Early Holocene palaeoseasonality inferred from the stable isotope composition of *Unio* shells from Çatalhöyük, Turkey

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Abstract

Seasonal δ^{13}C and δ^{18}O data are presented from 14 *Unio* subfossil shells unearthed at the archaeological site of Çatalhöyük in central Turkey, spanning the occupation period ca. 9,150-8,000 cal. yrs BP. The shells likely lived in the small lakes/wetlands around the site before being gathered and taken to Çatalhöyük. Wet-dry seasonal cycles are clearly apparent in the $\delta^{18}O_{shell}$ profiles with low winter values reflecting winter precipitation and high δ^{18}O in the summer resulting from evaporation. The most striking trend in the δ^{18}O data is the drop in maximum summer δ^{18}O ca. 8,300 yrs BP, which we infer as indicating lower summer evaporation and hence a reduction in seasonality. Previous palaeoclimate records from the area have suggested cooler and more arid conditions, with reduced precipitation, around this time. While the drop in summer δ^{18}O values could be due to reduced summer

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temperatures reducing summer evaporation, but there was little change in winter $\delta^{18}O$, perhaps suggesting winter growth cessation or reduced influence of winter climate change on $\delta^{18}O$. This shift in seasonal climate could be linked to solar-forced climate change beginning ca. 8,600 yrs BP, and enhanced by the regional expression of the 8.2k event. Changing water balance over the occupation period is likely an important contributory factor behind observed cultural changes at Çatalhöyük in the Late Neolithic/Early Chalcolithic period. Our results might be considered to support the fission-fusion farming hypothesis as we provide additional evidence for wet winter/early spring conditions during the Early Holocene which likely caused flooding of the Çarşamba Fan. The changing water balance after ca. 8,300 yrs BP (i.e. reduced seasonality and potentially reduced local summer evaporation) is also coincidental with the proposed end of this farming system due to multi-decadal drought.

Key words: Çatalhöyük, Konya, *Unio*, seasonal, palaeoclimate, stable isotopes, Neolithic, Holocene

Introduction

The world famous early Holocene settlement of Çatalhöyük in the western Konya basin of south central Turkey is one of the oldest and best studied Neolithic sites in the world, having been first excavated in the 1960s, an operation which resumed in 1993 and continues until present day (e.g. Mellaart, 1962; Hodder, 2006, 2007, 2013). It is also one of the largest Early Neolithic sites, with an area of ~34 acres and an estimated population of up to 8,000 people at its peak (Cessford, 2005) and one of the most complex sites in terms of art and symbolic expression (i.e. many wall paintings, wall reliefs, sculptures and installations; e.g. Hodder, 1999, 2006 and references therein). Archaeological evidence suggests that humans settled at Çatalhöyük for over 1000 years between 9,150-7,950 cal. yrs BP, occupying the eastern mound for the majority of this period, prior to abandonment around 8,200 cal. yrs BP (Cessford et al., 2005; Marciniak and Czerniak, 2007; Bayliss et al., 2015; Marciniak et al., 2015), and subsequent settling of the western mound, ca. 150 m away. The reasons behind this abandonment remain uncertain, but have been hypothesised to be a response to seasonal climate variations, which might have altered the local landscape, for example river avulsion and changing erosion/deposition centres (e.g. Marciniak and Czerniak, 2007; Biehl and Rosenstock, 2009; Roberts and Rosen, 2009). The abandonment broadly coincides with the widespread 8.2k event (Alley et al., 1997; Rohling and Pälike, 2005; Thomas et al., 2007), which manifests itself as a short-term cold, dry event in the Eastern Mediterranean (Rossignol-Strick, 1995; Bar-Matthews et al., 1999; Ariztegui et al., 2000; Rohling et al., 2002; Wenninger et al., 2006; Pross et al., 2009; Göktürk et al., 2011).

Climate records from the Konya Basin and surrounding area (south central Turkey) suggest that early Holocene climate was wetter than at present (Leng et al., 1999; Roberts et al., 1999; Roberts et al., 2001; Jones et al., 2002; Eastwood et al., 2007; Jones et al., 2007; Roberts et al., 2008; Göktürk et al., 2011; Dean et al., 2015), with a shift to long-term drier conditions occurring much later, somewhere between 6,500 cal. yrs BP (Roberts et al., 2001) and 4,000 cal. yrs BP (Pustovoytov et al., 2007). Estimations of palaeo-precipitation via an isotope mass balance model from the maar lake Eski Acıgöl suggest ~20% higher levels of rainfall in the early Holocene than in recent millennia (Jones et al., 2007), with a Mediterranean-type climate operating throughout (i.e. the majority of rain falling in the winter/spring, followed by dry summers; e.g. Wick et al., 2003; Jones et al., 2006; Kotthoff et al., 2008a; Peyron et al., 2011; Orland et al., 2012; Dean et al., 2015). However, super-imposed over this general millennial-scale trend are wet-dry centennial-scale oscillations (e.g. Eastwood et al., 2007; Orland et al., 2012; Dean et al., 2015) and related seasonal climate variations, which might have altered the local landscape and forced change in early societies living in the Konya Basin.

At the societal level, seasonal variations in climate might have as great, or even greater impact as large scale shifts in climate (e.g. Buckland et al., 1996; Jones and Kennett, 1999; deMenocal, 2001; Cook et al., 2004; Patterson et al., 2010; Büntgen et al., 2011; Wang et al., 2011). It has been proposed that the inhabitants of Çatalhöyük adopted a fission-fusion farming model based around the seasonal climate cycle of the region (Roberts and Rosen, 2009). During the wet season (winter and early spring), parts of the land immediately surrounding Çatalhöyük were likely flooded by tributaries of the Çarşamba and May Rivers and subsequently any crops sown in autumn around the site would have been damaged (Roberts and Rosen, 2009). Therefore, Roberts and Rosen (2009) infer that most cereal crops would have been grown on the dryland soils, away from the main site (perhaps up to 13 km distant) carried out by “task groups”, thus creating a pattern of nucleated settlement during spring/early summer. Later in the year, after the alluvial and marl plain had dried out (in the dry season) and the Çarşamba River had returned to its main channel (to the west of Çatalhöyük) these task groups would have returned to the main site. It has been hypothesised that the phase of nucleated settlement ended when river flooding ceased due to drier conditions and multi decadal drought between 8,300 to 8,100 cal. yrs BP (Roberts and Rosen, 2009) associated with the 8.2k event (occurring between 8,247-8,086 yrs BP; Alley and Ágústdóttir, 2005; Thomas et al., 2007), after which the larger ‘east mound’ appears to have been abandoned.

Evidence for seasonal flooding is based on sedimentary evidence and regional climate data. The sediments from this time are of lower alluvial “backswamp clays and silts” covering much the Çarşamba alluvial fan, followed by a transition to buff and reddish coloured oxidised sediments indicative of drier conditions (Roberts et al., 1999). As indicated above, regional climate data suggests substantially wetter conditions in the early Holocene (e.g. Leng et al., 1999; Roberts et al., 1999; Roberts et al., 2001; Jones et al., 2002; Eastwood et al., 2007; Jones et al., 2007; Roberts et al., 2008; Göktürk et al., 2011; Dean et al., 2015), whilst settlement patterns indicate the presence of only a single large site during the Early Pottery Neolithic to Late Neolithic. This is compared to several smaller sites existing in the preceding Aceramic Neolithic and succeeding Chalcolithic periods. However, the theory of flooding has been widely contested. An alternative is that the temporal and spatial distribution of backswamp silt/clay is exaggerated and that the buff-red oxidised sediments occur earlier (i.e. during the Neolithic) and are more widespread in other localities near to the site (Doherty, 2013) than suggested by the sites incorporated in the Konya Basin Palaeoenvironmental Research Program (KOPAL, Roberts et al., 1999). Bogaard et al. (2013) also contest this proposition and Asouti (2009) rejects climate change as a cause of the abandonment. Asouti (2009) highlights the lack of unambiguous evidence for detrimental societal impacts associated with the 8.2k event and suggests there was continuity of practices between inhabitants of both settlements. In addition, Marciniak et al. (2015) have observed that the occupation of the mound around that time was cut short and followed by a crisis that manifested in the demise of solid dwelling structures which were replaced by light shelters and open space.

To date, climate change remains poorly understood over the settlement phase at Çatalhöyük. Previous studies either lack the temporal resolution (e.g. Eski Acıgöl; Roberts et al., 2001; Jones et al., 2007) to study seasonal-scale climate variation and short-term wet-dry oscillations (such as the 8.2k event), or alternatively suffer from a sedimentary hiatus during the early Holocene (i.e. between 9,500-6,500 BP; Leng et al., 1999; Roberts et al., 1999). Following on from a pilot study by Bar-Yosef Mayer et al. (2012), this study attempts to address this paucity of data by analysing seasonal variations in $\delta^{13}C$ and $\delta^{18}O$ in subfossil *Unio mancus eucirrus* (a species of freshwater mussels) shells from Çatalhöyük, spanning the entire occupation phase of the site (9,150-8,000 cal. yrs BP). The pilot dataset is extended here (from 4 to 14 shells) in order to build up a more comprehensive record of seasonal climate variation over the study period. In semi-arid environments, $\delta^{18}O$ in freshwater mollusc shells tend to record local climate changes, particularly precipitation, evaporation and/or temperature of the ambient water, whilst $\delta^{13}C$ reflects the source of carbon utilised in shell growth (i.e. direct uptake from ambient water and from dietary intake) (e.g. Keith et al., 1964; Fritz and Poplawski, 1974; Grossman and Ku, 1986; Tanaka et al., 1986; Dettman et al., 1999; McConnaughey and Gillikin, 2008; Leng and Lewis, in press and references therein). Preliminary analyses have already demonstrated that strong seasonal variation is apparent in *Unio* shells from Çatalhöyük (Bar-Yosef Mayer et al., 2012), with low $\delta^{18}O$ in the winter months and increased $\delta^{18}O$ during the summer months, reflecting greater evaporation. The extended isotope dataset presented here is discussed in relation to existing regional climate data (including precipitation, evaporation, wind/storminess and temperature) and archaeological change.

Study site

The Neolithic site of Çatalhöyük (Hodder, 2007) is situated in the western Konya Basin, south central Turkey (Figure 1) on the gentle slopes of the alluvial and marl fan delta of the proto-Çarşamba and May Rivers (Doherty, 2013; Roberts, 2015). The Konya Basin was formerly covered by a large lake (Erol, 1978; Roberts et al., 1979) due to wetter climate conditions in the late Pleistocene (e.g. Roberts et al., 2008). Major shrinkage occurred before 18,000 yrs BP (Cohen, 1970; Roberts, 1982) and essentially dried up before the start of the Holocene (except for rivers and small, shallow lakes or wetlands in some depressions during the first half of the Holocene; Roberts et al., 1999; Doherty, 2013). By the time of first settlement, palaeoenvironmental records suggest that an oak-conifer forest dominated the uplands. Higher precipitation and subsequent increased drainage caused the development of seasonal wetlands around the site of Çatalhöyük and build-up of the alluvial fan of the Çarşamba River (e.g. Rosen and Roberts, 2006). However, despite its close proximity to the Çarşamba river, Çatalhöyük itself was never directly situated along a riverbank or lake shoreline (Gümüş and Bar-Yosef Mayer, 2013). Therefore, the molluscan fauna present must have originated from local freshwater sites and been taken to Çatalhöyük by humans. As a result, seasonal climate inferences must be considered as local to regional rather than strictly site-specific.

Çatalhöyük lies ~1000 m above sea level on Late Quaternary alluvium deposits, with lake marl deposits to the north and east (Roberts et al., 1996). The basin is encircled by uplands with the Taurus Mountains to the south and west, providing a barrier for precipitation and leading to a strong precipitation gradient from >800 mm per year along the southern coast of Turkey to <400 mm in the Konya basin (Türkeş, 2003). The modern climate of the area is defined as continental Mediterranean with cool, wet springs and winters, and dry, hot summers (Türkeş, 1996; Kutiel and Türkeş, 2005). Annual precipitation in Konya averaged 324 mm between 1960-2012; December and May are the wettest months, while July to September see only 7% of the total annual precipitation (TSMS, 2013). The hottest months are July and August when temperatures average +23.3°C, while December to February temperatures average +0.9°C (TSMS, 2013) (Figure 2). The strong seasonality in precipitation is caused by the alternating influence of subtropical high pressure in the summer and westerly depressions originating mainly from the Atlantic and Mediterranean in the rest of the year (Türkeş et al., 2009). This strong seasonality is also reflected by precipitation δ^{18}O data from Ankara (1963-2009), with a range from an average of –3.72‰ in July to –11.18‰ in January (IAEA/WMO, 2013).

Methods and materials

The *Unio mancus eucirrus* (Bourguignat, 1857) shells (Henk K. Mienis, personal communication) analysed in this study were collected during excavation (1993 to 2011), either being handpicked or found in the sieved sediments. *Unio* shells are abundant in middens and other archaeological contexts from Çatalhöyük (Bar-Yosef Mayer, 2013), and their suitability as palaeo-environmental indicators of seasonal scale change has already been demonstrated by Bar-Yosef Mayer et al. (2012), though limited to some degree by the availability of whole valves (see below). *Unio* species have a life span of several years and exhibit seasonal growth patterns, with maximum growth usually occurring in the warmest months (April to September in specimens observed in the UK; Bar-Yosef Mayer et al., 2012) and is dependent on temperature, food supply, water current and water chemistry (Pennak, 1989; Aldridge, 1999; Dettman et al., 1999). *Unio* growth ceases below certain temperature thresholds (e.g. Negus, 1966; Goewert et al., 2007), meaning that hiatuses often occur during winter (e.g. Versteegh et al., 2011; Bar-Yosef Mayer et al., 2012). The specific temperature at which growth ceases is species dependent. However, due to the lack of understanding of the distribution, habitat and growth preferences for *Unio mancus eucirrus*, the temperature at which growth ceases remains unknown (e.g. Graf and Cummings, 2007).

Unio species burrow into substrate with their posterior margins exposed. Consistent with many other aquatic bivalves, Unionidae obtain oxygen by exchange with ambient water pumped through their incurrent aperture and carbon (food) through filtering (e.g. Wilbur and Yonge, 1964; Vaughn and Hakenkamp, 2001). Utilisation of oxygen and carbon by *Unio* molluscs from the ambient water and organic carbon for shell synthesis means geochemical information (including δ^{18}O and δ^{13}C is preserved within their shells (e.g. Dettman et al., 1999; Goewert et al., 2007). This information can be used to infer palaeo-diet, carbon source and past climatic/environmental change from the local area (e.g. Aldridge and Horne, 1998; Versteegh et al., 2011; Bar-Yosef Mayer et al., 2012; Çakirlar and Şeşen, 2013). For a more detailed review of the growth and ecology of *Unio* species, see Aldridge (1999), Dettman et al. (1999), Bar-Yosef Mayer et al. (2012) and references therein.

Because the shells used in this study were collected by the inhabitants of Çatalhöyük and found in archaeological remains, rather than as samples from the places that they originally lived, we cannot be sure of the original habitat. However, since it is known that there were no large lakes left around Çatalhöyük by the early Holocene (Roberts et al., 1999; Doherty, 2013), we suggest the shells lived in local small lakes/wetlands, and were collected and taken to Çatalhöyük for both dietary and production purposes (i.e. used to make ornaments, artefacts and as a component in wall plaster; Matthews, 2005; Bar-Yosef Mayer, 2013).

Unfortunately, breakage and dissolution of *Unio* shells, likely due to both cultural usage and post-depositional processes, has meant that collection of whole shells for analysis has been problematic. As material was limited, all shells deemed suitable for drilling and isotopic analysis were included. *Unio* shells were deemed suitable if their (outer carbonate) exposed layer was intact and there was continuous shell from the umbo to the ventral margin. All selected shells matched this criteria, except one (shell 5, Table 1), which was fragmented and missing part of its upper surface.

Drilling and analytical methods remain consistent with Bar-Yosef Mayer et al. (2012). Briefly, after brushing under deionised water to remove any extraneous matter, each shell was dried before being sampled with a microdrill along its exterior from the umbo to the ventral margin (~0.5 mm sampling resolution, deemed a sufficient resolution to capture interannual trends, following previous *Unio* analyses (Versteegh et al., 2011; Bar-Yosef Mayer et al., 2012; Çakirlar and Şeşen, 2013)). Approximately 100 µg of material (as a shell powder) was analysed using a GV IsoPrime mass spectrometer with multiprep system at the NERC Isotope Geosciences Facilities. Precision was within 0.1‰ for both carbon ($\delta^{13}C$) and oxygen ($\delta^{18}O$) ratios.

Results

Details of the shells used in this study are provided in Table 1, including estimated age (archaeological ^{14}C dates), stratigraphic origin, archaeological context and related cultural period (discussed below), together with measurements and analysis statistics (i.e. shell height, number of samples analysed, estimated number of annual cycles and $\delta^{13}C$ vs. $\delta^{18}O$ regression statistics). $\delta^{13}C$ and $\delta^{18}O$ profiles for each shell are provided in Figure 3 (in chronological order), with associated shell-isotope metrics (i.e. range and average, $\delta^{13}C$ vs. $\delta^{18}O$) displayed in Figure 4. With the exception of *Unio* shell 17037, all shells offer at least two annual cycles, with several containing three cycles (Table 1; Figure 3).

Chronological control of the Çatalhöyük shell sequence

Chronological control is based on the sequence stratigraphy developed over time (via multiple ^{14}C ages from articulated bones and charred plant remains) for the archaeological deposits and levels excavated at Çatalhöyük (Cessford et al., 2005; Bayliss et al., 2007; Bronk Ramsey et al., 2009; Bayliss et al., 2015; Marciniak et al., 2015; Table 1). Further chronological details for the Çatalhöyük site are available in annual research reports available from http://www.Çatalhöyük.com/archive_reports/. Eight of the *Unio* shells analysed in this study were also directly ^{14}C dated (see supplementary data), but were not used for chronological control due to the unrealistic ages generated.

$\delta^{13}C$ values in the sub-fossil Unio shells

Consistent with the previous findings (Bar-Yosef Mayer et al., 2012) almost all $\delta^{13}C$ in the extended fossil dataset fall between –12‰ to –5‰. For most shells the $\delta^{13}C$ data manifests as weakly sinusoidal cycles, often at a similar wavelength to the $\delta^{18}O$ data. Individual cycles likely represent a single year, but the magnitude of change suggests very little seasonal/annual variation in carbon source.

$\delta^{18}O$ values in the sub-fossil Unio shells

In the extended fossil dataset, $\delta^{18}O$ range from ~–9.7‰ to +7.4‰. The $\delta^{18}O$ data generally exhibit a classic saw tooth pattern, marked by gradual increasing $\delta^{18}O$, followed by an abrupt decrease to lower values and likely represent an annual cycle. These cycles are distinctly more pronounced in the older shells (shells 1-7, Figure 3; ca. 9,150-8,300 cal. yrs BP). Cycles become less sinusoidal in the shells in the Late Neolithic (after shell 7), with lower magnitude shifts between maximum and minimum values. Additionally, only a few shells exhibit any distinct sharp decline from maximum to low $\delta^{18}O$ (e.g. 17809; 17208; Figure 3) in the late Neolithic and early Chalcolithic (shells 8 to 14; Figure 3). As all analysed shells are likely a similar age (2/3 years old according to the isotope data; Figure 3) and generally a similar size (Table 1), we deem physiological differences (e.g. Schöne, 2008) alone unlikely to account for the changing patterns evident in the isotope data between specimens (Figure 3 and 4).

This reduction in contrast between maximum and minimum $\delta^{18}O$ in the latest part of the Neolithic period is clearly demonstrated by the shell-isotope metrics (Figure 4). Particularly, the difference in range of maximum and minimum $\delta^{18}O$ (average range = 11‰) during the Early Pottery Neolithic and first part of the Late Neolithic (shells 1-7; Table 1, Figure 4), compared to an average of 4.3‰ (shells 8-12) in the Late Neolithic. Minimum $\delta^{18}O$ are relatively stable over the study period, generally falling between –6‰ to –8.5‰ (Figure 4), though perhaps with a very minor increase in minimum values ($\delta^{18}O$ of ~1-2‰) in the Late Neolithic (shells 8-12). Maximum $\delta^{18}O$ range from ~–2‰ to +7.5‰ (average +3.4‰) in shells 1-7 (Table 1, Figure 4), compared to a range of ~–4.6‰ to +0.4‰ (average –3.0‰) in the second part of the Late Neolithic (shell 8-12). Only two shells exist from the Early Chalcolithic period. The older *Unio* shell (17208) suggests a large contrast between minimum and maximum $\delta^{18}O$ (range of 12.8‰) similar in magnitude to the earlier shells (i.e. shells 1-7; Table 1, Figure 4). The later shell exhibits a narrower range (4.1‰), more like the Late Neolithic (shells 8-12) in the TP area of the East mound.

$\delta^{13}C$ vs. $\delta^{18}O$

$\delta^{13}C$ vs. $\delta^{18}O$ were compared for each shell and evaluated using regression analysis (Table 1 and Figure 4). Several individual shells appear to exhibit some covariation between $\delta^{13}C$ vs. $\delta^{18}O$ (e.g. 5291, 1563, 12318, 17208; Figure 3), though the regression analyses largely suggest that in most cases only very weak relationships exist between $\delta^{13}C$ and $\delta^{18}O$ ($r \leq 0.5$, Table 1), often below the level of significance ($p<0.01$; Figure 4). However, this might be partly explained by variable $\delta^{13}C$/ $\delta^{18}O$ correlation along single shell profiles (i.e. some shells exhibit both synchronous and anti-phase sections along a single profile; Figure 4).

Discussion

When dealing with shells from archaeological material for palaeoenvironmental reconstruction, there is inevitable concern as to how these shells were deposited and subsequently whether their palaeoenvironmental record incorporated is directly related to the archaeological phase or site from which they were excavated. This is exaggerated at a site like Çatalhöyük, where shells (including *Unio mancus-eucirrus*) were both consumed (collected live) and used in both ornamentation and construction, therefore potentially being incorporated into the sequence by other means. This might include collection of empty dead shells from the banks of waterbodies or even traded into the site from other communities, and therefore the palaeoenvironmental record might be unrelated to their archaeological deposit. Whilst we acknowledge it is difficult to entirely overcome these concerns, we argue that the shells used in this study are related to the archaeological deposits from which they originate. In the lowermost levels of the site, a shell midden appears to exist containing a very high abundance of shells. In these layers we can be more confident that the shells (including the analysed specimens shells 1-3; Table 1) were collected live, as a food source, and afterwards the shells discarded in a common place.

In the upper levels shell abundance drops considerably. This might be due to the fact that shellfish were first consumed, then their shells were used secondarily for the production of artefacts and for use in construction material or for making plaster (Bar-Yosef Mayer 2013). There is no way of ascertaining either live or dead collection in this section and assessment of the taphonomy of the shells cannot provide any further information here as all breakages of the analysed specimens seem to be post-depositional. Further, we cannot use the ^{14}C date from individual shells to determine when they alive/dead, due to the likely hard water effects causing erroneous reservoir offsets (see Supplementary Data, Table 1). Large reservoir offsets from aquatic shell material are likely in carbonate catchments such as Çatalhöyük (soft limestone/marl, overlain by alluvial deposits; Roberts, 1982; Boyer et al., 2006), due to the incorporation of ancient carbon from the catchment and/or groundwater. Reservoir offsets can be extremely large (commonly over >1,000 yrs; e.g. Geyh et al., 1998; Lanting and van der Plicht, 1998; Culleton, 2006; Keaveney and Reimer, 2012) and can also exhibit substantial local variation (e.g. Barnekow et al., 1998; Keaveney and Reimer, 2012; Lougheed et al., 2013; Philippsen and Heinemeier, 2013). Unfortunately, the 'hard water effect' has not been studied in Konya basin water systems to date, meaning no reliable correction factor can be applied. Therefore, for the upper levels we can only assume that *Unio* likely remained a food source and therefore, that live specimens must have been collected. We also argue that if the analysed shells were completely randomly collected for ornamentation and construction, then the results might be expected to be more random, whereas we actually see a systematic change in $\delta^{18}O$ patterns over the occupation phase (see Figure 3 and 4).

Greater analysis and understanding of the microstructural layers and drilling at much finer resolution might have provided us with more detailed annual cycles and perhaps in some cases enabled us to better assess whether there was an actual growth stop, or just where very slow growth occurred. However, we are confident that drilling at ~0.5mm resolution is sufficient to capture much of the annual variation (over multiple cycles) with individuals and that the shifts in seasonality between shells are also detectable at this sampling resolution (as demonstrated by the isotope profiles in Figure 3 and shell isotope metric data in Figure 4).

Interpretation of the extended isotope dataset:

The present study builds on the pilot study of from Bay-Yosef Mayer et al. (2012) by markedly expanding the dataset and placing more focus on the latter stages of occupation on the East Mound, in order produce a detailed temporal record of changes in seasonal water balance over the Çatalhöyük occupation phase (9,150-8,000 yrs BP). The shell- $\delta^{18}O$ data records changes in water balances (discussed below) over the life span of the specimens, thus making isotope-growth records of sub-fossil *Unio* shells an important (and likely, the only) proxy for establishing seasonal climate records from this important archaeological site. However, in the pilot only 4 sub-fossil shells were analysed (indicated in

Figure 3), meaning that the dataset could only provide spot estimates of seasonality and was insufficient to reconstruct temporal changes in seasonality over the occupation period. The addition of eight more shells from various archaeological layers, spread out over the entire occupation phase, has enabled us to explore the evolution of seasonal climate and the timing for comparison with regional palaeoclimate records and the Çatalhöyük archaeological record. Subsequently we have been able to infer possible links between the archaeological record and local to regional climate change (i.e. millennial scale cooling and the 8.2k event) at Çatalhöyük.

As the *Unio mancus eucirrus* specimens analysed in this study were likely collected from nearby freshwater sources including rivers and small lakes, then the δ^{18}O signal is likely local to regional. We cannot determine specifically where these shells come from (i.e. lake or river), as *Unio mancus eucirrus* can live in both environments. However, during this period of active river avulsion and seasonal flooding (e.g. Roberts and Rosen, 2009), small lakes and river channels within the region were likely continuously evolving. These local waterbodies would have been largely fed by water from the Çarşamba River as it floods across the alluvial fan delta during winter/spring. This is then followed by a season of evaporation during the summer months as these local water bodies gradually retract and the river flow returns to the main river channel. As the Çatalhöyük site was never situated directly on the banks of a river or lake (Gümüş and Bar-Yosef Mayer, 2013), then it is likely that shellfish were collected from a variety of water bodies across the plain (perhaps even including the main channel of Çarşamba River itself), all fed by same hydrological system, thus recording a local to regional climate signal. From a number of the analysed specimens the isotope data appear to suggest autumn collection (Figure 3; Bar-Yosef Mayer et al., 2012), though the data presented here are too limited to make any firm conclusions. An accurate determination of time of collection (or season of death) would require sequential analyses of the last few weeks/months of many *Unio* specimens (i.e. n=>12), each with an intact ventral margin (e.g. Shackleton, 1973; Mannino et al., 2003; Hallmann et al., 2013).

δ^{18}C

The range in δ^{13}C (between –12‰ to –5‰) is interpreted as the *Unio* shells utilising a mixed carbon pool of both dissolved inorganic carbon, directly from the ambient water and dietary organic carbon (Fritz and Poplawski, 1974), primarily particulate algae and plant debris (Bar-Yosef Mayer et al., 2012). Ingestion of the inorganic dissolved carbon (yielding high δ^{13}C of between –3 to +3‰; Leng and Marshall, 2004) is inferred by the relatively high δ^{13}C exhibited by all shells, which are above the values expected if carbon was utilised only from the dietary particulate algae and plant debris, as both of these components exhibit low δ^{13}C (between –10‰ to –30‰; Meyers and Teranes, 2001). Similar δ^{13}C of all fossil shells suggest that source carbon (i.e. diet) has not changed dramatically over the study period (Bar-Yosef Mayer et al., 2012). There is also little change in seasonal contrast of δ^{13}C between shells (Figure 4), suggesting that summer to winter carbon source and utilisation has remained relatively consistent over the study period. However, slight fluctuations in absolute values (i.e. minimum, maximum and average; Figure 4) are apparent, likely reflecting minor changes in the local environment.

δ^{18}O

As with Bar-Yosef Mayer et al. (2012), we suggest that the major driver of $\delta^{18}O$ in the shells is the precipitation/evaporation ratio of the water from which they formed (water balance). $\delta^{18}O_{shell}$ should be a function of the $\delta^{18}O$ of the water in which the shells grew and temperature of the water in which the shell grew (Leng and Marshall, 2004). However, temperature can be ruled out as the major driver of $\delta^{18}O$ change in these shells because of the size of the shifts. In some of the shells, there is >10‰ difference between maximum and minimum values, and for temperature alone to account for this, there would have to be a >40°C seasonal temperature variability, based on the palaeotemperature equation of Grossman and Ku (1986) during the growth period of the shell. Based on the modern meteorological data presented above (Figure 2), this is unlikely to have been the case. Furthermore, other regional climate records show colder conditions around 8.2ka (Rossignol-Strick, 1995; Bar-Matthews et al., 1999; Ariztegui et al., 2000; Rohling et al., 2002; Wenninger et al., 2006; Pross et al., 2009; Göktürk et al., 2011). During colder summers, summer $\delta^{18}O_{shell}$ would be expected to be higher in shells 8-12 (Figure 3 and 4) if temperature was the main driver of $\delta^{18}O$, not lower as we see in the Çatalhöyük $\delta^{18}O$ data, again supporting the argument that precipitation and evaporative (P;E) effects rather than temperature is main driver. Therefore, $\delta^{18}O_{shell}$ is likely related more to $\delta^{18}O$ of the water in which the shells grew, and given the size of the shifts and the fact it is thought any water bodies around Çatalhöyük where the shells might have lived were likely to have been small (Roberts et al., 1999; Doherty, 2013) and subject to evaporative effects, changes in water balance are therefore likely to be the major driver of $\delta^{18}O_{lakewater}$, and therefore $\delta^{18}O_{shell}$. Other controls on the shell $\delta^{18}O$ composition such as temperature and groundwater contributions might have been responsible for very minor shifts in the $\delta^{18}O$, but likely far outweighed by more dominant P;E effects. Similarly, there is also some evidence for changes in wind patterns and rainfall trajectories around 8.2ka (Dean et al., 2015), but again this could only account for very minor change in $\delta^{18}O$, and not the magnitude of change evident in this dataset.

The classic saw tooth pattern evident in many shells likely reflects the annual climate cycle with gradually rising $\delta^{18}O$ during late spring/summer due to evaporation, followed by a sharp shift to lower $\delta^{18}O$ during the winter, most likely due to enhanced precipitation (cf. Versteegh et al., 2011; Bar-Yosef Mayer et al., 2012 and see above). In the latest part of the Neolithic (after ca. 8,300 cal. yrs BP), a reduction in seasonality is inferred, characterised by a distinct drop in maximum summer values, but very little change in winter minimum values across the whole subfossil shell dataset. This suggests a change in summer climate, potentially indicating reduced summer evaporation (discussed in more detail below). Markedly different annual variability is displayed in the $\delta^{18}O$ data from the two shells corresponding to the Chalaolithic period (i.e. seasonal $\delta^{18}O$ range of 12.8‰ in the older (17208) compared to 4.1‰ in the younger (16918) shell; Figure 3). This might represent temporal change, perhaps unstable, fluctuating climate at this time, though any interpretation of seasonality must be treated with caution due the scarcity of data from the Chalcolithic period.

The lack of change in winter $\delta^{18}O$ over the study period (i.e. between –6‰ to –8.5‰; Figure 4) suggests relatively stable, wet winters. However, the very minor increase in minimum winter values ($\delta^{18}O$ of ~1-2‰) in the Late Neolithic, might infer slightly drier winters at this time, consistent with the shift towards more arid conditions recorded in regional palaeoclimate records (Bar-Matthews et al., 2003; Eastwood et al., 2007; Jones et al., 2007;

Dean et al., 2015). Alternatively, winter growth cessation below a certain temperature threshold might mean that winter conditions cannot be deduced from the δ^{18}O data.

δ^{18}O vs. δ^{13}C

The δ^{18}O and δ^{13}C profiles for each shell were compared to assess linkages between molluscan carbon source (particularly diet) and seasonal climate variation over the study period. Covariation is apparent in some shells (i.e. 5291, 1563, 12318, 17208; Figure 2 and 3) suggesting that seasonal climate change influences carbon source to some degree, but this relationship is ambiguous. Predominately, the data infers that in addition to seasonal climate variations, local, short lived factors must also be important for determining food source and carbon uptake in *Unio* shells. This is perhaps further supported by the lack of any longer-term trend when shell δ^{13}C/ δ^{18}O are plotted in chronological order (Figure 3 and 4).

Early Holocene climate change at Çatalhöyük

We show low winter δ^{18}O in all shells (average minimum of –8.5‰; Figure 3 and 4), which we take to suggest wet winters (e.g. Bar-Yosef Mayer et al., 2012), followed by rising δ^{18}O (up to the summer maxima) indicative of dry, hot summers. The big cyclical shifts seen in the shells indicate that the climate in the early Holocene at Çatalhöyük was highly seasonal, as it is in the present day. There is a distinct drop in summer δ^{18}O shortly after ca. 8,300 cal. yrs BP (Figure 4 and 5). This occurs around the same time as millennial-scale cooling across the northern hemisphere that began around 8,600 yrs BP and lasted for 400-500 years (Rohling and Pälike, 2005 and references therein) and the later, more intense cold, dry 8.2k event (Alley et al., 1997; Rohling and Pälike, 2005; Thomas et al., 2007). A drop in temperatures could have led to less summer evaporation, which would account for the lower δ^{18}O recorded by the shells in the summer months. In contrast to the change in summer δ^{18}O after ca. 8,300 cal. yrs BP, winter δ^{18}O minima in the shells exhibit very little change (<1‰) over this period, despite regional climate records from Turkey and the wider region generally inferring drier conditions and intensified aridity between ca. 8,600-7,800 cal. yrs BP (e.g. Rohling and Pälike, 2005; Fleitmann et al., 2007; Kotthoff et al., 2008b; Geraga et al., 2010; Göktürk et al., 2011; Figure 5). As summer rainfall is thought to be low in the early Holocene in the Eastern Mediterranean (e.g. Wick et al., 2003; Turner et al., 2010), we speculate that a reduction in rainfall occurred during the winter/spring months, but is perhaps not picked up in the δ^{18}O data. This might be due to growth cessation occurring during the winter below a certain temperature threshold, hence the similar winter minima values exhibited many of the sub-fossil shells. Alternatively, changing precipitation values might have had little impact on the δ^{18}O of freshwater bodies in the Çatalhöyük region in the winter. This might be due to winter precipitation quickly recharging local water bodies after the summer dry season, meaning these water bodies have δ^{18}O close to the mean precipitation, even under periods of reduced rainfall (up to a threshold level, that perhaps wasn't exceeded in the period around 8,300 cal. yrs BP).

Therefore, the reduction in seasonality that we infer after 8,300 cal. yrs BP was driven primarily by a reduction in summer δ^{18}O. This shift in seasonality occurs at the same time as there were shifts in other records. Many records from Turkey lack the temporal resolution to examine conditions at 8.2k (Eastwood et al., 2007; Roberts et al., 2011) or suffer from hiatuses (Leng et al., 1999; Roberts et al., 1999; Figure 1). However, a high resolution record from the Sofular Cave in northern Turkey suggests drier conditions between 8,400 and 7,800 yrs BP (Figure 5) relative to the generally wetter period between 9,600 and 5,400 yrs BP, related to much stronger storms in winter due to either enhanced summer insolation associated with high sea surface temperatures or summer monsoon rains (Göktürk et al., 2011). Similarly, a new stable isotope and carbonate mineralogy record from Nar lake (central Turkey) records a dry period peaking around 8,200 yrs BP (Dean et al., 2015). In terms of the proposed cause of this increased dryness in Turkey at 8.2k, a significant amount of the precipitation that falls in central Turkey originates in the North Atlantic (Türkeş et al., 2009), so a reduction in cyclogenesis when it was cooler in the North Atlantic (such as at the time of the 8.2k event) could have reduced the frequency of Mediterranean storm tracks and reduced the precipitation in the region (Prasad et al., 2004; Rowe et al., 2012).

This pattern is replicated throughout much of the eastern and southern Mediterranean region (see Figure 5 and below), the Middle East and Arabia (Bar-Matthews et al., 1999; Fleitmann et al., 2003; Fleitmann et al., 2007; Verheyden et al., 2008) and into Africa (e.g. Gasse, 2000). For example, a number of records from the adjacent Aegean Sea and borderlands (e.g. Figure 5) infer a shift to cooler temperatures and/or drier conditions between ca. 8,600-8,000 yrs BP, with some records documenting longer term climate deterioration (e.g. Rohling et al., 2002; Kotthoff et al., 2008b; Marino et al., 2009), likely associated with centennial-scale cooling and solar modulation of climate (e.g. Rohling et al., 2002; Rohling and Pälike, 2005) and other records suggesting that this is more focussed around the 8.2k climatic anomaly (e.g. Kotthoff et al., 2008b; Pross et al., 2009). Cold, arid events generally recur on centennial timescales (e.g. 10,500, 9,500–9,000 and 8,000–7,800 yrs BP; Marino et al., 2009) and appear to correspond with increases in intensity of the Siberian High pressure system (as reflected in the GISP2 K+ record; Mayewski et al., 1997), believed to be an important driver of winter climate over the eastern Mediterranean region (Kotthoff et al., 2008b; Marino et al., 2009; Pross et al., 2009).

In summary, we infer here that there was a shift in seasonal climate (i.e. seemingly lower rates of summer evaporation) at Çatalhöyük around ca. 8,300 yrs BP (Figure 4 and 5), broadly synchronous with widespread climate change across the region. While it is difficult to establish the exact hydrology of the water bodies in which the shells lived, since they were collected and taken to Çatalhöyük, it is likely they grew in wetlands which had significantly different hydrologies to the lakes in the eastern Mediterranean from which previous isotope records have been published. This is likely to explain why we infer less evaporation in the summer around 8,200 yrs BP whereas other records from around the region infer drier conditions. However, the fact that changes seem to occur at the same time suggests that they could be responding to the same driver. A potential cause is related to the complex interplay of regional monsoon systems (African, Indian and Siberian) in response to long term centennial cooling between ca. 8,600-8,000 yrs BP, ultimately linked to solar forcing (Rohling and Pälike, 2005), later intensified by the large magnitude 8.2k event via climate system feedbacks stemming from the North Atlantic Ocean (Barber et al., 1999; Clark et al., 2001; Alley and Ágústdóttir, 2005; Overpeck and Cole, 2006; Born and Levermann, 2010).

Climate implications for human settlement at Çatalhöyük

Here we confirm a strong seasonal wet-dry early Holocene period at Çatalhöyük, which supports the fission-fusion farming hypothesis (outlined in the introduction) proposed by Roberts and Rosen (2009). Briefly, heavy rainfall in the winter/early spring caused flooding of the Çarşamba fan, which forced crop growing in dryland soils distant from the main site (i.e. fission). Thus is followed by dry summers with intensive evaporation, which dried out the alluvial fan and enabled inhabitants to return to the main site in late summer (i.e. fusion). At the same time, this climate pattern would have enabled the growing of annual cereals in the vicinity of the site if flooding did not occur, or was restricted to a few channels, as proposed by Doherty (2013).

Between ca. 8,250-8,100 yrs BP, nucleated dispersal and the 'fission-fusion' farming system is thought to have ended due to multi-decadal drought (Roberts and Rosen, 2009), broadly coincidental (within ^{14}C dating errors; less than 100 years for Çatalhöyük stratigraphic sequences following bayesian modeling; Marciniak et al., 2015) with the shift in seasonality in the *Unio* $\delta^{18}O$ data presented here (i.e. beginning around 8,300 yrs BP; Figure 5). The inhabitants of Çatalhöyük could have already been subject to longer-term climate stress, which perhaps surpassed a threshold during the more severe conditions associated with the 8.2k event, forcing cultural change and adaptation (e.g. Wenninger et al., 2006; Roberts and Rosen, 2009). Whilst the resolution of the *Unio* isotope data presented here is far too coarse and the dating too imprecise to investigate seasonal conditions associated with the 8.2k event per se, the shells exhibiting the most reduced seasonality do date to the Late Neolithic, between ca. 8,300-8,100 cal. yrs BP according to the Çatalhöyük sequence stratigraphy (Figure 4 and 5). Thus, any farming system employed by the inhabitants of Çatalhöyük was closely connected to the climate of the region, and any change in climate is likely to have changed how agriculture could be practised around the site. Farming and cultural changes dating back to 8,200 cal. yrs BP have been observed at other Near East sites (e.g. Tell Sabi Abyad, Syria, Akkermans, 2010). However, as described by van der Horn (2015), extreme care must be taken deciphering climate-related impacts from anthropogenic activities and cultural development.

Overall, we argue that changing water balance (i.e. potentially reduced local summer evaporation post ca. 8,300 yrs BP) inferred from the shell $\delta^{18}O$ data could be considered an important contributory factor behind observed cultural changes at Çatalhöyük in the Late Neolithic/Early Chalcolithic period. However, we acknowledge that other factors, including environmental (e.g. catastrophic earthquake; Marciniak et al., 2015), behavioural and socio-economic factors must also have played an important role, particularly concerning the short relocation distance (~150 m) to the west mound around 8,200 yrs BP.

Conclusions

$\delta^{18}O$ data from *Unio* shells from Çatalhöyük record early Holocene seasonal changes in regional water balance, documenting a clear 'saw-tooth' pattern that we argue is due to dry, evaporative summers (increasing $\delta^{18}O$), and wet winters (rapid decline in $\delta^{18}O$, returning to 're-charged' rainwater/groundwater values, prior to growth/cessation during the winter months). This supports previous work that has suggested a marked seasonal climate shift at Çatalhöyük in the early Holocene. The *Unio* shells indicate a reduction in seasonal contrast after ca. 8,300 yrs BP, mainly driven by a drop in summer $\delta^{18}O$, potentially caused by reduced summer evaporation in the local area. These changes coincide with widespread cooling (between 8,600-8,000 yrs BP), changes in the intensity of monsoon systems and the 8.2k event. For humans inhabiting the Çatalhöyük site and wider Konya basin, changing water balance seasonality and cooler climate might have caused long-term climate stress and therefore these should be must be considered potential contributory factors to observed cultural changes evident in the archaeological record.

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Tables and Figures:

Table 1: Details of the *Unio* shells analysed in this study, including sample number, stratigraphic origin, cultural period, ^{14}C age, $\delta^{13}C$ vs $\delta^{18}O$ regression statistics (see also text, Figure 4) and shell information (i.e. height, no. of samples, estimated no. of annual cycles).

Figure 1: A. Location of the study site Çatalhöyük (in the Konya Basin, south central Turkey) and others site mentioned in the text. B. Regional setting. C. Sub-fossil *Unio mancus eucirrus* (shell 1563) analysed in this study showing drilling pattern for isotope analyses along of the direction of growth.

Figure 2: Mean precipitation and temperature data (including mean maximum and minimum temperatures) for Konya, 1960-2012 (TSMS, 2013).

Figure 3: Temporal (i.e. interannual) profiles of $\delta^{13}C$ and $\delta^{18}O$ from all *Unio* shells analysed in this study (plotted in chronological sequence order; oldest shell at top to youngest at bottom). Isotope data are plotted against sample number (on x-axis), starting from the umbo (i.e. youngest part of the shell = 1) and moving away towards to the ventral margin. Dotted lines represent inferred maximum summer (July/August) evaporation and subsequently the number of summers represented in each shell. Potential growth stops are indicated with arrows. The shell ID numbers correspond to the excavation unit numbers in which the shell were found (see Table 1). Shells included in the pilot study (Bar-Yosef Mayer et al., 2012) are underlined.

Figure 4: $\delta^{13}C$ and $\delta^{18}O$ shell-isotope metrics ordered chronologically (from oldest on left to youngest on right, with archaeological divisions) including average, minimum, maximum (i.e. plot **A** for $\delta^{13}C$ and plot **C** for $\delta^{18}O$) and range of values (i.e. plot **B** for $\delta^{13}C$ and plot **D** for $\delta^{18}O$). $\delta^{13}C$ and $\delta^{18}O$ silhouettes based on smoothed (loess, 0.5 span) maximum and minimum values for fossil shells. Plot **E** illustrates regression statistics r (line graph) and r^2 (bar chart) for $\delta^{13}C$ vs. $\delta^{18}O$ for each shell. Black bars= statistically significant ($p<0.01$); grey bars not statistically significant ($p>0.01$); reference line added at 0.2. The sequence is divided into three cultural periods (i.e. EPN=Early Pottery Neolithic (Early Central Anatolia; ECA II), Late Neolithic (ECA III) and E. Chal.= Early Chalcolithic (ECA IV) using the CANeW system after Gérard (2002).

Figure 5: Comparison of $\delta^{18}O$ range and standard deviation data for the subfossil *Unio* shells collected from Çatalhöyük (this study) with regional climate data (and event stratigraphy) for the Eastern Mediterranean Sea and the Middle East, and archaeological settlement and flooding history for the Çarşamba Fan (after Baird, 2005; Roberts and Rosen, 2009). **A.** Pollen-inferred summer and winter temperatures from Tenaghi Philippon (northeast Greece); **B.** Pollen-inferred annual precipitation from Tenaghi Philippon (all from Pross et al., 2009). **C.** $\delta^{18}O$ from Qunf Cave in Oman (Fleitmann et al., 2003; Fleitmann et al., 2007). **D.** $\delta^{18}O$ from Soreq Cave in Israel (Bar-Matthews et al., 1997); **E.** Foraminifera-inferred summer sea surface temperatures from the Aegean Sea (Marino et al., 2009). **F.** $\delta^{13}C$ (200-year smooth) and $^{234}U/^{238}U$ from Sofular Cave in north Turkey (Göktürk et al., 2011). **G.** Range (in black) and standard deviation (in grey) of $\delta^{18}O$ values of the *Unio* shells from Çatalhöyük (this study). NB. Solid circles indicate known sequence ages (using mid-point depths following calibration; see Table 1), whilst dotted circles indicate interpolations based on the chronological sequence order and therefore are not real ages, but estimates. Solid lines indicate interpolation (from mid-point depths) of dated sequences, whilst dashed lines indicate hypothetical interpolation as specific ages have not been determined. **H.** Excavated archaeological sites on or near the Çarşamba Fan and predicted flooding regime (from Roberts and Rosen, 2009). Grey shaded area indicates period of more arid conditions in the Eastern Mediterranean and Middle East according to regional palaeoclimate records (e.g. Rohling and Pälike, 2005; Göktürk et al., 2011; see text). The timing of the 8.2 k event (8,247–8086 yrs BP; Thomas et al., 2007) is also shown (i.e. white section interrupting grey shaded arid phase) and dotted lines indicate the timing of the ~70 year central event (8,141-8212 BP; Thomas et al., 2007). Solid back box (on chart A) indicates period of centennial scale cooling (8,600-8,000 BP) according to Rohling and Pälikhe (2005). Archaeological phases follow the CANeW system after Gérard (2002).

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Shell No.	Archaeological unit (shell code)	Stratigraphic origin	Period	Sequence Age (cal. yrs BC)	Sequence Age (cal. yrs BP)	$\delta^{13}C$ vs $\delta^{18}O$ (regression statistics)	Shell height (mm)	No. of samples	Estimated no. of years
1	11376	South.G	Early Pottery Neolithic (ECA II)			r=0.62 (r^2=0.38, p<0.01)	26.6	31	2
2	5291	South.G	Early Pottery Neolithic (ECA II)			r=0.40 (r^2=0.16, p<0.01)	39	46	3
3	5306	South.G (Space 181)	Early Pottery Neolithic (ECA II)	7,000 cal. BC	8,950 cal.BP	r=0.55 (r^2=-0.31, p<0.01)	31.48	66	2
4	1563	South L. (Space 115)	Late Neolithic (ECA III)	6,500 cal. BC	8,450 cal. BP	r=0.51 (r^2=0.26, p<0.01)	33.31	41	3
5	17037	South.P	Late Neolithic (ECA III)			r=0.45 (r^2=0.20, p>0.01)	30.79	12	1
6	16718	4040	Late Neolithic (ECA III)			r=0.35 (r^2=0.13, p>0.01)	n/a	28	2-3
7	12318	4040.G	Late Neolithic (ECA III)			r=55 (r^2=0.30, p<0.01)	n/a	36	3
8	17670	TP.M#	Late Neolithic (ECA III)	6,360-6,250 cal. BC	8,310-8200 cal. BP	r=0.49 (r^2=0.24, p<0.01)	33.46	48	2
9	17809	TP.N	Late Neolithic (ECA III)	6,345-6,240 cal. BC	8,295-8,190 cal. BP	r=0.46 (r^2=0.21, p>0.01)	27.61	26	2
10	13532	TP.N	Late Neolithic (ECA III)	6,345-6,240 cal. BC	8,295-8,190 cal. BP	r=0.44 (r^2=0.19, p>0.01)	n/a	31	2
11	17687	TP.O	Late Neolithic (ECA III)	6,210-6,175 cal. BC	8,160-8,125 cal. BP	r=0.39 (r^2=0.15, p>0.01)	27.74	30	3
12	12278	TP.Q	Late Neolithic (ECA III)	6,135-6100 ca. BC	8,085-8,050 cal. BP	r=0.46 (r^2=0.21, p>0.01)	27.64	24	Unknown
13	17208	Trench 5 (west mound)	Early Chalcolithic (ECA IV)	5,900 BC (direct date different*)	7,850 BP	r=0.58 (r^2=0.33, p<0.01)	25.11	31	2
14	16918	Trench 7 (west mound)	Early Chalcolithic (ECA IV)			r=0.84 (r^2=0.71, p<0.01)	n/a	32	1-2

Table 1

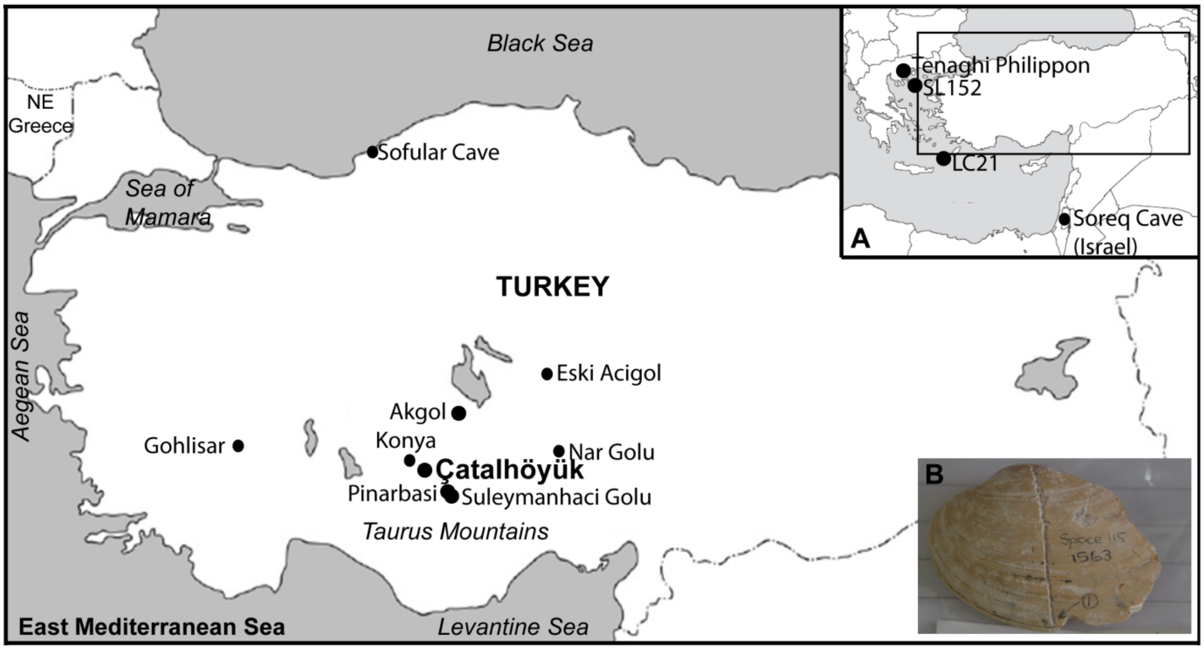


Figure 1

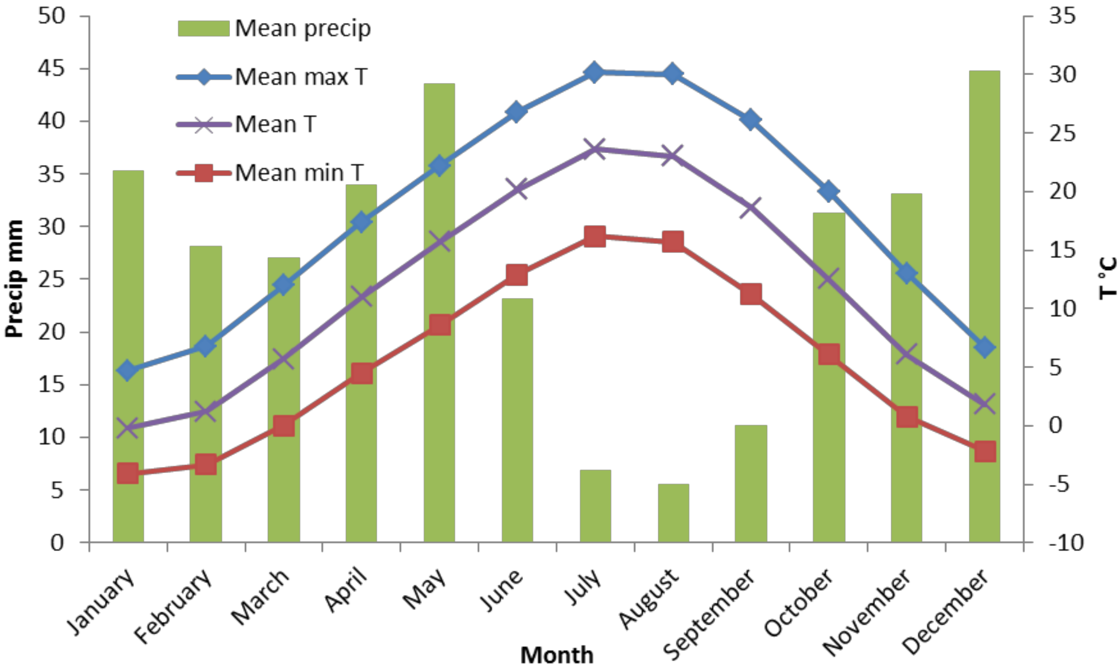
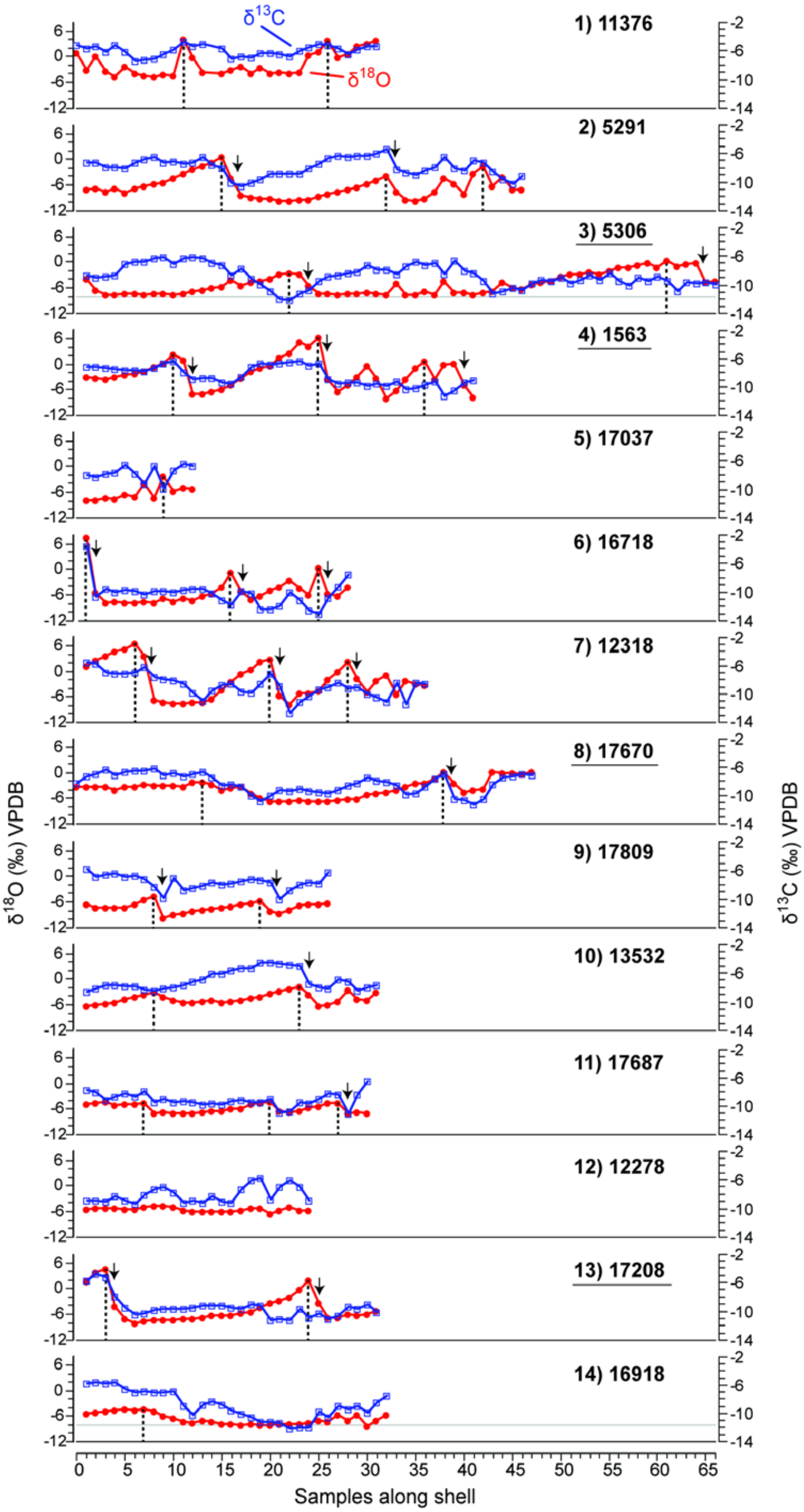
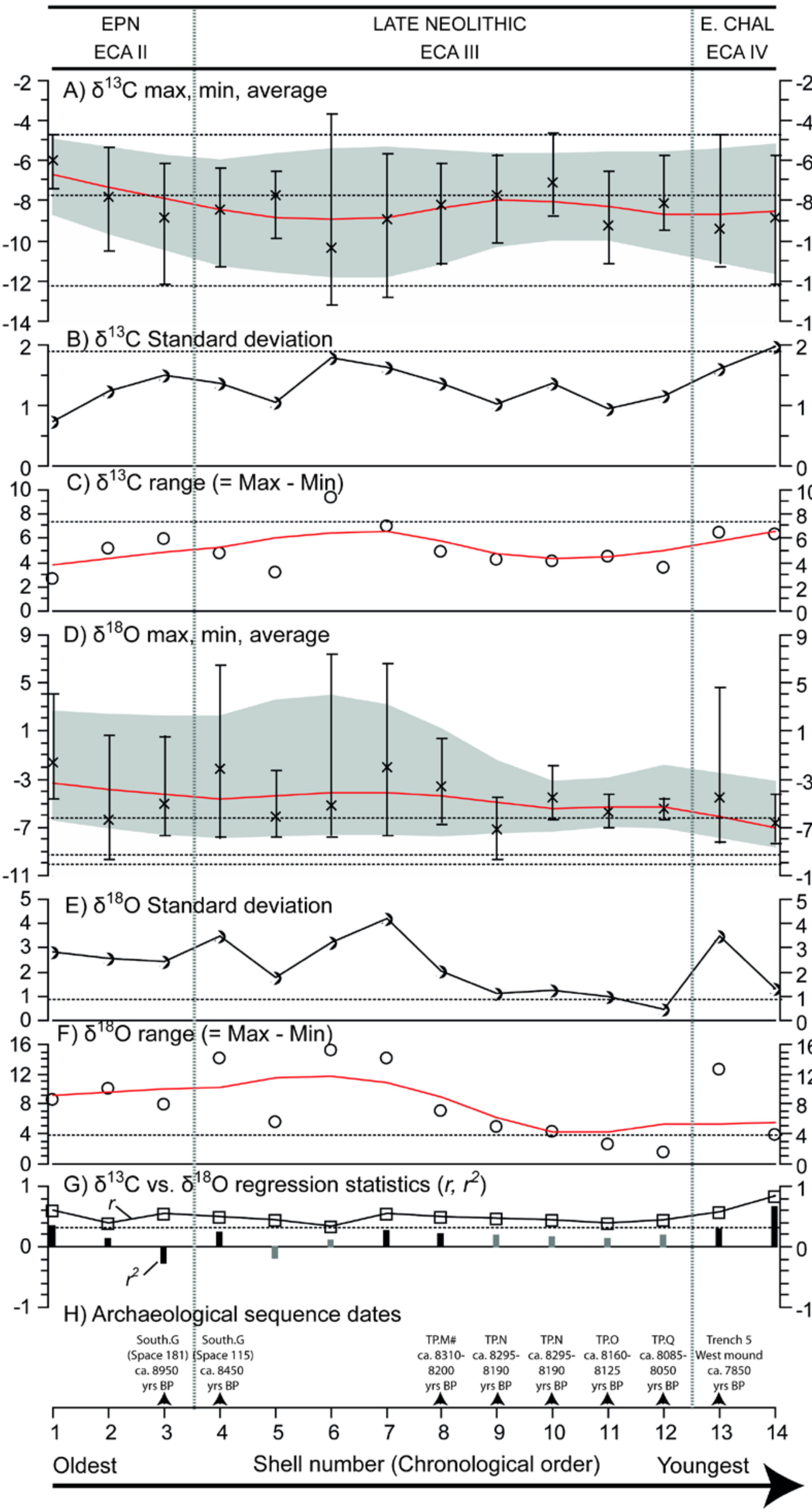


Figure 2



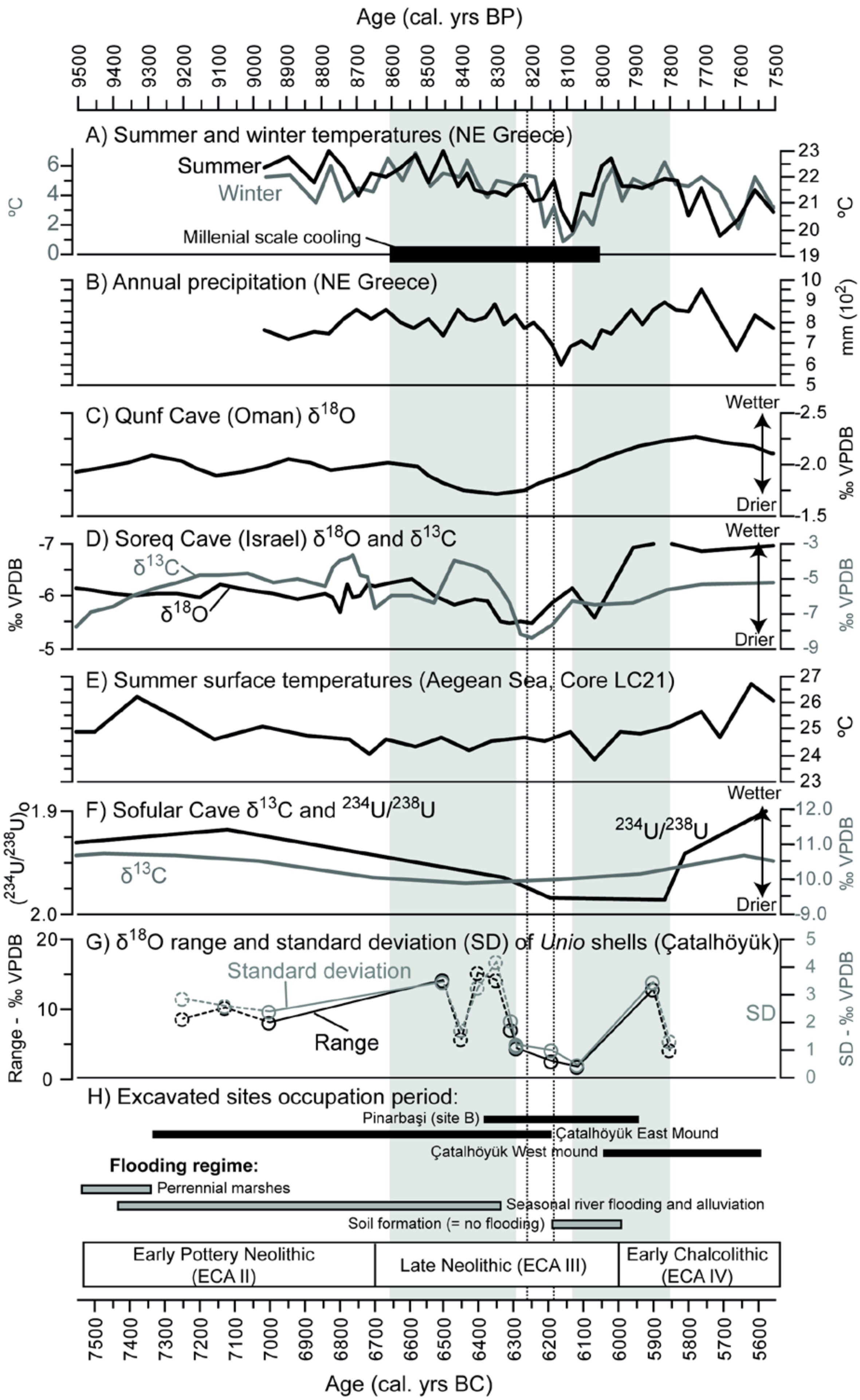
δ13C
δ18O
1) 11376
2) 5291
3) 5306
4) 1563
5) 17037
6) 16718
7) 12318
8) 17670
9) 17809
10) 13532
11) 17687
12) 12278
13) 17208
14) 16918
δ18O (‰) VPDB
δ13C (‰) VPDB
Samples along shell

Figure 3



EPN
ECA II
LATE NEOLITHIC
ECA III
E. CHAL
ECA IV
A) δ13C max, min, average
B) δ13C Standard deviation
C) δ13C range (= Max - Min)
D) δ18O max, min, average
E) δ18O Standard deviation
F) δ18O range (= Max - Min)
G) δ13C vs. δ18O regression statistics (r, r2)
H) Archaeological sequence dates
‰ VPDB
cal. yrs BP
South.G (Space 181) ca. 8950 yrs BP
South.G (Space 115) ca. 8450 yrs BP
TP.M# ca. 8310-8200 yrs BP
TP.N ca. 8295-8190 yrs BP
TP.N ca. 8295-8190 yrs BP
TP.O ca. 8160-8125 yrs BP
TP.Q ca. 8085-8050 yrs BP
Trench 5 West mound ca. 7850 yrs BP
Oldest
Shell number (Chronological order)
Youngest

Figure 4



Age (cal. yrs BP)
9500
9400
9300
9200
9100
9000
8900
8800
8700
8600
8500
8400
8300
8200
8100
8000
7900
7800
7700
7600
7500
A) Summer and winter temperatures (NE Greece)
Summer
Winter
°C
Millenial scale cooling
B) Annual precipitation (NE Greece)
mm (10^2)
C) Qunf Cave (Oman) δ^{18}O
Wetter
Drier
‰ VPDB
D) Soreq Cave (Israel) δ^{18}O and δ^{13}C
δ^{13}C
δ^{18}O
% VPDB
‰ VPDB
E) Summer surface temperatures (Aegean Sea, Core LC21)
F) Sofular Cave δ^{13}C and ^{234}U/^{238}U
(^{234}U/^{238}U)$_0$
G) δ^{18}O range and standard deviation (SD) of *Unio* shells (Çatalhöyük)
Standard deviation
Range
Range - ‰ VPDB
SD
SD - ‰ VPDB
H) Excavated sites occupation period:
Pinarbaşi (site B)
Çatalhöyük East Mound
Çatalhöyük West mound
Flooding regime:
Perrennial marshes
Seasonal river flooding and alluviation
Soil formation (= no flooding)
Early Pottery Neolithic (ECA II)
Late Neolithic (ECA III)
Early Chalcolithic (ECA IV)
Age (cal. yrs BC)

Figure 5

Lab No.	Sample	Sample No.	Stratigraphic origin	Radiocarbon Date (BP, 1δ)	Calibrated Age (cal. yrs BP)	
					1σ(68.2%)	2σ(95.4%)
BA111364	Shell (*Unio* spp.)	17208	West.T5	8575±30	9550BP (68.2%) 9530BP	9560BP (95.4%) 9490BP
BA111363	Shell (*Unio* spp.)	17670	TP.N	8180±30	9200BP (6.2%) 9180BP 9140BP (62.0%) 9030BP	9260BP (95.4%) 9020BP
BA111361	Shell (*Unio* spp.)	1563	South.L	8575±45	9560BP (68.2%) 9500BP	9630BP (95.4%) 9480BP
BA111362	Shell (*Unio* spp.)	5306	South.G	10100±35	11820BP(68.2%)11610BP	12000BP(95.4%)11400BP
Poz-58534	Shell (*Unio* spp.)	13532	TP.N	8360±50	9464BP (37.1%) 9398BP, 9292BP (2.9%) 9376BP 9362BP (28.3%) 9309BP	9493BP (95.4%) 9300BP
Poz-58535	Shell (*Unio* spp.)	12278	TP.Q	8680±50	9702BP (68.2%) 9554BP	9886BP (0.5%) 9248BP 9864BP (0.8%) 9851BP 9785BP (94.2%) 9537BP
Poz-58536	Shell (*Unio* spp.)	17687	TP.O	11010 ± 50	13050BP (3.5%) 13034BP 12968BP (64.7%) 12753BP	13086BP (95.4%) 12700BP
Poz-58537	Shell (*Unio* spp.)	16918	Trench 7 (west mound)	**8050 ± 50 BP**	9028BP (30.2%) 8971BP 8964BP (2.4%) 8954BP 8920BP (17.1%) 8863BP 8833BP (18.5%) 8781BP	9092BP (95.4%) 8726BP

Supplementary Data Table 1: Details of ^{14}C dates from 8 of the *Unio* shells and associated calibration (into calibrated years BP using the IntCal04 calibration curve (Reimer et al., 2004). NB. These ^{14}C dates were discarded due to the unrealistic ages generated. Instead, we use the ^{14}C Çatalhöyük archaeological sequence dates (e.g. Cessford et al., 2005; Marciniak et al., 2015; see main text, particularly Table 1).

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