the EBA beginning ~5200 calBP, there also appears to be a glaring gap in the Thessalian FN-EBA sequence. The gap is >800 years, just as in the tells of Northern Greece. Notwithstanding, already in the mid-1990s, Maran (*1998*) had provided evidence that the Thessalian coast was not entirely deserted during the 6000–5000 calBP, at least not in the second half of this RCC. This is shown by important cultural finds from the site of Petromagula, *i.e.* bowls (or lids) of so-called 'Bratislava' type. Similar finds are known from sites of the Boleráz/Cernavoda III cultures, with widespread distribution in Eastern and Southeastern Europe (*Maran 1998.Abb. 6*). There are further indications of a settlement of the Thessalian coast dating to the second half of the 6th millennium calBP from recent finds in Mikrothiva (*Adrymi-Sismani 2007*).

Site distribution study: Thessaly

Independent evidence in support of the proposed hiatus in the Thessalian FN/EBA transition is obtained by application of site mapping which shows the almost complete lack of FN sites in the eastern plain of Thessaly (Fig. 19). From the west plain there is little available data. Due to extensive archaeological surveys (*Gallis 1992; 1994*) and geomorphologic studies (*e.g. van Andel et al. 1990; van Andel and Runnels 1995; van Andel 1995*), as well as diachronic analysis of prehistoric settlement patterns (*e.g. Halstead, Perlès 2001; Johnson and Perlès 2004*), the fertile palaeo-floodplains of eastern Thessaly (Larissa plain) present one of the most extensively surveyed and best-studied archaeological regions in Greece.

In eastern Thessaly, the site data (Fig. 20) points strongly to a switch in settlement patterns during the FN. As already concluded by Perlès (*2001*), and again described in detail by Johnson and Perlès (*2004*), the site distribution during the FN (N = 34) reveals an almost complete desertion of areas that were previously densely settled throughout the EN (N = 112), MN (N = 117), LN–1 (N = 135), and LN–2 (N = 140) periods. Following the FN, there is a switch back to higher EBA (N = 133) site density. The numerical values given here in brackets describe the total number of settlements known for each of these periods.

Also evident from Figure 20, in the eastern (and indeed lower) part of the plain there is an area largely void of settlements during all these periods. This area is widely known as 'Lake Karla' (*Grundmann 1937*). However, there is no geomorphologic data available that actually demonstrate the existence of Lake Karla, despite speculations on its geological background (*e.g. Caputo et al. 1994*) and its influence on settlement patterns during prehistoric peri-

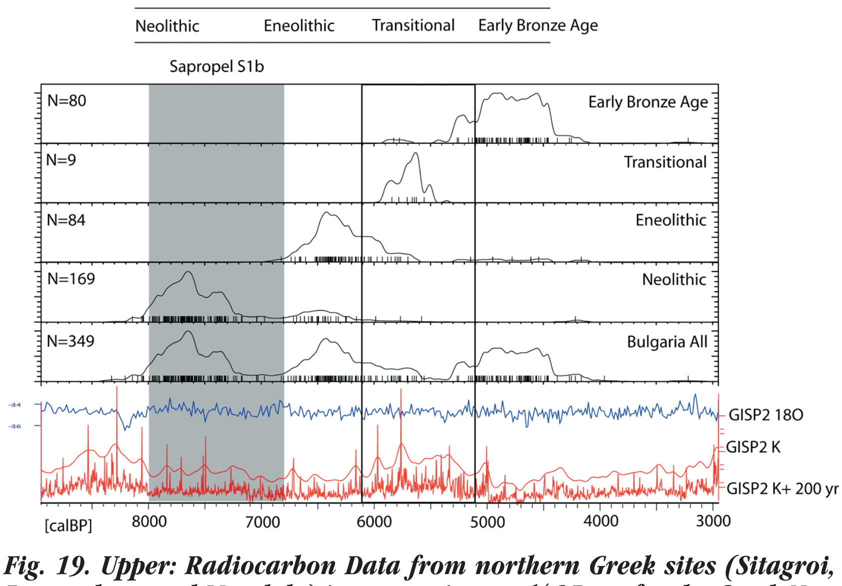

Fig. 19. Upper: Radiocarbon Data from northern Greek sites (Sitagroi, Promachon, and Mandalo) in comparison to ^{14}C-Data for the Greek Neolithic and Early Bronze Ages. Lower: Greenland GISP2 ice-core stable oxygen isotope and nss [K^+] chemical series. The box indicates a widespread chrono-stratigraphic hiatus at 6100–5200 calBP.

ods (*e.g. Perlès 2001*). This is crucial for RCC-interpretation. If Lake Karla did not exist then is no reason to assume a correlation between lake level fluctuations and settlement dynamics, as suggested by Perlès (*2001*). Thus, we immediately drop all considerations that the loss of settlements during the FN may be related to lake level variations. A remaining problem is how to explain the lack of settlement data in the 'Lake Karla' area. But since this applies constantly to all study periods (EN, MN, LN–1, LN–2, FN, EBA), it can hardly be explained by climatic variability, and surely not RCC.

Site study: Sitagroi (northern Greece)

Scaling up from the regional level, we now approach the 6000–5000 calBP interval at our first Greek site. It is now nearly four decades ago that a major tell-site in eastern Macedonia (Photolivos, later referred to as Sitagroi), was subjected to intensive excavations (*Renfrew 1970*). The radiocarbon ages obtained at Sitagroi were earlier proclaimed to have triggered a revolution in European Neolithic and Copper Age chronology (*Renfrew 1970*). In our judgment, the narrative underlying this revolution has remained incomplete for the past 40 years. We now attempt to complete the story by providing arguments for the fact that the many errors underlying the earlier (entirely pottery-based) archaeological chronologies were not caused by any fundamental problems of stylistic dating methods (*e.g.* for the Rachmani style at Pevkakia where major stratigraphic disturbances are encountered). For the RCC study interval (6000–5200 calBP), there is even today a quite remarkable scarcity of archaeological data in the study regions. Hence, it is no wonder that such errors in early pottery dating occurred. The crucial question instead is: what caused this lack of data?

As originally postulated by Renfrew in 1970, we first confirm that the ^{14}C-ages from Sitagroi (^{14}C-Database, Appendix) really do demonstrate the existence of a gap (here: ~1000 years) in the stratigraphic sequence of the settlement. The gap is particularly evident in excavation Trench ZA (Fig. 21), where it is situated at a depth of ~4m. The identification of this stratigraphic discontinuity was one of the main new insights provided by the original Sitagroi excavations (*Renfrew 1970*). As is well-known, it corresponds to a cultural break between the Neolithic (Sitagroi III) and the Early Bronze Age (Sitagroi IV).

Meanwhile, more archaeological data has become available, and it has become clearer that a virtually identical gap exists at the neighbouring sites of Promachon (Central Macedonia), as well as at Mandalo (West Macedonia). Unfortunately, even taken together with Sitagroi, there are still only these three sites on the Greek mainland for which Late and Final Neolithic ^{14}C-dates have been obtained (Fig. 19). Due to the complexity of pottery dating, we are best

Lab Code	^{14}C-Age (BP)	Material	Material	Period	Locus	Phase
Hd–9146	3860 ±70	–25,20	charcoal	EBA	1024	Pits near Surface
Hd–9216	4130 ± 70	–25,70	charcoal	EBA	7140	–
Hd–9835	4300 ±100	–26,00	charcoal	EBA	8152	–
Hd–9907	3920 ± 40	–25,10	charcoal	EBA	8199	Pits near Surface
Hd–9915	4130 ± 40	–25,30	charcoal	EBA	8231	Phase III
Hd–9559	5490 ± 60	–24,70	charcoal	Neolithic	2156	Phase II
Hd–9563	5430 ± 70	–24,00	charcoal	Neolithic	2202a	Phase II
Hd–9596	5290 ± 70	–24,80	charcoal	Neolithic	7229	Phase II
Hd–9602	5460 ±100	–25,20	charcoal	Neolithic	1022	Phase II
Hd–9832	5420 ± 40	–24,50	charcoal	Neolithic	7251	Phase II
Hd–9833	5460 ± 50	–24,80	charcoal	Neolithic	7253	Phase II
Hd–9834	5340 ±100	–25,90	charcoal	Neolithic	7275	Phase II
Hd–9939	5430 ± 45	–24,30	charcoal	Neolithic	2292b	Phase II
Hd–9595	6410 ±190	–24,70	charcoal	Neolithic	2224	Phase II (too early ?)
Hd–9265	5540 ± 70	–24,10	charcoal	Neolithic	4020	Phase Ib
Hd–9557	5440 ± 60	–24,10	charcoal	Neolithic	5032	Phase Ib
Hd–9603	5520 ± 80	–24,80	charcoal	Neolithic	3040	Phase Ib
Hd–9562	5600 ± 70	–25,80	charcoal	Neolithic	3120	Phase Ib
Hd–9601	5710±150	–22,00	charcoal	Neolithic	4007	Phase Ib
Hd–9597	6630 ±100	–24,80	charcoal	Neolithic	D12	too early ?

Tab. 8. Radiocarbon Ages from Mandalo (West Macedonia, 40°52' N, 22°13' E). Data Source: Maniatis and Kromer (*1990*). Outliers in italics.

advised to cite the regional specialists, especially those working on-site. Concerning the site of Promachon, Koukouli-Chryssanthaki (*2008.48*) writes:

"...architectural remains of the last phase of habitation are present (Phase IV). These strata, which also contain pottery from an earlier phase, probably come from the levelling of the ruins of the buildings from the preceding settlement levels. The last phase of habitation on the site can be dated to a late phase of the Late Neolithic, based on scattered pottery sherds. Typical [...] incised and graphite painted pottery provides links to Dikili Tas II and Sitagroi III in Eastern Macedonia, as well as to Marica I–II in North Thrace."

This evidence, which is supported by two ^{14}C-dates from the final stages of Promachon, indeed contemporaneous with Sitagroi III (Fig. 19), provides further indication for the existence of a long gap between the Greek FN and the EBA.

Let us now put the evidence together. Firstly, in chronological terms the hiatus is defined by an abrupt drop in overall ^{14}C-data from Greece (Fig. 19). This is understandable due to the above mentioned selective radiocarbon dating of major agrarian sites. Secondly, in pottery-stylistic terms the hiatus is identified by the significant lack of FN-sites in eastern Thessaly (Fig. 20). This appears to be caused by a significant switch during the FN in Thessaly from an agrarian to a pastoralist economy. Hence, corresponding sites have neither been excavated, nor have they provided samples for ^{14}C-dating. Further, our argumentation relies heavily, although not critically, on dismantling the often supposed continuity of Thessalian FN-EBA.

At Mandalo (^{14}C-dates: Tab. 8), the painted Rachmani-style pottery ends around ~6100 calBP. At this site, Rachmani pottery is in direct stratigraphic superposition below the much less glamorous EBA pottery. The same stratigraphic superposition of Late/Final Neolithic underlying EBA pottery is evident at Sitagroi, with ^{14}C-ages again in support of a large intervening time span (in the order of 1000 yrs: Fig.21). Finally, the hiatus is also apparent at the site at Promachon. Here, the site abandonment dates to a late phase of the Late Neolithic (*Koukouli-Chryssanthaki 2008*).

In search of further evidence pro (or contra) the influence of RCC, we now direct our attention to more north-easterly parts, *i.e.* along the lines of the incoming RCC-winds.

Bulgaria

Chronology

For Bulgaria, the relative and absolute chronology of prehistoric cultures is comparatively well-established, particularly for the Neolithic, Eneolithic, and Early Bronze Age periods. In addition, these periods are well synchronised with cultures in neighbouring regions (*e.g. Gaul 1948; Todorova 1984; Pernicheva 1995*). This is due not least to the outstanding richness of the local archaeological heritage that, together with other (partly historical) factors, provides us with one of the most detailed and well-dated chronological frameworks anywhere in Europe. Important factors in this respect are: (i) the unique number of deeply stratified Neolithic, Eneolithic and Bronze Age tell-settlements; (ii) early recognition of the necessity for tree-ring calibration of ^{14}C-ages by archaeologists working in Bulgaria, as early as the 1970s (*e.g. Quitta and Kohl 1969; Neustupny 1973; Todorova 1978*); and (iii) continuous support from the Berlin Radiocarbon Laboratory, where the majority of Bulgarian ^{14}C-ages were produced (*e.g. Quitta und Kohl 1969; Görsdorf and Boyadziev 1996*). Just as in Greece (excepting Rachmani), for the purposes of the present paper it is therefore entirely sufficient to make use of the pre-established Bulgarian absolute chronology. The cultural periodisation currently in use by Bulgarian researchers is as follows: Early Neolithic, Middle Neolithic, Late Neolithic; Early Eneolithic, Middle Eneolithic, Late Eneolithic; Transitional Period (with a subdivision into a Post-Eneolithic and a Proto-Bronze stage), and Early Bronze Age. We have applied this periodisation to the Bulgarian ^{14}C-database (Fig. 22).

From Figure 22 it may not perhaps become immediately apparent that there is a glaring gap in the Bulgarian ^{14}C-sequence between 6100 and 5200 calBP. In Bulgarian periodisation this time interval corresponds to the Transitional Period. Consequently, and in agreement with literary sources (*Todorova1995; Bojadžiev 1995*), we have assigned the ages of 6100 calBP to the beginning and 5200 calBP to the end of this period. As mentioned above, Bulgarian researchers have especially emphasised obtaining ^{14}C-dates for this period (*e.g.* Yagodina, Pevec). Nevertheless, there is not a single ^{14}C-sample of this period from the second half of the 6th millennium calBP.

The paucity of archaeological data from the Transitional Period is well-known to researchers working in Bulgaria. Just as in Greece during the same time window, the Bulgarian Transitional Period is charac-

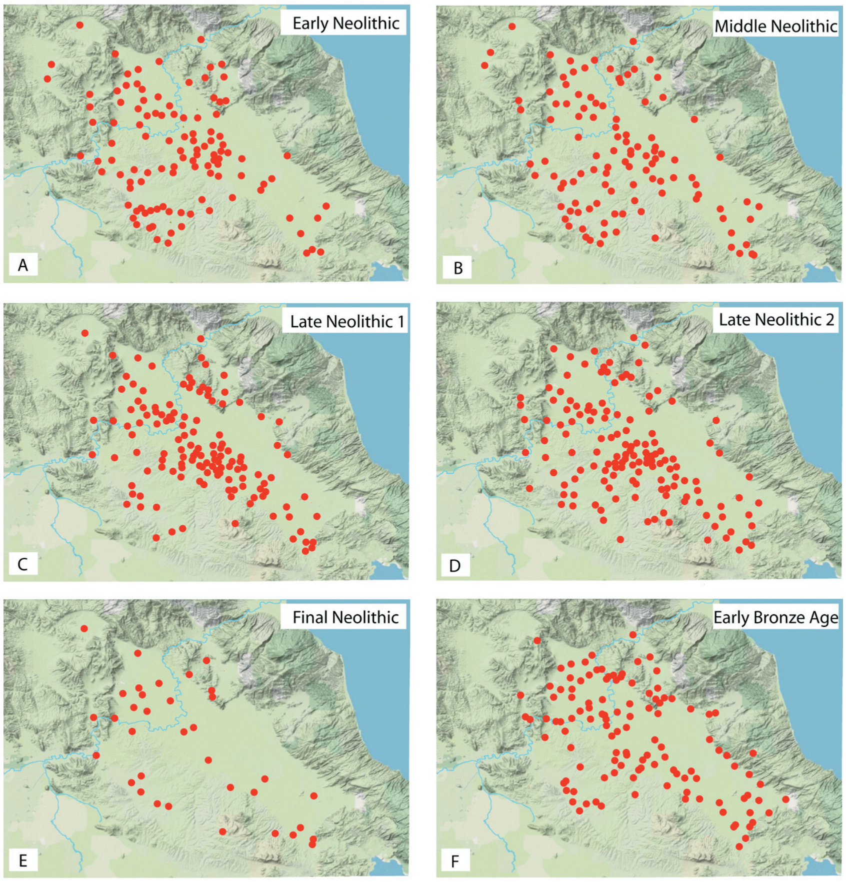

Fig. 20. Distribution of Prehistoric Settlement in Thessaly (Greece). From Top to Bottom (A): Early Neolithic, (B), Middle Neolithic, (C) Late Neolithic 1, (D) Late Neolithic 2, (E) Final Neolithic, (F) Early Bronze Age. Data from Gallis (*1992*), Perlès (*2001*), Hanschmann (*1976.Abb. 2*), van Andel (*unpubl., pers comm*).

terised by a switch from an agrarian (tell-based) economy to pastoralism (with small ephemeral settlements in upland locations). As is so eloquently summarised by Bailey and Panayotov (*1995*), the dramatic explanation for these changes given by Todorova (*1995*) reads very much like a text-book study on environmental determinism. We cite here the relevant passages from Todorova (*1995.80*), noting that the age designations she gives in years 'B.C' are derived from tree-ring calibrated ^{14}C-ages:

"*The brilliant development of the Late Eneolithic cultural block was terminated at the end of the fifth and the beginning of the fourth millennium B.C. [...] by a colossal, global and multi-causal environmental catastrophe [p. 89]. [...] The catastrophe was of colossal scope, as seen from changes in the settlement density which by the late Eneolithic included more than 600 settlements. By the start of the Transitional Period not a single site is known. It was a complete cultural caesura.*"

Due to the given complex regional differences, the construction of detailed site maps showing these settlement patterns for Bulgaria is beyond the scope of this paper. The relevant passages from Todorova (*1995.90, 91*) read as follows:

"*In the Rhodopes, there are no descendants of the Krivodol-Salcuta-Bubanj phase IV of the complex, either in northeast Bulgaria or in Thrace. The latest Eneolithic settlements in Thrace (phases IIIb/C of the KGK VI complex) were destroyed after enormous fires (*e.g. *at Yunatsite and Dolnoslave) and were not re-established. It is interesting to note that a new phenomenon (the Yagodina culture) developed in the caves of the Rhodopes during the final Eneolithic. [...] Little, if anything, is known of the cultural development in the Rhodope region after the end of the Yagodina culture.*"

"*In Thrace, there is not a single archaeological site belonging to the Transitional Period. [...] This situation has always prevented the resolution of the problem of the early Bronze Age Ezero culture, which, when it did appear in Thrace, did so without any links to any local antecedents.*"

We have little to add to this interpretation, although it should be mentioned that necessary high-resolution environmental (which includes palaeo-botanical and archaeo-zoological) data in support of the postulated catastrophic system collapse (however plausible) was not available.

Site study: Yagodina (western Bulgaria)

Whereas on the Greek Mainland there is a gap in the ^{14}C-chronology, in Bulgaria, fortunately, there is at least one site where the switch in economy during the 6000–5200 calBP RCC-period is well-dated by radiocarbon. Yagodina is a cave-site in the Rhodope Mountains (western Bulgaria) which has supplied evidence (hearths, pottery, animal bones, stone tools) for semi-permanent occupation during the Bulgarian Transitional Period (*Avramova 1991*). Due to the site-location in a semi-mountainous area, a seasonal occupation and the prevalence of stock-breeding over agriculture have been proposed (*Avramova 1991*). The site has supplied a small but consistent set of ^{14}C-ages (Tab. 9). Allowing for one outlier (Bln-2385), all samples can be assigned to the early 6th millennium calBP.

According to Bojadžiev (*1995*), a subdivision of the Yagodina occupation into two phases is possible (called Yagodina I and II) based on pottery styles. However, given that both these phases have yielded similar absolute dates (and also in view of the above mentioned Pevec dates), there are currently no indications that Yagodina (resp. the Bulgarian Intermediate Culture) extends into the second half of the 6th millennium calBP. The question arises, at least for the site occupation documented during the first half of the 6th millennium, as to which region the pastoralist occupants of Yagodina used to supply themselves with supplementary resources (*e.g.* plants and human contact). During this period, the large agrarian tell settlements – at least in the Bulgarian flood-plains – had long been in disuse. Whatever the solution to this question, in view of the steadily increasing GISP2 nss [K$^+$] values during the 6th millennium calBP, it appears that the climate finally became even too extreme to support the (assumed) less sensitive pastoralist economy. In terms of understanding RCC-impact on prehistoric communities, the Transitional Period in Bulgaria is clearly a key candidate for future studies. We also conclude that the geographic scope of present studies in Southeastern Europe needs to be expanded.

Site: Ezero (Thrace)

Following Eneolithic occupation (Karanovo V–VI), the large multilayer tell settlement called Dipsis (Ezero) in Thrace was abandoned, and subsequently resettled during the Karanovo VII in the Early Bronze Age. A number of studies by wiggle matching have aimed at deriving exact dates for the stratified EBA-horizons I–XIII at this site. These studies have been based on (i) architectural stratigraphy (*Neustupny 1973; Bojadžiev 1995; Weninger 1986*), and (ii) pottery seriation (*Weninger 1992; 1995*).

The wiggle matching results achieved at Ezero for the beginning of the Karanovo VII Period are shown schematically in Figure 23, together with results from Pietrele (see below). Allowing for the dating only of *long-lived charcoal* (*i.e.* old wood) at Ezero, the entire site chronology must be set ~100 years younger. The site chronology at Pietrele is mainly based on (short-lived) grain samples, for which case no taphonomic age corrections are necessary. When the two site chronologies are combined in a single graph and compared with the GISP2 [K$^+$] record a good correlation (i) between the end of the KGK–VI (*id est* Karanovo VI) period with large GISP2 nss [K$^+$] peak at 6162 calBP, and (ii) the beginning of Karanovo VII site occupation at Ezero with large GISP2 K$^+$ peak at 4992 calBP becomes apparent. In between these two well-dated (ice-core precision) events lies the time interval allocated to the 6000–5200 calBP RCC interval. What is more, it appears as if cultural development is being switched on and off by RCC-peak values.

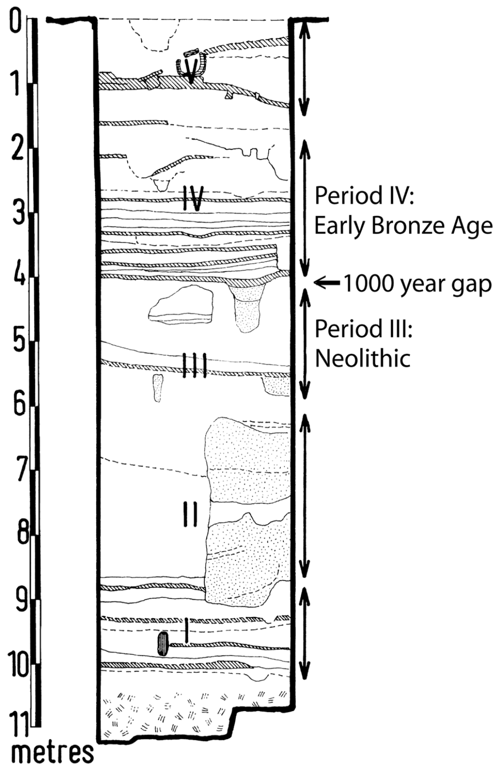

Fig. 21. Trench ZA (South Face) at Sitagroi with periods (Sitagroi I–V) according to Renfrew (*1970. Fig. 5*), redrawn and adapted. The arrow indicates the stratigraphic position of a cultural hiatus separating Sitagroi III (Late Neolithic) from Sitagroi IV (Early Bronze Age) and formerly identified by Renfrew using tree-ring calibrated ^{14}C-ages.

Romania

Site study: Pietrele (lower Danube region)

Moving northeast, we now address the 6000–5200 calBP RCC-period in Romania. Based on ongoing excavations at Pietrele, Giurgiu country, some 150km from the Black Sea littoral, it is now possible to derive an accurate date for the end of the Copper Age in Southeastern Europe, at least in the Lower Danube region. In brief, Pietrele is one of the largest tell sites in Southeastern Europe; accumulated deposits measure approximately seven metres. One of the specific aims of ongoing excavations at the site is to accurately date and study the reasons for the catastrophic termination of the Eneolithic in Southeastern Europe. With this in mind, Pietrele is a natural key site for RCC impact studies. Although the exact reasons for site abandonment are still the subject of scientific enquiry, it can be stated that the settlement was abandoned following a major conflagration (*Hansen et al. 2008.Abb. 86; Reingruber and Thissen in print*).

Recent stratigraphic analysis and application of the wiggle-matching technique provide us with a date of 6200±50 calBP for this last major burning event (Fig. 24, for details see *Weninger et al. 2009*). Within error limits, this date is directly equivalent (i) to the site abandonment at Pietrele, and (ii) the end of the KGK–VI (Kodžadermen-Gumelniţa-Karanovo-VI) complex in Romania. Previous studies (*e.g. Bojadžiev 1996; Lazarovici 2007*) concluded that the KGK–VI complex came to a close at a significantly later time, around 6000 calBP. The reasons for these dating differences concern technical limitations in ^{14}C-measurements performed at the Berlin Radiocarbon Laboratory (Bln) some 40 yrs ago (*Quitta/Kohl 1969. 238–240*). This became clear by recent re-measurements of similarly old samples from Cãscioarele in the Lower Danube-region by Jochen Görsdorf (Berlin ^{14}C-Lab). What is important is that the new Bln-measurements from Cãscioarele confirm the results obtained at Pietrele – that the end of the Chalcolithic period in SE Europe should be revised to ~6250 calBP (*Hansen et al. in print*). This complies with observations by Thomas Higham and colleagues of the Oxford Radiocarbon Laboratory that the dates for the Varna cemetery "*advance by one or two centuries the beginning of the late Copper Age in the Black Sea zone*" (*Higham et al. 2007.652*).

A question arises as to the cause of the KGK-VI system termination. Indeed, this is one of the main research incentives of the Pietrele excavations. With the aim of reconstructing the prehistoric landscape in the Lower Danube region, Jürgen Wunderlich (University of Frankfurt/M.) has recently undertaken geo-electrical investigations and drilling in the Danube floodplain. AMS-dates were obtained from organic sediments and plant remains from core Piet10 at a depth of 10 metres (*Hansen et al. 2007.103, Abb. 103*). This core is in the immediate vicinity of the Pietrele site. The drill samples show that large-scale sedimentation of fine-grained sands deposited by annual floods of the Danube at this location – and of course, rivers may change their course – did not occur prior to 5930–5750 calBP (*Hansen et al. 2008.Abb. 12*). If confirmed, the 200-year age difference between site abandonment (~6200 calBP) and the onset of flooding in the Danube plains (later than 5930 calBP) does *not* provide a likely (supra-regional) climatic-explanation for site abandonment at Pietrele. In terms of RCC, it *does* appear conspicuous that the abandonment of Pietrele dates closely

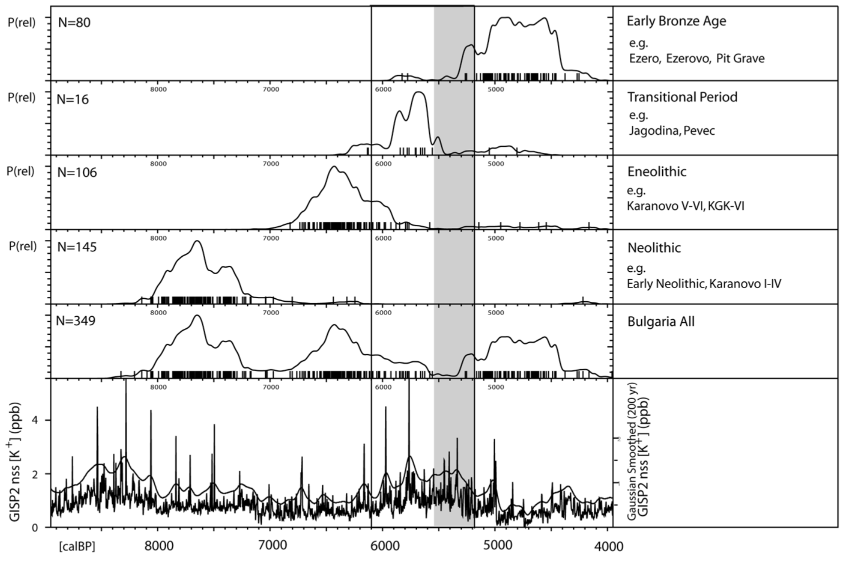

Fig. 22. Radiocarbon Chronology of the Neolithic, Eneolithic, Transitional and Early Bronze Age Periods in Bulgaria based on a number of individual site chronologies (indicated by cultural names e.g. Ezero), in comparison to high-and low resolution GISP2 nss [K⁺] proxy for the Siberian High (*Mayewski et al. 1997; Meeker and Mayewski 2002*). The Box indicates 6000–5000 calBP RCC study interval. Note the lack of dates in the second half of the Transitional Period.

(well within given decadal error limits) to the earliest (at 6165 $calBP_{GISP2}$) of the three large GISP2 nss [K^+] peaks mentioned above. This is the closest we can come, in chronological terms, to an environmental (and possibly RCC-related) explanation for the end of the Romanian Copper Age.

Site Distribution Study: Lower Danube Region

Finally, again applying the site-mapping method, we take a closer look at site distributions during the RCC-period under study. As shown in Figure 25a, by mapping the (pottery-dated) KGK-VI sites we can confidently state that prior to 6200 calBP the entire region of the Lower Danube and its tributaries was densely inhabited. Following the collapse of KGK-VI, settlement densities remain high, but a regionalisation has taken place (Fig. 25b). New settlements appear mainly on the left bank of the Danube and in the Dobrogea. The desertion of the KGK-VI core region is especially evident for the previously densely populated river valley that connected the large sites like Pietrele (in the NW) with Varna and Sava (in the SE). Interestingly, in the former northern KGK-VI area (in the area of the Gumelniţa KGK-VI variant), a new type of settlement occurs. As opposed to the multilayered KGK-VI tell-sites, the settlements of the new Cernavodã I culture are single-phased. The Cernavodã I culture is characterised by completely different pottery (with graphite-decoration and sharply profiled vessels disappearing).

Unfortunately, there is no extended ^{14}C-sequence for the Cernavodã I-culture. The three ^{14}C-ages from the eponymous site (*Meyer 2008.126–127, Taf. 38*) span such a long period (from 5700 to 4600 calBP) that they appear meaningless. According to pottery comparisons between the Cernavodã I-culture and the neighbouring Bulgarian Transitional cultures, the Cernavodã I-culture appears to date to the first half of the 6th millennium calBP (*Görsdorf and Bojadžiev 1996.107; Govedarica 2004.53*). To conclude, in Romania (just as in Greece and Bulgaria) further work is required to establish the sequence and economy of cultures dating to the 6000–5200 calBP RCC interval.

Lab Code	^{14}C-Age (BP)	Material	Phase	Calibrated Age (calBP)
Bln–2385	5980 ± 50	Charcoal	Yagodina I	6820 ± 60
Bln–2389	5265 ± 50	Charcoal	Yagodina I	6060 ± 90
Bln–2247	4960 ± 50	Grain	Yagodina II	5700 ± 60
Bln–2249	5000 ± 50	Charcoal	Yagodina II	5760 ± 90
Bln–2250	5240 ± 50	Charcoal	Yagodina II	5810 ± 70

Tab. 9. Radiocarbon ages from Yagodina (Bulgaria), Transitional Period (*Bojadžiev 1995*).

RAPID CLIMATE CHANGE IN SOUTHEASTERN EUROPE (3000–2930 calBP)

Excluded topics

Turning to next younger RCC, on the broader scale of ~3.5–2.5 ka calBP as defined by Mayewski *et al.* (*2004*), this time extended interval coincides with such an enormous set of cultural events in the Eastern Mediterranean that we are well-advised to begin the discussion by listing the topics not taken into consideration. These topics include the quasi-simultaneous destruction ~3150 calBP (1200 histBC) of all major Mycenaean palaces, the collapse of the Hittite Empire in Central Anatolia, a high frequency of sacked and burned towns on Cyprus and in the Levant, as well as large amounts of good archaeological and historical documentation of catastrophic raids and other atrocities on land and sea throughout the Eastern Mediterranean. Not enough, all this is paralleled by a sequence of destructive earthquakes, it seems acting simultaneously on the major Mycenaean palaces on the Peloponnese. Not surprisingly, there is mention of tsunami destruction of a Bronze Age site on the island of Paros dating to LHIIIB2. Altogether, there is so much evidence for internecine warfare, cultural collapse, human migration, social disruption, and the supra-regional catastrophic impact of earthquakes, all operating between 1250 and 1100 histBC, that we have no need for climate deterioration, on top of all this, to further complicate our understanding of these complex processes.

In search of an archaeological site that would provide the best chance to recognise the social effects of the (deliberately restricted) 3000–2930 calBP RCC event (~1050–980 histBC) the choice immediately falls on Troy. Troy is a multi-period tell-settlement located in the northwestern corner of the Aegean basin, in close vicinity to the Dardanelles. This is the perfect geographic setting to control the natural bridge connecting Asia and Europe. With strong winds blowing from the northeast essentially all year round (for monthly details see *Korfmann 2006*), the Trojans could control all shipping entering the Black Sea. The boats would have been forced to seek harbour in Besik-Bay, just a few

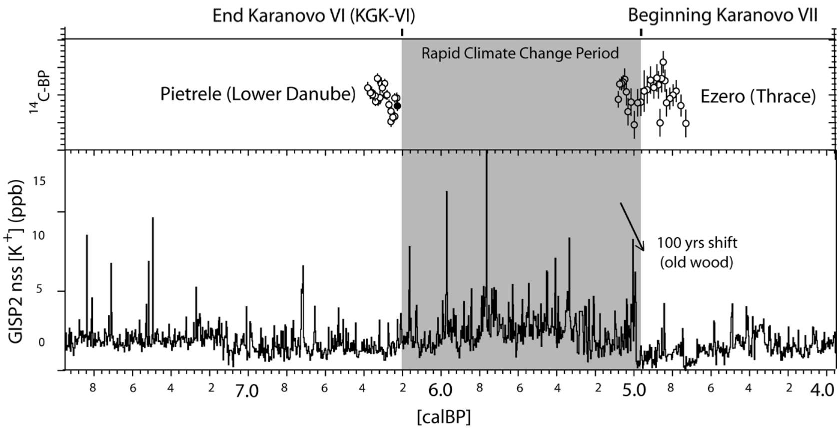

Fig. 23. (Upper): High-precision settlement chronologies for Ezero (Thrace) and Pietrele (Lower Danube) achieved by wiggle matching of stratified ^{14}C-Ages in comparison to (Lower): high-resolution GISP2 nss [K$^+$] proxy for the Siberian High (*Mayewski et al. 1997; Meeker and Mayewski 2002*). Note: the Ezero-chronology should be adjusted younger by ~100 yrs, due to dating of old-wood charcoal. This is indicated by an arrow. The ^{14}C-ages from Pietrele and Ezero follow the tree-ring calibration curve (not shown).

kilometres west of Troy and some would have been dragged overland, to be launched again in the Dardanelles, a few kilometres north of Troy It is this superb geo-political location of Troy that appears to have been responsible for the unusual wealth of the Trojans throughout its many cultural phases and periods. In the present paper, we argue that this very location may ultimately have caused its downfall at the end of the Bronze Age – *i.e.* due to its position within the RCC-corridor.

Site study: Troy

Late Bronze Age chronology of Troy

The date assigned to the end of Troy (Period VIIb) by the Tübingen excavation team (*Korfmann 2006*) is ~1050 histBC, or perhaps a few decades younger. Within given error limits, this date is equivalent to the onset of the RCC at 3000 calBP$_{GISP2}$ (~1050 histBC) Fig. 26). However, due to remaining dating errors, it is not yet out ruled that the final Troy phases VIIb2–3 may extend by some decades into the RCC time-window. We note here that, based on ongoing research, it appears possible to further subdivide the Troy VIIb period by adding on a new phase (Troy VIIb3) (*Becks et al. 2006*). The chronological position of the new Troy VIIb3 phase is already shown in Figure 26. Its exact date remains to be established.

There are variations in the exact dating of all Troy VIIb1–3 phases, depending on the author. These archaeological dating errors are within the range of a few decades. Similar dating errors can be expected for the targeted GISP2 nss [K$^+$]-record.

Site abandonment at Troy

Not all specialists agree that Troy was actually deserted at the end of the Bronze Age. The controversies have the following background. As a result of major building activities in later periods, and especially when the central part of the hill was levelled during the construction of Roman Ilion (*Blegen et al. 1958. 247*), large parts of the inner citadel were destroyed, leaving only the outer perimeters of Troy VI, VII and VIII for later excavation. As a consequence, it remains to be established whether the observable discontinuity between the youngest preserved phase of the Late Bronze Age (VIIb2–3), and the oldest known buildings of Troy VIII (Iron Age), is the result of site abandonment (*e.g. Korfmann 2006*) or perhaps caused by the destruction of the intermediate archaeological units (*e.g. Hertel 1991; 2008*).

Korfmann (*2000.215*) gives some of the most convincing arguments in support of site abandonment, as follows:

"*In the northeast of the Citadel is a bastion with a deep cistern, as well as a spring line ... a source of water like this would only have been abandoned when nothing more was going on in the place, when there were not enough resources to keep it clean, or indeed any need for such a large water system ... By the latest during Troy VIIb2, the spring was abandoned. Five metres (!) of fill or mud are available for the entire process ... that meant the end of supplying water from a central source to an upper class that lived within the Citadel.*"

To conclude, again following Korfmann (*2000.215*) "*the very latest from* c. *1000/950 BC, there was no more settlement in Troy worthy of the name.*"

This date agrees well (within a few decades) with the 3000–2930 calBP RCC interval (~1050–980 histBC). As with the other RCC periods, the prime mechanism for the abandonment of Troy during the

3000–2930 calBP RCC would be the stochastic outbreak into the Aegean basin of cold and fast-flowing air masses, with the source in Siberia. These cold air masses would have been channelled down through the Balkan valleys, resulting in a series of unusually cold and dry winters and springs. In recognition of a dense Bronze Age farming population on the coastal plains in all regions of the northern Aegean (Macedonia, Thrace, Marmara, Troas), the first order hypothesis would be that local farming communities would have experienced repeated and devastating crop failures, often in consecutive years, for at least three decades, and probably for twice as long.

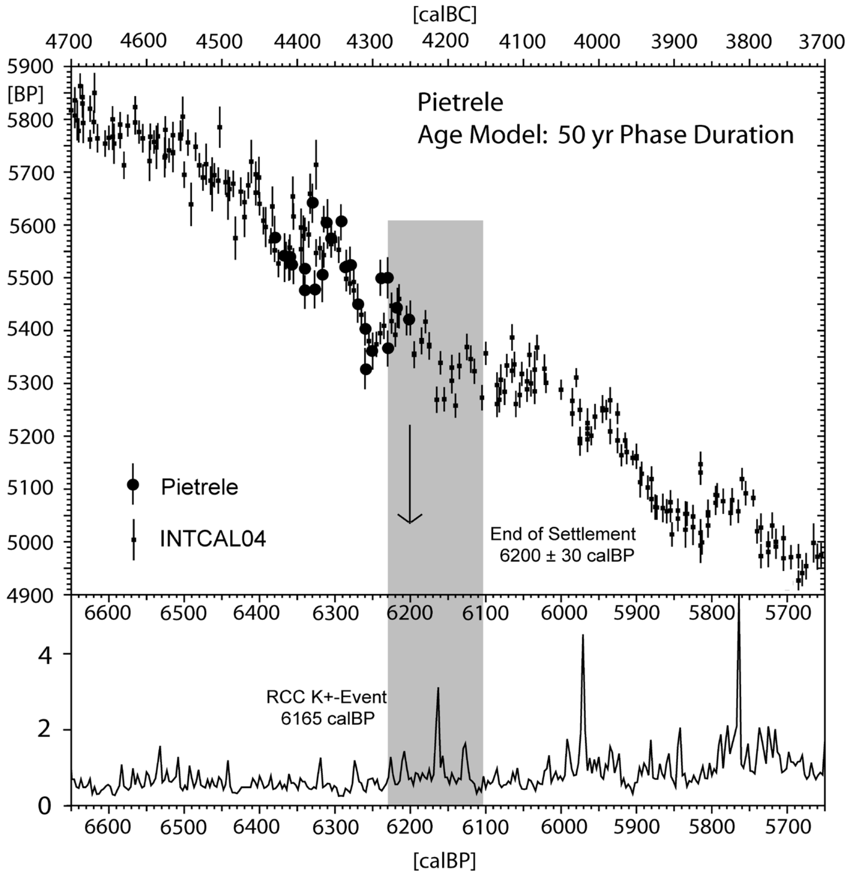

Fig. 24. Upper: Archaeological Age Model for Stratified ¹⁴C-Data from Lower Danubian Multi-period Settlement at Pietrele (**Hansen et al. 2009; Weninger et al. 2009*****). Assumed 50-yr phase length. Mostly short lived samples. Lower: Greenland GISP2 nss [K⁺] record (*****Mayewski et al. 1997; 2004*****). Note: close coincidence of site abandonment following major fire (6200 ± 30 calBP) with peak GISP2 nss [K⁺] value at 6165 calBP$_{GISP2}$.***

However tempting this notion may be, already in terms of dating it is too early to simply postulate a causal relation between the desertion of Troy and the 3000–2930 calBP RCC event. Such a climatic explanation requires, first, a study dedicated to fine-tuning the GISP2-age model in the crucial time-window. Second, we must look yet closer at the site history. When dating is based on high-resolution pottery seriation (*Weninger 2009*), the distinct possibility arises that the 3000–2930 calBP RCC event occurred at some time during Troy VIIb2–3 (Fig. 27), *i.e.* when the site was evidently still occupied. Perhaps significant, this date covers the time when a new style of pottery was introduced into Troy – that is (curiously), hand-made *Buckelkeramik* pottery most likely deriving from the Balkans (*e.g. Hänsel 1976; Koppenhöfer 1997*). Further indications in this direction (RCC-upwind) are supplied by the use of vertical stones (Orthostats) in house foundations. This unique building technique appears for the first time during Troy VIIb2. Interestingly, it also known from Durankulak (*pers. comm. to BW by Pieniazek-Sikora 2008*). This would provide a reason to imagine RCC-downwind habitat-tracking (here: from the Black Sea region into the Troias), as has been inferred as a typical response of farming communities to climate deterioration during the 4.2 ka calBP event in northern Mesopotamia (*Weiss 2000; Staubwasser and Weiss 2006*). But further, as far as we presently know, Orthostats fall out of use again in Troy VIIb3. Around the same time (Troy VIIb3), pottery of (high quality) Protogeometric style was imported, with the probable source in Central- or North Greece (*Koppenhöfer 1997; Becks et al. 2006, with further references*).

At Troy, all these quite intricate problems, and many others (*e.g.* social structure, demographic development, food resources), require further study. We simply do not (yet) know whether site abandonment at Troy was due to climatic deterioration. It appears possible.

Regional study: Thrace

We now shift our search for RCC evidence to neighbouring regions. We first move directly north, along the track of the incoming cold RCC winds. According

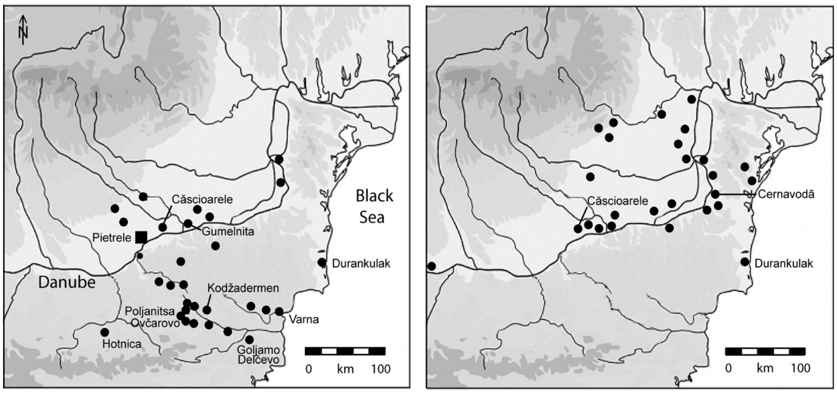

Fig. 25a (left). The Lower Danube Region in the second half of the 7th Millennium calBP. Dots: sites of KGK-VI complex (after **Mayer 2008.Karte 8***). Figure 25b (right). The Lower Danube Region in the first half of the 6th Millennium calBP. Dots: sites of Cernavoda I culture (after* **Toderaş et al. 2009.Pl. 1.1***)*

to Özdoğan (*1993*), in Thrace and the Marmara region, the transition from the Late Bronze to the Early Iron Age is a period of dramatic change, often quoted as 'Crisis Years'. A marked increase in small, single-period sites is observed, along with small burial mounds, as well as megalithic architecture. Many of these sites have pottery similar to the *Buckelkeramik* of Troia VIIb2, with similarities extending to the Psenchevo ware of Bulgaria. Özdoğan (*1993*) comments on the possibility of population pressure in Thrace at this time, but mentions that there are no signs of strongholds, and that all appears to have remained peaceful.

Regional study: northern Greece

In northern Greece, the general picture is one of settlement continuity throughout the restricted time window we have allocated to the 3000–2930 calBP RCC event (~1050–980 histBC). It is nevertheless fair to speak of troubled times, also in northern Greece. In the transition from the Late Bronze Age to the Early Iron Age some 30% of Central Macedonian sites are either completely abandoned or show at least temporary desertion (*Hochstetter 1984.Abb. 54*). However, such phenomena are rather common in many regions and periods. Site abandonment alone cannot be taken as evidence of climate impact. This explains our interest in a thorough archaeological evaluation of the forecasting capabilities of the RCC-mechanism.

Regional study: southern Greece

It is especially informative to search for the effects of the 3000–2930 calBP RCC event in southern Greece, since here during the Mycenaean period we have a highly vulnerable Late Bronze Age palace system. For the so-called 'palatial' period, widespread destruction is in evidence around 1200 histBC, followed by the so-called 'post-palatial' period (Late Helladic III C) and the transition to the Early Iron Age (Sub-Mycenaean and Protogeometric). We note that the Mycenaean palatial system did not develop everywhere in Greece, but only in a few regions (*e.g.* Argolid, Messenia).

In the post-palatial period – the period from *c.* 1200 to 1050 histBC – Mycenaean culture continued to thrive, but lacked the formerly highly centralised palace system. These are troubled times, that are best studied on a local level. Some researchers would speak of this period as 'Dark Ages'. But there are variations in terminology. Quite often, this term is used for the entire period 1200 to 800 histBC (covering all LH IIIC through to Geometric). However, due to increasing amounts of archaeological data, the term is now best avoided, at least for LH IIIC. Beyond terminological caution, we must be cautious in supra-regional comparisons, due to pertaining differences in the social development of different regions (*e.g. Deger-Jalkotzy 1994; Mühlenbruch 2004*). Climatic explanations for the end of the palatial system are discussed among many other scenarios by Deger-Jalkotzy (*1994*), and are taken as a more specific background for the 12th century hist BC by Falkenstein (*1997*). Altogether, climate variability does not figure among the major factors under discussion to explain societal change, in contemporary Bronze Age research. This is not due to any underestimation of its importance, which is widely acknowledged, but rather to the lack of convincing (high-resolution) climate data. Another drawback of earlier climate explanations was the lack of any plausible meteorological mechanism for climatic variability, but we are now confident in being able to supply this.

In the context of the 3000–2930 calBP RCC event, with its given (Greenland ice-core based) ultra-high dating precision we are now in a position to reconsider the question of whether the settlement system in the Late Bronze Age shows responses that could be attributed to climatic variability. Following the palace destruction around 1200 histBC, and quasi-immediate site re-occupation on a clearly reduced organisational level (for Tiryns see *Mühlenbruch 2004*), one of the next important cultural breaks comes at the end of the post-palatial period. Following this period, important changes have been identified in settlement patterns (site densities and locations; *e.g. Eder 1998.199–201; Maran 2006; Mühlenbruch 2004*). But these have dating insecurities ranging over decades. We must take further care in differentiating between the different regions. In southern Greece there are a remarkably fewer settlements showing evidence for occupation during the Sub-Mycenaean period. In this area, during the RCC time-window (~1050–980 histBC *i.e.* Sub-Mycenaean and/or Protogeometric), we must therefore either assume a particularly low population density compared with the preceding LH III C, or we assume, in view of the widespread lack of settlements dating to this period in southern Greece, that corresponding sites have been destroyed, *e.g.* by later removal of stone or erosion (*Eder 1998.199–201; Mühlenbruch 2004*).

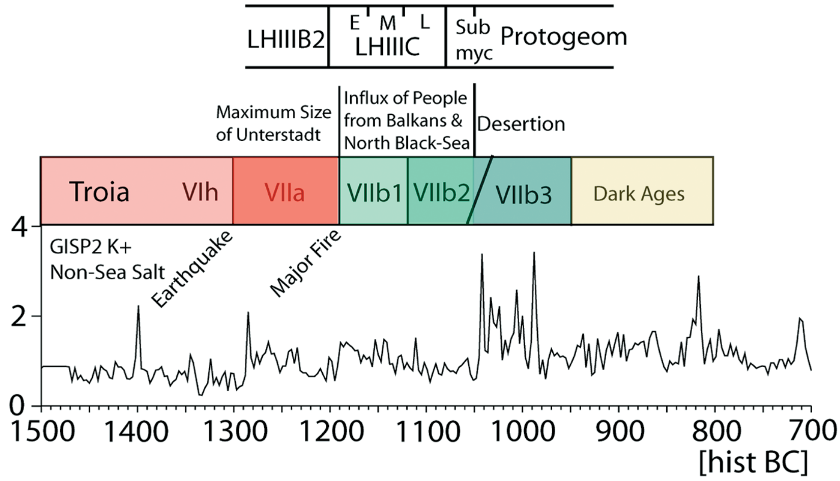

Fig. 26. Upper: Architectural Periodisation of Troy (*Korfmann 2006*). The definition of a new phase (Troia VIIb3) at the end Troy VII is subject of ongoing research (see text). Lower: Greenland GISP2 ice-core nss [K⁺] chemical series (*Mayewski et al. 1997*).

Put together, there is no great necessity to explain the archaeological vacuum on the Peloponnese as resulting from climatic deterioration. Nor do we need such an explanation to understand the troubled times in other regions of Greece at the end of the Bronze Age. Nevertheless, it does seem advisable to keep in mind the possibility that climate-induced stress may have been operating at this time, in addition to other factors, and this remains to be explored.

CONCLUSIONS

We have explored the potential impact of Rapid Climate Change (RCC) on prehistoric communities during the Holocene in the Eastern Mediterranean. The RCC cooling anomalies are well-dated (with quasi-annual resolution) due to synchronisms between marine cores and Greenland ice-core records. In our archaeological RCC-studies, we use GISP2 nss [K^+] chemical ions as proxy for the polar air outbreaks, which are caused by an intensification of the semi-permanent Siberian high pressure zone. For the Eastern Mediterranean region, recent palaeoclimatological research has inferred the existence of six periods with distinct major climatic anomalies, the most recent of which is the Little Ice Age. All these anomalies appear related to the same (but in archaeology not yet widely recognised) climatological mechanism, which would have caused the inflow of intensely cold and dry polar and continental air masses into the eastern Mediterranean basin. During RCC periods the cold air influx occurs quite regularly, although not every year, and typically only for several days to weeks during winter and early spring. The GISP2 age- model then supplies the following time-intervals for major (age-delimited) RCC-variability (1) 10.2–10.0 ka calBP, (2) 8.6–8.0 ka, (3) 6.0–5.2 ka, (4) 3000–2930 calBP (~1050–980 histBC).

We have investigated in detail contemporaneous cultural developments in the Eastern Mediterranean. Special focus was on the following archaeological events and periods, for each of which we have analysed the possibility of a climatic background. Our main research results can be summarised as follows:

(1) ~10 200 calBP & LMP
- Initial domestication of plants and animals in the Levant has *no relation* to RCC and also dates *prior to onset of LMP*.
- LMP supports major demographic expansion in Near East
- Jericho deserted due to ~10.2 ka calBP RCC

(2) ~8600–8000 calBP
- RCC- & Drought-triggered cultural collapse in Southern Levant

- RCC-related social change at Çatalhöyük
- RCC-triggered abandonment of Çatalhöyük
- RCC-triggered abandonment of Cyprus (*cf. Weninger et al. 2006*)
- RCC-triggered spread of early farming from Anatolia to SE Europe

(3) ~6000–5200 calBP
- widespread RCC-triggered social change in SE-Europe
- RCC-triggered collapse of SE-European Copper Age
- End of RCC: onset of Southeastern European Early Bronze Age

(4) ~3000–2930 calBP
- RCC-triggered abandonment of major Late Bronze sites (*e.g.* Troia VIIb)

In the northern Levant, the cultural expansion during an early phase of the PPNB appears directly related to changes in precipitation, as documented in Dead Sea Levels. The possibility that RCC was the cause of major environmental deterioration is indicated by the temporary abandonment of Jericho at around 10.1 ka calBP, and also by the occurrence of Rubble Slides in southern Jordan, at around 8.6–8.0 ka calBP. Concerning the 6.0–5.2 ka calBP RCC, it remains to be established whether the remarkable switch in economic systems in Southeastern Europe during this period, let alone the widely observed system collapse at the beginning of this period, has any relation to RCC. It does appear possible. The same applies to cultural trajectories at Troy, as well as more generally towards the end of the Bronze Age in the Eastern Mediterranean.

From these studies it follows that RCC-deterioration may well have been a major factor underlying social change, but if so, always reacting within a wide regional spectrum of social, cultural, economic and religious factors. We acknowledge the existence in the Near East of other important climatic and environmental factors, besides RCC. Interestingly, some of these factors appear to interact with the RCC mechanism. This requires further attention.

In terms of data, we have assembled substantial evidence for the existence of rapidly occurring supra-regional Holocene cooling periods in the Eastern Mediterranean, and this evidence has been cross-referenced at high temporal resolution with the prehistoric cultural development in this same region.

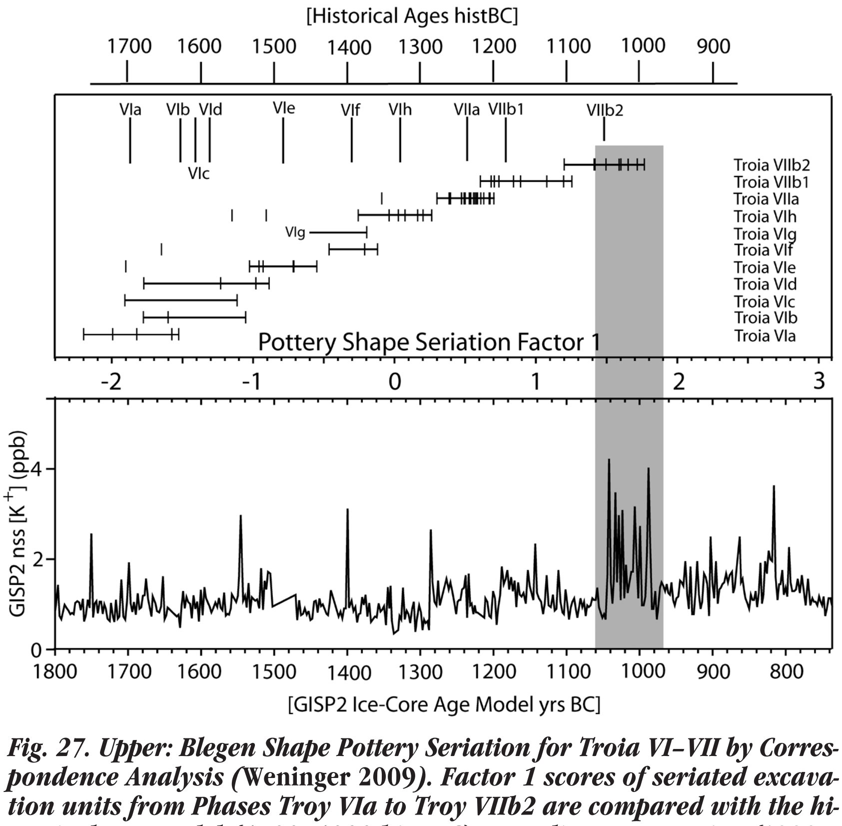

Fig. 27. Upper: Blegen Shape Pottery Seriation for Troia VI–VII by Correspondence Analysis (*Weninger 2009*). Factor 1 scores of seriated excavation units from Phases Troy VIa to Troy VIIb2 are compared with the historical age model (1700–1000 hist BC) according to Mountjoy (*1999a; 1999b*). Lower: Greenland GISP2 ice-core records; stable oxygen isotopes (*Grootes et al. 1993*) and nss [K+] chemical series (*Mayewski et al. 1997*). Site abandonment at Troiy probably occurs during Troy VIIb2–3; note that this seriation does not include finds from the new Troy VIIb3 phase (see text).

OUTLOOK

In terms of method, this paper highlights the importance of developing highly precise archaeological chronologies in RCC-studies. Otherwise, there is a danger of confounding different processes. The GISP2-age model probably requires fine-tuning for all RCC-periods, but this was beyond the scope of the present paper. Already now, the GISP2 nss [K^+] record can be used to forecast the dates at which major social change may occur. In the Near East, some quite complex interactions of the RCC mechanism with (partly synchronous) variations of Holocene Dead Sea Lake Levels (*Migowsky et al. 2006*) have become evident. We nevertheless hope to have convincingly demonstrated the strong climatic sensitivity of cultural developments in the Levant during the early Holocene. This accepted, the GISP2 nss [K^+] RCC-proxy can be used, with foreseeable advantages in many disciplines, *e.g.* in extending results already achieved by comparing the palaeo-botanical data with the GISP2-$\delta^{18}O$- record (*Willcox et al. 2009*).

The predictability of societal change also applies to southeast Europe. Here, a climate-related switch between two modes of economy, agrarian and pastoralist, is apparent. Although such modes are surely not mutually exclusive, it does appear possible to forecast accurately (with decadal precision) the dates at which the major agrarian tell-settlements where abandoned. This also applies to the reoccupation of these sites, following the – again abrupt – onset of non-RCC-conditions. As such, the tell-communities appear especially sensitive to climatic deterioration. This is probably due to their central economic position, as well as enhanced social stratigraphy. But there are indications that even the assumedly less sensitive pastoralist communities experienced increasing climate-related stress, notably during the second half of the 6000–5200 calBP RCC interval.

Taking all regions and periods together, it is quite remarkable how rapidly human societies appear to have responded (social stress) or adapted (by economic switching) to RCC-conditions. Both modes of response are in-phase with RCC. The emerging predictability of social change in prehistoric periods may be useful to researchers in other disciplines.

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Appendix

Radiocarbon Database

The studies in this paper are based on a substantial archaeological radiocarbon database for the Epipalaeolithic, Mesolithic and Neolithic periods in Europe and the Near East which presently compromises 14 627 ^{14}C-ages, of which 65% are from georeferenced sites. The ^{14}C-database contains N = 1856 different (usually multi-period) georeferenced sites, and is assembled from a number of large archaeological ^{14}C-databases compiled in recent years by different authors (*Housley 1994; Görsdorf and Bojadžiev 1996; Gérard 2001; Bischoff 2004; Bischoff et al. 2004; 2005; Rollefson pers comm 2002; Reingruber et al. 2004; 2005; Thissen 2004; Thissen et al. 2004; Weninger et al. 2006; Böhner and Schyle 2009*). In the present paper we use the Neolithic, Chalcolithic and Bronze Age components of this database with geographical focus on the Levant (Jordan, Israel/Palestine, Syria), northern Mesopotamia (Iraq, SE-Turkey), Cyprus, Bulgaria and Greece. In all these regions the ^{14}C-database is known to be characterised by some strong bias in favour of large sites, and in particular multi-phase settlements, which for historical reasons have seen more extensive excavation than smaller sites. The geographic setting of archaeological sites cited in the present study is shown in Figure 1. We typically reference both original and secondary publications. In the case of the large ^{14}C-datasets often used in this paper it is impossible to provide data sources for individual ^{14}C-ages. Detailed references for these ages are provided in the on-line databases of Gérard (*2001*), Bischoff (*2004*), Bischoff *et al*. (*2005*), Thissen (*2004*), Thissen *et al.* (*2004*), Reingruber *et al.* (*2005*), Weninger et al. (*2006*), and Böhner and Schyle (*2009*).

Time-Scales and Terminology

The archaeological chronologies discussed in this paper are mostly based on tree-ring calibrated ^{14}C-ages that are typically measured on terrestrial samples (charcoal, grain, bone). Numerical ages given on the calendric time scale using [calBP] units, with the year AD1950 = 0 calBP as reference. Conventional ^{14}C-ages are given on the ^{14}C-scale with units [^{14}C-BP]. All tree-ring calibrated ^{14}C-ages are obtained from CalPal software (www.calpal.de), based on methods described in Weninger (*1986*). For ^{14}C-age calibration, we have applied the tree-ring based data set INTCAL04 (*Reimer et al. 2004*). As an exception, the chronology of the Late Bronze Age is largely based on pottery synchronisms within the framework of Eastern Mediterranean historical-astronomical age models. In such cases, reference is made to historical ages with units [hist BC].

Data Representation

Extensive use is made in the present paper of a method for graphic representation of large archaeological ^{14}C-datasets called 'multi-group ^{14}C-age calibration' (*Weninger 2000*). This method addresses the problem of how to maintain visual control over large sets of archaeological ^{14}C-ages, without losing the often important information contained in the properties of individual ^{14}C-dates. The solution is to show the accumulative probability distribution of calibrated ^{14}C-ages as an envelope curve for the total data, in addition to showing the median values of individual calibrated ^{14}C-ages as small lines. This leads to graphic representations of calendric age data spread in a manner similar to the well-known bar-codes. Caution is to be taken, in rare cases, when the calibrated probability distribution is non-Gaussian. In such cases the median value may not have a central position within the calibrated probability distribution. For the large data densities we are aiming at, these cases become invisible.

Acronyms

AMS	Accelerator Mass Spectrometer
EBA	Early Bronze Age
EN	Early Neolithic
EPPNB	Early Pre-Pottery Neolithic B
FN	Final Neolithic
KGK-VI	Kodžadermen-Gumelniţa-Karanovo VI
LGM	Late Glacial Maximum
GISP2	Greenland Ice Sheet Project 2
LIA	Little Ice Age
LHIIIB2	Late Helladic IIIB2
LMP	Levantine Moist Period
LN–1	Late Neolithic 1
LN–2	Late Neolithic 2
[mbsl]	meters below sea level (Dead Sea)
MN	Middle Neolithic
nss [K^+]	non sea-salt Potassium concentration
PN	Pottery Neolithic
PPNA	Pre-Pottery Neolithic A
PPNB	Pre-Pottery Neolithic B
PPNC	Pre-Pottery Neolithic C
LPPNB	Late Pre-Pottery Neolithic B
MPPNB	Middle Pre-Pottery Neolithic B
PPNA	Pre-Pottery Neolithic A
RCC	Rapid Climate Change
SE	southeast
SST	Sea-Surface Temperature
THC	Thermohaline Circulation
YD	Younger Dryas

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