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LO STUDIO DEGLI ISOTOPI DEL CARBONIO E DELL'AZOTO PER RICOSTRUIRE CRONOLOGIA, CLIMA E AGRICOLTURA NELL'OLOCENE MEDIO AD ARSLANTEPE (ANATOLIA)

CARBON AND NITROGEN ISOTOPE ANALYSIS REVEALS CHRONOLOGY, PALAEOCLIMATE AND AGRICULTURAL PRACTICES AT ARSLANTEPE (TURKEY) DURING THE MID-HOLOCENE

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A te,
che mi hai insegnato l'onestà intellettuale
oltre che morale.

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INTRODUCTION

The main goal of the archaeobotanical research is to investigate the past relationship between human communities and natural environment. The study of plant remains from archaeological sites is traditionally focussed on the reconstruction of past vegetation and the way in which plant resources were used and managed by human groups. Food consumption, agricultural practice (processing, storage, food preparation), textile production, pharmacology, timber exploitation, land use and fodder supply are some of the main topics in which archaeobotanical analysis can provide useful information (Thiébault ed. 2002; Asouti, Austin 2005; van der Veen 2008; Mercuri et al. 2010; Sadori et al. 2015; González Carretero et al. 2017).

Particularly seeds and fruits analysis looks at the various aspects of plant use related to both cultivated and wild species. Firstly, crop production and plant landscape are inferred from taxonomic identification of plant remains (Pepe et al. 2013; Sabato et al. 2015). Secondly, inference of yield management system and primary economy successfully results in joining archaeobotanical data with the study of archaeological contexts in which plant remains are recovered (Chevalier et al. eds. 2014). On the other hand charcoal analysis, as wood is mainly preserved by carbonisation, leads to the reconstruction of evolutionary trends in vegetation cover and human exploitation (Rubiales et al. 2011; Arranz-Otaegui et al. 2017). Hence, charcoal assemblages display the long-term transformations of local environment into a cultural landscape, implying that local communities used what was present nearby (Shackleton, Prins 1992; Figueiral, Mosbrugger 2000). It is noteworthy that the integrated approach centred on archaeological sites is now one of the most developed in archaeobotany across Europe and beyond (Piccione et al. 2015).

In recent years archaeobotanical research has additionally reached a significant position in the production of palaeoclimatic, palaeoenvironmental and agronomic knowledge thanks to interdisciplinary applications. Plant remains have been disclosed as powerful tool to explore the role of climate in the evolution of environment and ancient societies. Climate oscillations during the Holocene have been often pointed out as the major factor in the emergence and collapse of ancient civilization (Staubwasser, Weiss 2006). This might be true in particular for semi-arid environments of eastern Mediterranean where seasonal fluctuations have a strong influence not only on plant growth, but also on their persistence (Roberts et al. 2011). In these regions modern studies have shown that plant growth is more closely related to rainfall than to temperature variation (Riehl 2008). Thus changes in rainfall amount or a lowering of groundwater level can cause major landscape alteration. For this reason archaeological sites in the Near East are turned out to be very sensitive to mid-Holocene climate trends (Rosen 2007).

These sites and their plant assemblages lend themselves to an evaluation of human capacity for adapting to palaeoclimate and shaping the landscape. Anyway palaeoecological reconstruction based on merely quantification of plant remains could lead to misleading conclusions (Masi et al. 2013a). In fact, as stated above, charcoal remains may reflect human selection, rather than humidity and vegetation changes (Masi et al. 2017, **Chapter 2**). Also seed/fruit remains may have recorded water inputs from different sources (i.e. precipitation and/or irrigation; Masi et al. 2014). Although various research methods have tried to identify irrigation evidences from cereal remains (Ferrio et al. 2005; Altaweel 2008), the quantitative analysis of archaeobotanical data doesn't still suffice for reconstructing ancient management systems (Dennell 1992).

Especially stable carbon and nitrogen isotope analyses on different plant remains are now used to reconstruct past climatic and environmental conditions (Ferrio et al. 2006; Fiorentino et al. 2008; Aguilera et al. 2012; Masi et al. 2013a,b; Arranz-Otaegui et al. 2017) and reveal ancient agricultural practices (Ferrio et al. 2005; Aguilera et al. 2008; Riehl 2012; Araus et al. 2014; Masi et al. 2014; Styring et al. 2017). The high potential of stable isotope studies in semi-arid regions of eastern Mediterranean is widely reported from literature (Hartman, Danin 2010).

There is a physiological relationship between water availability and carbon isotope composition in C3 plants (i.e. from temperate regions). In order to prevent water loss during stress events, plants close their stomata reducing intercellular CO_2 concentration and fixing not only the lighter ^{12}C (usually preferred) but also the heavier ^{13}C (Farquhar et al. 1989). Although physiological factors involved in carbon fixation are in turn affected by several environmental variables, $^{13}C/^{12}C$ ratio ($\delta^{13}C$) can be mainly related to climate fluctuations that influence plant water status (Cernusak et al. 2013). In fact, water availability is the main abiotic factor limiting plant growth, especially in semi-arid environments (Hartman, Danin 2010). As Tieszen (1991) already reported for archaeological remains, differences in temperature, solar radiation and soil salinity slightly affect the carbon isotope composition. In addition changes in $\delta^{13}C$ of atmospheric CO_2 during the Holocene have to be taken into account when comparing isotope signatures from plant remains of different time periods (Farquhar et al. 1993).

Furthermore, recent studies on stable nitrogen isotope ratio have shown that the presence/absence of soil nutrients constitutes a limiting factor for plant growth (Templer et al. 2007). As suggested for carbon composition, a variety of environmental factors can also modify plant nitrogen composition (Heaton 1987; Yousfi et al. 2010). Nevertheless N cycle in soils and cultivated plants is mainly conditioned by anthropogenic activities as manuring practices (Bogaard et al. 2007; Fraser et al. 2011). Since water availability is the main factor limiting cereal production in non-fed agricultural regimes and, in turn, ^{15}N abundance of cultivated plants integrates field conditions during growth, information on ancient crop management can be achieved by combining ^{13}C and ^{15}N abundances (Kanstrup et al. 2011).

The potential of archaeobotanical studies for palaeoclimate and palaeoenvironment reconstruction based on archaeological records also deals with the definition of the site chronologies. This is a poorly investigated topic since archaeologists usually refer to the merely radiometric analysis (Taylor, Bar-Yosef 2014). But the contribution of plant study from archaeological contexts is invaluable since it can lead to a better selection of dating materials (Walker 2005). It is worth to noting that a valid chronology is the framework for all of the multidisciplinary researches carried out on archaeological sites and allows to compare a number of regional proxies for reconstructing past general trend in natural and human processes (**Chapters 3-4**).

This PhD project has been carried out on plant remains recovered at the site of Arslantepe (Malatya, Turkey), whose research team the candidate is member. Excavations have been carried out by Sapienza University of Rome since 1961. The Italian archaeological project at Arslantepe has collected both national (Premio "Rotondi" ai Salvatori dell'Arte 2017; Premio "Vittorio de Sica" 2015) and international (Discovery Award 2015 by the "Shanghai Archaeology Forum") awards. Chronologically, the site can be placed as early as 4700 BC, when the first settlement so far investigated has been dated (Vignola et al. 2017a). The occupation is exceptionally long-term and continues until historical times. The site is an outstanding case study in eastern Mediterranean for both archaeological and archaeobotanical evidences (Frangipane ed. 2012). The archaeobotanical research at Arslantepe has been carried out for 35 years (Sadori, Masi 2012). Several studies were focussed on huge amount of charcoal (Sadori et al. 2006; Sadori et al. 2008; Piccione et al. 2015) and seed/fruit (Sadori et al. 2006; Balossi Restelli et al. 2010; Piccione et al. 2015) remains. In the very last years complementary stable carbon isotope records from charred wood and cereal remains of 3400-2000 BC levels were established in order to describe climatic conditions and agricultural practices (Masi et al. 2013a, b, 2014). The present research project aims firstly for the improvement of chronological framing by new ^{14}C-AMS dates on plant remains. Secondly, the extension of stable carbon isotope analysis to charcoal and cereal remains from 4700 BC and the establishment of new nitrogen isotope records from cereal grains have to be ensued. As a result, the first high-resolution isotope records from an archaeological site of the Near East for the mid-Holocene have been achieved, displaying more than 2500 years of unfailing climate changes and agronomic conditions behind cultural developments. A preliminary study on the recent ^{14}C-AMS dating from the site has been also published in the Proceedings of the 14th International Conference on

Accelerator Mass Spectrometry (University of Ottawa, Canada; Vignola et al. 2017a). The work is in progress: further data are essential for improving the chronostratigraphy and confirming the Arslantepe sequence as a pilot chronology in the Near East.

The thesis is divided into 2 sections on the basis of the applied archaeobotanical approach: a traditional one, focussed on palaeoecological and palaeoeconomic reconstruction from quantification of plant assemblages (**SECTION 1**); a multi-proxy one, based on the application of geochemical analyses on plant remains (**SECTION 2**). In each section, the study of different remains is reported in different chapters: seeds and fruits in **Chapter 1** and **Chapter 3**; charcoals in **Chapter 2** and **Chapter 4**.

This manuscript is a collection of several papers on archaeobotanical data from Arslantepe (Vignola et al. 2014; Masi et al. 2018; Vignola et al. 2017b; Vignola et al. 2018), obtained by the candidate during his PhD research project. Formats are displayed as journal publications. All the papers have been peer-reviewed and are published in journals indexed in Scopus and Web of Science. Two of the journals are in Q1 and one is in Q2 quartiles according to the Scientific Journal Report (SJR).

The primary economy of the earliest settlements excavated at the site (4300-3900 BC) is reconstructed in **SECTION 1**, **Chapter 1**. Results of the analysis of cereal crop remains are joined with data from animal remains. Comparisons with other Near Eastern sites are provided and discussed. It consists of the paper "Investigating domestic economy at the beginning of the Late Chalcolithic in Eastern Anatolia: the case of Arslantepe period VIII" authored by Vignola C., Balossi Restelli F., Masi A., Sadori L., Siracusano G. and published in *Origini* 36 (2014): 7-36.

The reconstruction of wood exploitation and timber use during 4300-2000 BC is presented in **SECTION 1**, **Chapter 2**. Results of charcoal analysis and the palaeoclimatic data already available for the site (Masi et al. 2013a, b) make this study suitable for the interpretation of human-environment interaction. Changes in charcoal assemblage through archaeological levels allow interpreting wood selection and cultural choices made by local communities. It consists of the paper "Timber exploitation during the 5th-3rd millennia BCE at Arslantepe (Malatya, Turkey): environmental constraints and cultural choices" authored by Masi A., Balossi Restelli F., Sabato D., Vignola C., Sadori L. and published in *Archaeol Anthropol Sci* 10 (2018): 465-483.

The investigation of agronomic conditions for crop production in the study area by way of stable carbon and nitrogen isotope analyses is reported in **SECTION 2, Chapter 3**. New ^{14}C-AMS dates are published in order to exceptionally improve the chronological framework on which isotope records are built up. Changes in agricultural practices are highlighted from *Hordeum vulgare*, *Triticum dicoccum* and *Triticum aestivum/durum* grains. In particular crop field management is discussed in the context of the relationship with social and cultural transformations in the region between 4700 and 2000 BC. It consists of the paper "δ^{13}C and δ^{15}N from ^{14}C-AMS dated cereal grains reveal agricultural practices during 4300-2000 BC at Arslantepe (Turkey)" authored by Vignola C., Masi A., Balossi Restelli F., Frangipane M., Marzaioli F., Passariello I., Stellato L., Terrasi F., Sadori L. and published in *Rev Palaeobot Palyno* 247 (2017): 164-174.

The essential reconstruction of palaeoclimate fluctuations between 4700-2000 BC from carbon isotope signature of charcoal remains is shown in **SECTION 2, Chapter 4**. Both radiocarbon and stable isotope analyses are involved. The two woody taxa here selected, i.e. deciduous *Quercus* and *Juniperus*, reveal different patterns in seasonal precipitation and local water table recharge. Ecological and hydrogeological features are taken into account. Influences of Mid-Holocene climate trend on the regional occupational setting are investigated. It consists of the paper "δ^{13}C values in archaeological ^{14}C-AMS dated charcoals: assessing mid-Holocene climate fluctuations and human response from a high-resolution isotope record (Arslantepe, Turkey)" authored by Vignola C., Masi A., Balossi Restelli F., Frangipane M., Marzaioli F., Passariello I., Rubino M., Terrasi F., Sadori L. and published in *Rapid Communications in Mass Spectrometry* 32 (2018): 1149-1162.

In **Chapter 5**, the last one, a synthesis of plant remains and isotope data is suggested. Conclusions represent the effort of the candidate to assess the Arslantepe archaeobotanical records as invaluable proxies for the palaeoclimatic, palaeoenvironmental and archaeological reconstruction in the eastern Mediterranean region during the Holocene. The follow-up could be a new publication in which a new chronology will be assessed, based on radiocarbon analyses carried out on selected plant remains. The interpretation of archaeobotanical data under the light of the new chronostratigraphy will be one peculiar topic.

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SECTION 1

Archaeobotany: plant data in archaeological studies

CHAPTER 1

Investigating domestic economy at the beginning of the Late Chalcolithic in Eastern Anatolia: the case of Arslantepe period VIII

Vignola C., Balossi Restelli F., Masi A., Sadori L., Siracusano G.

ORIGINI XXXVI, 2014: 7-36

INVESTIGATING DOMESTIC ECONOMY AT THE BEGINNING OF THE LATE CHALCOLITHIC IN EASTERN ANATOLIA: THE CASE OF ARSLANTEPE PERIOD VIII

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ABSTRACT – *The present article analyses the charred seeds and faunal remains from the Late Chalcolithic 2 (ca. 4200-3900 BCE) occupation at Arslantepe, in the Anatolian Malatya plain. Charred seeds are all found in situ, in a single room clearly interpretable as a kitchen on the basis of its installations and materials. Faunal remains are from all sealed and well stratified contexts dated to this period.*
The identification of species is here presented and evaluated within the broader framework of a reconstruction of primary economy at the site. Comparisons with later Late Chalcolithic agricultural and herding practices at the same site are made with the aim of investigating the changes undergone by the primary economy in the phases of increasing social complexity, along the path that brought to the origin of the first state systems in Upper Mesopotamia.

KEYWORDS – Late Chalcolithic, primary economy and social complexity, Anatolia.

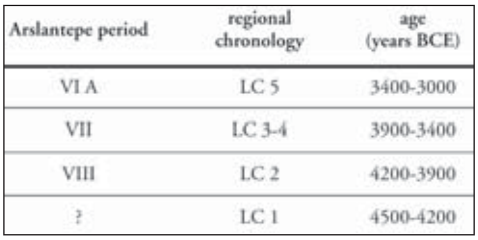
RIASSUNTO – In questo studio vengono analizzati semi e frutti carbonizzati e resti faunistici provenienti dai livelli d’occupazione del Tardo Calcolitico 1-2 (ca. 4200-3900 a.C.) di Arslantepe, nella piana di Malatya (Anatolia orientale). I carporesti sono stati rinvenuti *in situ*, in un unico ambiente chiaramente interpretabile come una cucina sulla base delle installazioni e dei materiali ad esso pertinenti. I resti faunistici provengono invece da tutti i contesti sigillati e ben stratificati di questo periodo.
L’identificazione delle specie vegetali e animali è qui presentata e valutata nell’ambito di una più ampia ricostruzione dell’economia primaria del sito. Confronti con pratiche d’agricoltura e d’allevamento delle successive fasi del Tardo Calcolitico ad Arslantepe vengono discussi con l’obiettivo di analizzare i cambiamenti avvenuti nell’economia primaria durante le fasi di crescita della complessità sociale, lungo il percorso che ha portato alla nascita dei primi sistemi statali in Alta Mesopotamia.

PAROLE CHIAVE – *Tardo Calcolitico, economia primaria e complessità sociale, Anatolia.*

INTRODUCTION

By the end of the 6th millennium BCE significant changes start taking place in Upper Mesopotamia. Even though not all scholars agree on the exact definition of its social and political organisation, the fifth millennium Ubaid period is considered to be a phase of incipient hierarchical complexity (Frangipane 2007, 2010; Özbal 2010; Pollock 1983; Stein 1994, 1996). Undeniably in the Ubaid there is scattered but consistent evidence for social inequalities, suggested by monumental architecture in which some form of administrative activity is also found (i.e. the Gawra XIII temples), by the presence of specialised crafts, of large grain storage spaces, of luxurious goods (like objects in lapis lazuli and carnelian at Tepe Gawra), and of competing households within the same settlements (like at Tell Abada, where one of the houses also has concentrations of particular objects and infant burials that indicate its prominent role). The first mass produced ceramics (Coba bowls) also suggest some form of distribution of foodstuff might have been taking place (Gürdil 2005; Caneva *et alii* 2012) and attests concepts as ownership and control of goods (Stein 2010). Even though there is no general consensus on the degree of socio-political complexity of Ubaid society, traces of incipient social complexity are undeniable.

The following Late Chalcolithic (LC) 1-2 periods (starting approximately around 4500 BCE) are still poorly known but excavations are giving evidence of an increasing complexity. At Tell Brak in the Khabur basin the monumental Basalt Threshold Building of TW20 (Oates, Oates 1997) is adjacent to an industrial area suggesting a possible economic function of this structure. In the following TW19 the Red Building too has a working area (ovens) as well as evidence of administrative activities and the presence of an extraordinary obsidian and marble chalice and in later TW18 a feasting hall is built. Brak is not the only site to show evidence of a social and economic organisation that is getting varied and more elaborated. At the site of Hammam et-Turkman too, on the Balikh, a niched monumental building dated to the beginning of the Late Chalcolithic has been partly brought to light that possibly had a communal function.



Arslantepe period	regional chronology	age (years BCE)
VI A	LC 5	3400-3000
VII	LC 3-4	3900-3400
VIII	LC 2	4200-3900
?	LC 1	4500-4200

Table 1 – Late Chalcolithic chronology of Arslantepe with approximate calibrated BCE dates.

With the advance of the Late Chalcolithic, in periods LC 3-4 we have unequivocal data confirming the existence of elites and the dependence of their power on the accumulation and redistribution of staples. In Arslantepe period VII (Tab. 1) an elite residential area has been distinguished from that of commoners (Frangipane 2010, 2012*a*). The elite area is in the highest point of the mound and next to it, but at a lower elevation, is a monumental temple (Temple C), where redistributive ceremonies took place. Large storage rooms also characterise this area. The presence of sealings and mass produced bowls in the temple confirms its redistributive character and demonstrates that the transformations that will culminate in the first state systems during the LC 5/Late Uruk period were by this time well underway. It is clear that Arslantepe period VII elites controlled the circulation of foodstuff both in prestige and labour corvée circuits. Again, Tell Brak too has evidence of this, and in comparison to Arslantepe also shows an advanced process of urbanisation. This implies a complexity in the organisation of primary economy too, as its large size suggests that the population at Brak probably depended on food products of other rural sites for its survival. There must have been thus a hierarchy between settlements in the region.

Numerous studies have demonstrated how political and social complexity in Greater Mesopotamia has direct implications on the choices of primary economy (Weber 2003; Hald 2008; Frangipane ed. 2010). Even though it is difficult to understand exactly how much early elites were controlling agricultural and pastoral production, it is clear that the increase of political complexity brought to a change in domestic economies. It has been demonstrated that animal herds constitute not simply mobilised valued resources but are also highly visible symbols of status for their owners, as they reflect possession and wealth (Zeder 1998). Likewise, the redistribution of food during ceremonial feasts emphasises the social distinction and inequality between those who own and give and those who don't own and receive. In Greater Mesopotamia, strategies of crop and animal management appear to be one of the central elements on which emerging elites build their success. The mixed caprine, cattle and pig husbandry typical of private domestic contexts gradually left place to a more caprine oriented economy (Zeder 1991) and on the long run agriculture too appears to be influenced by the central administration.

Cattle's role in state organisation is somewhat different from that of caprines: cattle rearing is more energy consuming, but their meat intake much greater. Cattle are big and visible and probably served as ideological symbols of power denoting status of their owners. Again Arslantepe VII is an example of this as elite residences have more than 35% cattle, whilst the commoners have less than 25% (Bartosiewicz 2010).

Pigs are generally considered to be appropriate for household production, but not for supplying state organisation, whilst sheep and goat are perfect state resources. Pigs are difficult to rear in great numbers and thus do not create surplus, but their high meat yield makes them ideal for family consumption. At Arslantepe VII, pigs constitute more than 20% of domesticates in the commoners' residences, whilst they are less than 15% in the elite area and they will be nearly absent in the period VI A (LC 5, Tab. 1) public building storage rooms (Bartosiewicz 2010). In the same period in Tell Brak cattle has decreased to less than 10% and pig is extremely rare (Dobney *et alii* 2003; Emberling *et alii* 1999).

It is thus evident that animals had a central social role within complex societies, as well as an economic one (deFrance 2009). The change in herding patterns visible during the 4th millennium BCE contributed directly to the formation and consolidation of the power of elites.

But how did they get to this level? When did this process start? When did economy start changing from a more "classic" and balanced system for the procurement of food to one that also contributed to the functioning and sustenance of a non-egalitarian social and political system?

At Tell Zeidan in the Middle Euphrates, during the Ubaid period there is an evident shift from a mixed hunting and herding economy to a mostly domestic one. Caprines are 62,5% of the animals found at the site, cattle 19% and pig 10%, with proportions thus that reflect an expected domestic economy (Grossman, Hinman 2013). Since by LC 3-4, Arslantepe (period VII) and Tell Brak show an economy already strongly biased by the presence and role of elite groups, it appears evident that in order to analyse the origin of the transformation in animal herding we need to concentrate on the intermediate period of Late Chalcolithic 1-2.

In comparison to fauna, agriculture is more difficult to interpret since carbonised seeds found are very few and often do not allow quantitative evaluations of crops, but in this case too we suspect an intensification of production in correspondence with the beginning of primary states. In later Mesopotamian state societies there will be preferential selection of more adaptive and productive crops (McCorriston, Weisberg 2002), but during the Late Chalcolithic we have very little evidence of this. At the coastal site of Mersin-Yumuktepe, Fiorentino and colleagues (2014) found in Chalcolithic levels a clear predominance of hulled wheats (*Triticum dicoccum* and *T. monococcum*) on barley. Some authors have suggested that barley will then be preferred as a state controlled and centralised crop by the end of the 4th millennium BCE (Miller 1997) and at Tell Brak Colledge noticed a decrease in glume wheat already with LC 1-2 (Hald 2008) and a corresponding increase in barley that might signal the beginning of the intensification of production.

Preliminary results from Arslantepe period VII appear to indicate that the most abundant presence of barley is in temple C, whereas the residences have greater quantities of *Triticum*. Whether this indicates a preference for barley in the redistributive system, or simply reflects environmental conditions is at the moment too early to tell. Other sites as Hamman et-Turkman and Kurban Hoyuk appear to have mostly barley during LC 3-4 (Miller 1986; Van Zeist *et alii* 1988). Legumes do not appear to be centralised staples and thus probably their production remains domestic even when we notice changes in wheat and barley crops (Hald 2008).

Apart from influencing crop choices, the organisation of agriculture too might be influenced by social transformations in society. In a recent study it was suggested the use of irrigation systems during Arslantepe VI A, whilst after the collapse of the state system this use appears to have been abandoned (Masi *et alii* 2014). This could be read as an intensification and an at least partly centralised or centrally supported crop management system. Representations (wall paintings and seal impressions) of the figure of the ruler furthermore show him on the *tribulum*, thus as an active author of food production.

In sum, as Frangipane has demonstrated with the 2010 thematic volume, the role of early state rulers in the organisation of primary staple production and distribution – even though difficult to demonstrate in detail – appears to be widely accepted. What is still not as clear is the route that has brought to this point, the contexts and timing in which these changes in primary economy start taking place. Attempt of the present article will be that of contributing to this debate through an analysis of primary economy at Arslantepe during the Late Chalcolithic 1-2 levels. Botanical evidence will be compared with the animal bones found in these levels.

THE SITE

The settlement mound of Arslantepe, approximately 15 km west of the banks of the Euphrates, in the modern Malatya plain in eastern Turkey, has been under systematic excavations since 1961 by the Italian Archaeological Expedition to Eastern Anatolia (MAIAO) of the University of Rome "La Sapienza", directed in the last decades by Prof. Marcella Frangipane. This archaeological site, north of the Taurus range, is well known by scholars for its imposing and well preserved architecture and finds related to the phase of pristine state. A long and accurate excavation of the most ancient secular public structure as yet known worldwide has greatly contributed to the understanding of the dynamics of state formation, especially from the point of view of its economic and bureaucratic organisation and has been extensively published (Frangipane 1997, 2001, 2012*a*; Frangipane ed. 2010).

Occupation at Arslantepe though started probably already during the Neolithic period (Halaf sherds are attested at the site) even though the earliest levels exposed until now are those dated to period VIII (Tab. 1), corresponding to Late Chalcolithic 2 in North Mesopotamian chronology (Rothman 2001). Radiocarbon dates from the latest phase of period VIII indicate 4200 calibrated BCE as the absolute date (Balossi Restelli 2012*a*). Below this is still a rather long sequence of at least another eight superimposed levels dated to period VIII. Those exposed more extensively, over an area of 300m^2, all appear to be domestic contexts, with kitchens, courtyards, small storage and living areas (Balossi Restelli 2010, 2012*b*).

The importance of period VIII, as has been introduced above, is linked with the steps towards social and political complexity that are testified by other contemporary sites in the Near East (Stein 2012), with still limited data from the Anatolian Euphrates basin (Marro 2012).

In the Malatya plain the only excavated site with early Late Chalcolithic levels is Arslantepe. Other evidence for primary economy during the end of the 5th millennium BCE is thus not available in the Malatya region. Overall information on bioarchaeological studies from Late Chalcolithic sites of southeastern Turkey and northern Syria can be found in the form of a few summaries (Nesbitt 1995; Nesbitt, Samuel 1996*a*; Miller 2014*a-b*). Best comparisons for Arslantepe are LC 2-3 sites in the Altinova plain (Elaziğ region) and along the Upper Euphrates, Balikh and Khabur valleys.

ENVIRONMENTAL SETTING

The Malatya plain is a plateau (about 900 m a.s.l.) with an average annual temperature varying from 10 to 14 °C. The present-day climate is of a semi-arid type: Taurus Mountains enclosing the plain to the south and south-east prevent moisture originating from the Mediterranean Sea to reach the more inner areas of Anatolia. The mean annual precipitation is low, on average 350-400 mm, most of which is represented by snow (Murat 2002; Atalay 2004). Palaeoclimatic data for Arslantepe early LC levels are not available so far. But the reconstruction, based on isotopic analyses from plant macroremains dating 3350-2000 BCE (LC 5-EBA III), indicates that climate was overall wetter in the Malatya plain than it is nowadays (Masi *et alii* 2013*a-b*). The $\delta^{18}O$ record from speleothem of Soreq cave (Bar-Matthews, Ayalon 2011) has been tuned with the stable carbon isotope record from Arslantepe charcoals (Masi *et alii* 2013*a-b*) and shows quite similar trends. This "parallelism" authorises us to use Soreq palaeoenvironmental data also for the age of period VIII: it appears that at that age there was a clear decrease in precipitation (Roberts *et alii* 2011, fig. 5) that could have caused a reduction of the available plant biomass.

The area surrounding Arslantepe is, still today, well-suited to agricultural pursuits. The hydrogeological and geomorphological investigations carried out in the Malatya plain (Marcolongo, Palmieri 1983) point out the presence of numerous springs resulting from the outcrop of water-bearing strata both in the plain and near the mound. Soils consist of alluvial deposits originating from the Euphrates basin. These favourable conditions make the land around Arslantepe exploitable for intensive cultivation.

Malatya is located in the Irano-Turanian phytogeographical region of Eastern Anatolia. Steppe vegetation nowadays is dominant, while forests are present at the edge of the plains and in tectonic depressions. Shrubs are common, whereas the rare summer rainfalls limit the growth of arboreal species (Kaya, Raynal 2001). Despite strong influence of human activities, the potential vegetation of the Malatya plain consists of deciduous broadleaved plants (mainly *Quercus* sp. and rosaceans) and conifer (*Juniperus* sp.). A few species of mountain coniferous, as *Pinus sylvestris*, are present on the Antitaurus Mountains, some tens of kilometres south of the mound (Davis 1965-1985; Atalay 2006). The local naturally watered soil also allows the growth of hydrophilous vegetation as *Alnus* sp. and *Populus* sp. (the former is no longer found in the plain). The biomass richness of the plain makes Malatya an important producer of apricots today and a favoured place for communities in the past (Sadori *et alii* 2006, 2008; Balossi Restelli *et alii* 2010; Sadori, Masi 2012). Archaeozoological remains of wild *taxa* also reveal different habitats or biotopes, both open (hare) and forest (red deer, bear), in the Malatya area since the beginning of Late Chalcolithic period, as it will be seen below (Siracusano, Bartosiewicz 2012).

BOTANICAL EVIDENCE FOR THE RECONSTRUCTION OF DAILY LIFE PRACTICES IN A KITCHEN FROM PERIOD VIII

The investigated context

Botanical remains presented in this work come from the latest occupation level of period VIII discovered in trench D5 at Arslantepe. This level is characterised by a small but composite domestic context (Balossi Restelli 2012*b*) formed by an open courtyard (including contexts: A719, A720, A721), a kitchen (A718) and a room devoid of materials, but with its wooden door collapsed on the floor. Two other rooms have been only partially brought to light and it is not possible at the moment to understand whether they were part of the same domestic unit. The structure has been completely burnt by fire, thus sealing and preserving for us all materials *in situ*. The most informative room is the kitchen, A718, filled with installations and materials. A domed oven occupied one end of the room (Fr1) and against the eastern wall were a hearth (Fr3) and what has been interpreted as a parching oven (Fr2). The latter is similar in shape to the hearth, but was found with its roof still standing and indicating that fuel and food were kept in two distinct spaces. Between the parching and domed oven there is a raised area, a kind of mud platform (Q1), that might have been used to keep goods or as a working place. At its base, on the floor of the kitchen is a very burnt area, that was interpreted as a hearth during excavation (Fc1). Two flat grinding slabs, three spherical grinding stones and three cylindrical pestles have been found lying at the opposite end of the room from the oven. Some might have originally been on shelves, completely destroyed by the fire. A small hole, reinforced and coated with cobbles and sherds, was built in the floor of the room and might have been used either as vessel holder or as a mortar. Four cooking pots were found in this kitchen and one large storage vessel of a capacity of more than 100 kg. Small bottle like containers, a bowl and a small juglet complete the pottery repertoire and are concentrated in the northern side of the room. With all these installations in the room, the available floor space left for moving about and for activities was of little more than 5 m^2.

During the burning of the kitchen all the staples stored there by the family were destroyed. More than 994 kilograms of soil have been collected full of charred seeds. Charcoal instead was limited to specific places, in the hearths and ovens. Most seeds were concentrated in three areas of the room, where sacks might have been standing since there is no pottery present: one sack was next to the northern wall of room A718 whilst the other two concentrations were at the two sides of the large domed oven entrance. Seeds to the east of the entrance were more spread out and might have been kept in the large storage jar, the break of which by fire could have scattered the contents.

All staples were apparently kept in the kitchen as the courtyard was devoid of charred seeds and of storage jars. Bowls and consumption vessels were instead mostly found there. It is probable that grinding activity took place in the courtyard, at need, even though mortars and pestles were kept in the kitchen.

Materials and methods

Plant macroremains were collected in the 1992 and 1997 excavations according to the archaeobotanical protocol in use at Arslantepe. All plant materials were preserved by charring.

Soil samples were taken from the fill and the supra floor surface of room A718, where the presence of charred plant remains was recognised. All the samples were dry sieved on site by using sieves of several mesh sizes (6, 3, 1 and 0.5 mm). Charred materials were picked out separately from all fractions. It is noteworthy that flotation cannot be applied to Arslantepe dry sediments, because the water separation method definitely dissolves charcoals and charred seeds/fruits (Follieri, Coccolini 1983).

Forty samples of seeds/fruits were selected among the previously sieved ones, on the basis of both stratigraphic and topographic criteria. Arslantepe's reference system, in fact, allowed to recognise the original position of each botanical sample inside the room. They were then analysed in the Laboratory of Palynology and Palaeobotany of the Department of Environmental Biology at the University of Rome "La Sapienza". "Smaller" samples were counted entirely, whilst samples particularly rich in charred items were sub-sampled before examination by using a riffle box (sample splitter), in order to recover a smaller portion of sample that would still yield a representative number of plant remains (van der Veen, Fieller 1982). Validation method was applied to test samples. Mean and standard deviation (σ) showed that in samples particularly abundant in charred remains, the sub-sample 1/16 retains the statistical homogeneity of the whole sample (Masi, Sadori 2008; Vignola 2014). In order to be able to compare the results of the varying quantities of analysed samples, the total number of charred seeds in fractionated samples is estimated (Tab. 2).

Charred seeds and fruits were generally in a good state of preservation. Taxonomic identifications were mainly carried out by naked eye. Stereomicroscopes at different magnifications (Zeiss stemi SV11, LEICA M205 C) were also used when the recognition of morphological diagnostic characteristics of *taxa* was needed. Botanical nomenclature for crops and weed/wild *taxa* follows Davis (1965-1985), Renfrew (1973), Zohary, Hopf (2000), Jacomet (2006), Neef *et alii* (2012). Seed determination is usually at the species level. Only *Avena*, *Secale* and weed/wild *taxa* were identified at the genus level due to the lack of all morphological features. Charred macroremains with a bad preservation or high fragmentation moreover were classified as *indeterminate*.

Results and Discussion

The results of seed and fruit analyses are given in table 2 and figure 1. Samples are grouped by different depositional types on the basis of their archaeological contexts, which can be categorised primarily into fire installations and room collapse/fills. Plant macroremain data related to each archaeological context are shown in table 2. The percentage and concentration values are presented in graphs (fig. 1). The spatial distribution of *taxa* in relation to kitchen installations can be seen in figure 2.

Crops - A total number of more than 15,600 counted charred seeds, fruits and ear parts (spikelet, fork, rachis) have been ascribed to seventeen *taxa*, twelve of which represent cultivated plants. These, following our sub-sampling method, represent an estimated total of about 87,000 (Tab. 2). The highest concentration of identified remains occurs in the samples from the inner chamber of the parching oven (fig. 1, *b*).

T. dicoccon Schrank (emmer) (8,952 total grains) and *T. monococcum* L. (einkorn) (4,201 total grains) are by far the dominant crops (Tab. 2). Their ratio is similar in all areas of the room (emmer from 50 to 59% – einkorn from 24 to 30%), with the exception of the samples localised on the upper surface of the parching oven, in which the former was found in major quantities (74%) compared to the latter (19%) (fig. 1, *a*). A few emmer grains were even paired. Some spikelets, forks and rachis parts of hulled wheats were also found on the bench, but mostly in the fuel chamber of the parching oven (Tab. 2). By contrast, only 176 total grains of *Hordeum vulgare* L. (barley) were recorded in the whole kitchen (Tab. 2). Despite its very low presence (in the average <0.5%), hulled barley occurs in all contexts except for the hearth (fig. 1, *a*). Few rachis fragments come from the bench samples (Tab. 2), although barley rachises generally don’t survive charring as well as glume wheat chaff (Boardman, Jones 1990). In the overlying burnt levels of Arslantepe, archaeobotanical data from private dwellings of Early Bronze Age

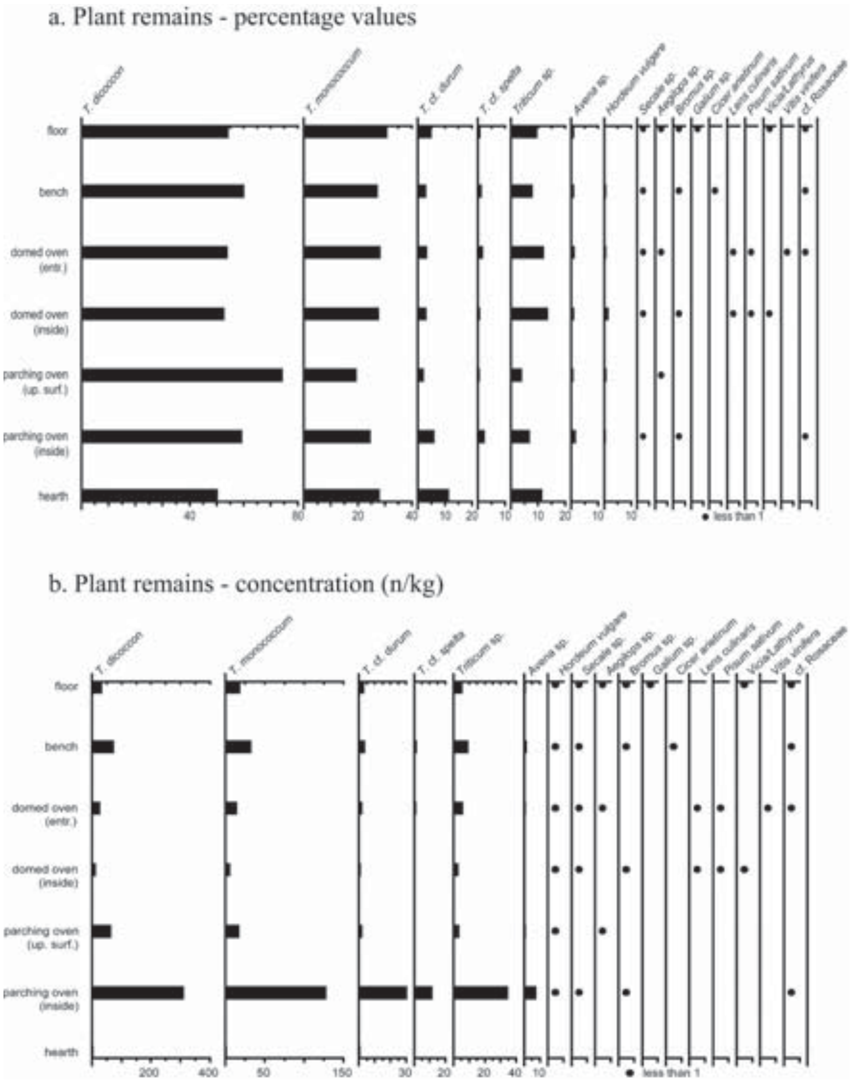


Fig. 1 – Charred seeds and fruits from room A718, Arslantepe period VIII: *a*. Total percentage of *taxa* for each context; *b*. Total concentration of *taxa* for each context.

I (VI B2, 2800-2750 BCE) and II (VI C, 2750-2500 BCE) indicate that barley is the most common *taxon* (Follieri, Coccolini 1983; Sadori *et alii* 2006; Susanna 2007; Sadori, Masi 2012). In the Upper Euphrates valley archaeobotanical studies from other Late Chalcolithic sites indicate that emmer and barley were the main crops at the end of the 5th millennium BCE, but unlike Arslantepe it seems that einkorn was not growing everywhere. At Korucutepe, on the Altinova plain (Elaziğ region), *T. dicoccon* occurs in much larger frequencies than *Hordeum vulgare*, while *T. monococcum* is not present (Van Zeist, Bakker-Heeres 1975).

Taxon	type of macro-remain	**above floor**	**bench**	**domed oven**		**parching oven**		**hearth**	Total
				entr.	**inside**	**up. surf.**	**inside**		
		n.	n.	n.	n.	n.	n.	n.	n.
T. dicoccon	grain	2861 (14441)	1899 (17958)	2967 (4270)	374	493	349 (9866)	9	**8952 (47411)**
	spikelet		1 (16)	5			18		**24 (39)**
	fork [rachis]	5 (35)	27 (195)	9	1	2	46 [1] (1193)		**90 [1] (1435)**
T. monococcum	grain	1391 (8171)	853 (8089)	1497 (2232)	196	128	131 (4068)	5	**4201 (22889)**
	spikelet	1	1 (16)	6			7		**15 (30)**
	fork [rachis]	5 (35)	25 [2] (202)	20	9	3	31 [2] (868)		**93 [4] (1137)**
Triticum sp.	grain	490 (2494)	217 (2287)	612 (942)	95	24	34 (1088)	2	**1474 (6932)**
	fork		5 (56)	3	2		42 (1344)		**52 (1405)**
T. cf. *durum*	grain	175 (1255)	82 (790)	102 (237)	20	12	30 (960)	2	**423 (3276)**
	rachis						7 (224)		**7 (224)**
T. cf. *spelta*	grain	27 (132)	37 (286)	37 (112)	3	2	11 (352)		**117 (887)**
Avena sp.	grain	25 (205)	35 (242)	28 (73)	6	3	7 (224)		**104 (753)**
Secale sp.	grain	15 (30)	30 (192)	9 (24)	3		1 (32)		**58 (281)**
Hordeum vulgare	grain	6	11 (104)	22	9	3	1 (32)		**52 (176)**
	rachis		1 (16)						**1 (16)**
cf. Rosaceae	endocarp	1	3	1			1		**6**
Bromus sp.	grain	4	4		1		1		**10**
Aegilops sp.	grain	1		2		1			**4**
Vitis vinifera	pip			1					**1**
Cicer arietinum	seed		1						**1**
Pisum sativum	seed			1	3.5				**4.5**
Lens culinaris	seed			0.5	2				**2.5**
Vicia/Lathyrus	seed	1			1				**2**
Galium sp.	seed	1							**1**
indeterminate		2	1			3	2	1	**9**
total seed/fruit (n.)		**4998 (26772)**	**3172 (30046)**	**5279.5 (7947.5)**	**713.5**	**666**	**566 (16686)**	**18**	**15413 (82853)**
total spikelet (n.)		**1**	**2 (32)**	**11**			**25**		**39 (69)**
total fork/rachis (n.)		**10 (70)**	**57 (501)**	**32**	**12**	**5**	**126 (3632)**		**242 (4252)**
soil samples (kg)		475	255	171	40	8	32	13.1	994.1
concentration (n./kg)		**56.5**	**120**	**46.7**	**18.1**	**84.2**	**637.7**	**1.4**	

Table 2 – Identification of plant remains by archaeological contexts (floor, bench, domed oven - entrance/inside, parching oven - upper surface/inside, hearth) from botanical samples in room A718, Arslantepe period VIII. Total number of finds for each *taxon* is given. In brackets the estimated number, calculated on the basis of sub-sampling, is shown only for the major *taxa*. Total concentration of plant remains for contexts per kilograms of sampled sediment is given.

Hauptmann (1979) reports the presence of only barley and emmer at Norşuntepe, in the same region from a food preparation area of a domestic structure. At the early 4th millennium BCE settlement of Hacinebi, Miller (1994, 1996*a-b*) identified in the public building levels very low quantities of both einkorn and emmer compared to barley, which is by far the most important cereal type. The same author found wheats and barley to a comparable extent in the contemporary domestic structures of Kurban Höyük (Miller 1986). In the Balikh region (Syria), the archaeobotanical assemblage from the late 5th/early 4th millennium BCE levels of Hammam et-Turkman (Van Zeist *et alii* 1988, 2003) shows that barley played a key role in crop husbandry, followed by emmer and, in minor quantities, einkorn. At Tell Brak in the Khabur basin (Syria) Hald (2008) reports the presence of both glume wheats and *Hordeum vulgare* in similar proportions from LC 2-3 samples of public buildings.

In A718 free-threshing wheat is represented by 423 counted grains of *T.* cf. *durum* (durum wheat, Tab. 2). This *taxon* was found in all contexts of the kitchen to a variable extent: the higher percentage comes from samples inside the parching oven (5,7%, fig. 1, *a*). In the same context rachis internodes of *T. durum* were also found (Tab. 2). The importance of the latter ones lies in the fact that, unlike grains, their morphological features help to distinguish between the two cultivated species of free-threshing wheat (hexaploid *T. aestivum* and tetraploid *T. durum*) (Jacomet 2006). Such evidence allowed therefore to ascribe the recovered grains to durum wheat remains. The presence of glume bases on most rachis internodes could indicate that the ears had not yet ripened. We cannot exclude though the contemporary presence of the hexaploid *T. aestivum*. At Arslantepe in the similar domestic contexts of EBA I-II settlements (Follieri, Coccolini 1983; Sadori *et alii* 2006; Susanna 2007) *T. aestivum/durum* grains also occur as secondary crops, but no rachis fragments were ever found. Naked wheats are recorded in most of the Late Chalcolithic sites of Anatolia and Syria mentioned above, without distinction between hard and bread types (Van Zeist, Bakker-Heeres 1975; Miller 1994, 1996*a-b*; Van Zeist *et alii* 1988, 2003; Hald 2008). Since *T. aestivum* came into existence outside the Fertile Crescent (Van Zeist 1976; Zohary, Hopf 2000; Lev-Yadun *et alii* 2000), the identification of *T.* cf. *durum* remains at Arslantepe period VIII, in southeastern Turkey, seems to confirm that the first cultivated free-threshing wheat in the Near East was the tetraploid form (Özkan *et alii* 2002, 2011).

The last recognised *taxon* of *Triticum* is spelt (*Triticum* cf. *spelta*) (Tab. 2). Its 117 counted grains were present in most samples to a lesser extent than other wheats (maximum 2%, fig. 1, *a*). Due to the absence of rachis fragments, identification is exclusively based on morphological characteristics of grains (Kühn 1991; Jacomet 2006) and is thus tentative. Some remains ascribed to this *taxon* were also found in LC 5 (VI A, 3350-3000 BCE) and EBA I levels of Arslantepe (Balossi Restelli *et alii* 2010; Follieri, Coccolini 1983). Archaeobotanical data from Anatolia, Syria and Mesopotamia (Zohary, Hopf 2000) indicate that hulled spelt wheat was not growing in both earlier and later sites. Like *T. aestivum*, the habitat of spelt wild ancestor lies in central Asia and the spread of the cultivated form must have started from Transcaucasia towards eastern and central Europe in the mid-5th millennium BCE (Nesbitt, Samuel 1996*b*; Salamini *et alii* 2002; Junhua *et alii* 2011). The Malatya plain is very close to this domestication core and cultural relations with the Transcaucasian region are attested since Late Chalcolithic 5 (Palumbi 2008, 2010; Frangipane 2012*b*). The presence of these plant macroremains at Arslantepe during the late 5th millennium BCE is, therefore, the first evidence of spelt crop husbandry in the Near East.

Other secondary cereal crops are *Avena* sp. (oat - 104 counted total grains) and *Secale* sp. (rye - 58 total grains) (Tab. 2).

Pulses were found in negligible quantities, suggesting a completely random presence though they are usually underrepresented in the charred seed record (Cappers, Neef 2012). *Cicer arietinum* L. (chickpea - 1 seed), *Lens culinaris* Medik. (lentil - 2.5 total seeds), *Pisum sativum* L. (pea - 4.5 total seeds) and two poorly preserved seeds of *Vicia/Lathyrus* were recognised (Tab. 2). Chickpeas only occur on the bench, while the other legumes come from the domed oven samples (fig. 1). Among these *taxa*, the identification of chickpea is meaningful because it was not documented in the other Late Chalcolithic sites of Anatolia and Syria (Zohary, Hopf 2000). The probable wild progenitor of chickpea has been indeed identified in a small area of southeastern Turkey (Hopf 1986), not far from the Malatya plain. At Arslantepe *C. arietinum* seeds occur in an Early Bronze I house (Susanna 2007) and again in a mid-3rd millennium BCE house (Sadori *et alii* 2006).

One broken pip of *Vitis vinifera* L. (grape) was found at the entrance of the domed oven (Tab. 2 and fig. 1). The identification of the find was possible thanks to the presence of the chalaza (Cappers, Neef 2012). However such a morphological feature cannot be used to distinguish the cultivated grapevine from the wild form by itself (Renfrew 1973; Zohary, Hopf 2000; Rivera *et alii* 2007). Charred grape pips of both domesticated and wild types were recorded in the LC 5 palace and the EBA private dwellings of Arslantepe (Belisario *et alii* 1994; Susanna 2007; Balossi Restelli *et alii* 2010). These evidences suggest that grape cultivation was common at the site and its domestication had begun at the end of the Late Chalcolithic period, since Arslantepe lies outside the present range of the wild *Vitis* (Zohary, Hopf 2000). Van Zeist and Bakker-Heeres (1975) found wild grapevine seeds to an important extent in the late 5th millennium BCE deposits of Korucutepe, where *Vitis* is also not present nowadays. We can therefore assume that the Malatya and Elaziğ regions could be a domestication area of *Vitis vinifera* in the Upper Euphrates valley even before the end of the 4th millennium BCE.

Weeds - Very low quantities of weed crop remains are present in the kitchen samples. *Aegilops* sp. (4 total grains), *Bromus* sp. (10 total counted grains) and one single seed of *Galium* sp. were found in random patterns (Tab. 2 and fig. 1). Their proportion among wheat grains suggests that the crops were cleaned to a certain degree. In all later archaeobotanical records of Arslantepe only a few herb plant parts were identified from both public and domestic contexts (Sadori, Masi 2012).

Wild taxa - Finally, fruit fragments of cf. Rosaceae, probably hawthorn (*Crataegus* sp.), were found (Tab. 2). This *taxon* occurs in very poor frequencies especially on the bench and in relation to fire installations (fig. 1). Wild shrubs of the Rosaceae family are widespread in the Malatya plain still today (Atalay 2006) and charcoal remains of *Crataegus* sp. were just recorded from Late Chalcolithic and Early Bronze Age levels of Arslantepe (Sadori *et alii* 2006, 2008). On the Altinova plain hawthorn fruits were also gathered at Korucutepe during the end of the 5thmillennium BCE (Van Zeist, Bakker-Heeres 1975).

The charred remains and artefacts from kitchen A718 are an important find because they represent an instant in time of the Arslantepe LC 2 settlement and because they were found *in situ* in an undisturbed state. It appears that the conditions of charring were uniform throughout the room and the differing concentrations reflect the distribution of crops prior to fire. Evidences of cereal storage, processing and cooking are shown by the data displayed on the map (fig. 2).

Emmer and einkorn are the main staples. But their co-occurrence with other wheat (durum wheat, spelt) and other cereal (oat, rye) types in all contexts suggests that these samples derive from a "maslin" (two and more crops grown together), rather than the mixing of separately grown and processed crops (Jones, Halstead 1995).

Barley occurs in very low quantities compared to other cereal crops. Unfortunately no other domestic context of period VIII has been found yet with such rich archaeobotanical remains for comparisons from this point of view. It is unlikely that barley crop was not part of the staple economy of the Arslantepe community at the end of the 5th millennium BCE, as shown from LC 2-3 sites of the Upper Euphrates valley. Since wheat could be threshed more easily, it might have been preferred for human consumption, whereas barley for fodder (Yakar 2000; Ertuğ 2000). We should not forget indeed that unpalatable glumes adhere to grains in hulled barley. We also know from Mesopotamian historical texts (Milano 1987, 1990) that barley was not only used to feed animals, but also for fermented drink production (beer) and only to some degree for human food. In this particular context the rareness of barley is certainly surprising and might suggest that barley, not part of the houses daily food provisions, was kept elsewhere. It is evident that further excavations are necessary to compare other period VIII contexts of Arslantepe with room A718 and its household and contribute to the understanding of this apparently anomalous distribution of charred seeds.

As seen in figure 2, wheat grains were stored in the corners of the room, probably on shelves like some grinding stones and small liquid vessels found overturned next to the northern wall. Therefore the floor had been left free for daily activities. On the basis of stratigraphic evidences, no staple was placed on the roof. Grains might have originally been kept in perishable containers such as baskets or sacks, because of the absence of storage jars, except for one partial but very large jar of a capacity over 100l next to the domed oven's opening.

Wheat crop appear to have been carefully cleaned before storing, but a low proportion of chaff and weed seeds among grains suggests that the final hand sorting of the crop most likely had not been undertaken (Hillman 1981; Jones 1990; Hald, Charles 2008). Ethnographic studies from rural communities of the Near East indicate that the separation of chaff

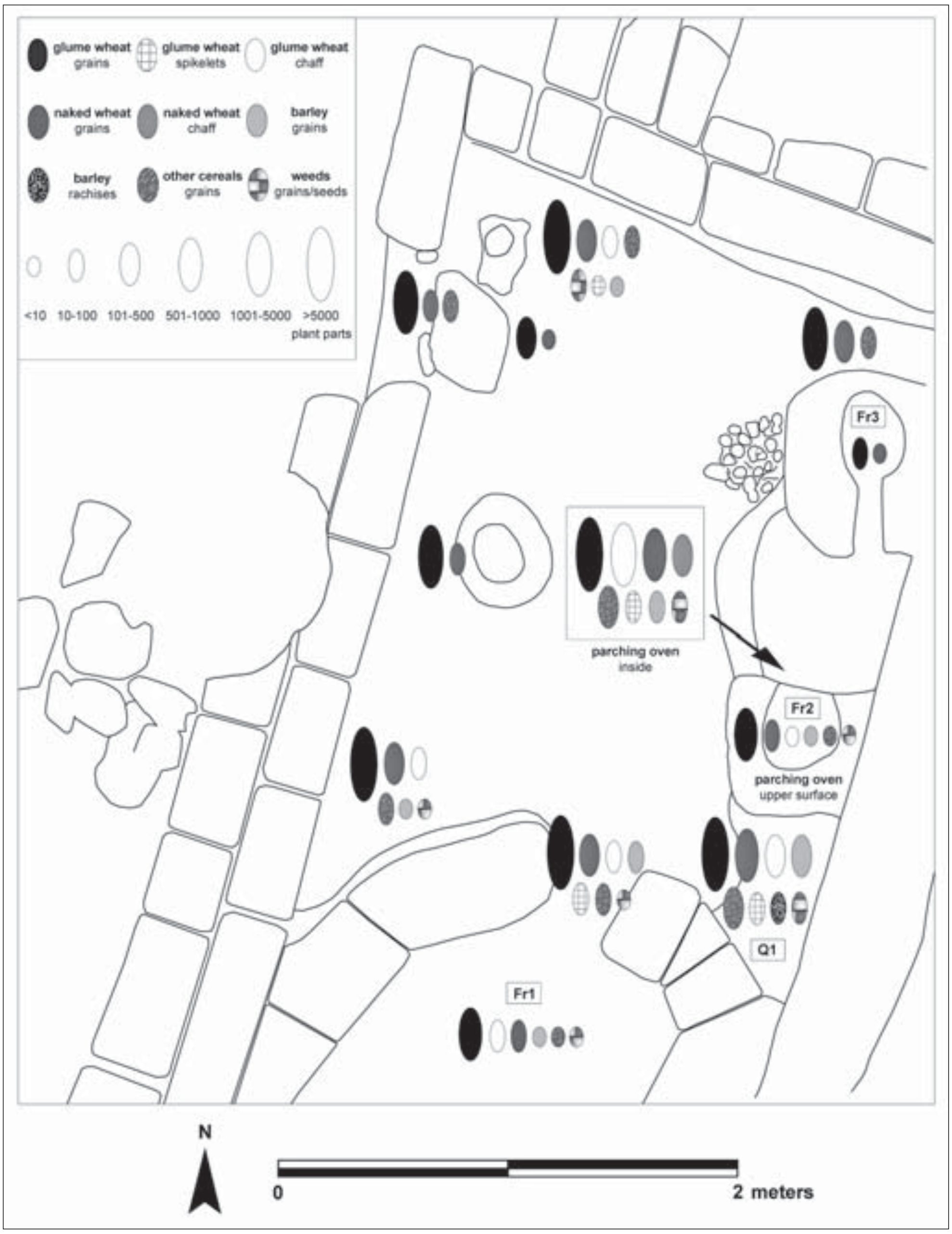


Fig. 2 – Distribution of cereal crop and weed remains inside room A718, Arslantepe period VIII.

and weeds from threshed grains by winnowing and coarse sieving took place directly in the fields or open areas near the settlement (Hillman 1984; Yakar 2000). Instead a fine sieving was carried out in household spaces, picking grass grains and small weed seeds before crop grinding and cooking.

In two samples recovered next to the "mortar-hole" and to a flat grinding slab only wheat grains occur (fig. 2): it is possible that these cleaned crops were going to be ground indoors. Mortars and pestles were still *in situ* besides these ones. Nevertheless the stored crops appear not to be milled prior to carbonization, as shown by the smooth fracture of broken grains (Willcox 2002). Grinding activity probably took place both outdoors in the courtyard and indoors, at need. The large number of stone tools kept in the kitchen seems to indicate a great variety of grinding activities and possibly of people involved. Functional analyses of Arslantepe period VIII grinding stones are still in progress.

In the southeastern side of the room it was mainly crop processing and cooking practices that took place. The analysis of plant remains confirms the functional interpretation of the so-called parching oven, according to which food and fuel were kept in two different spaces. Cereal grains were identified on the plastered plain roof of the oven, suggesting that crop, after cleaning, might have been placed on it for drying to prevent microbiological deterioration or roasting. Thanks to this operation grains were probably also ground more easily. It is not plausible that the small heated surface could be used for dehusking unprocessed wheat crop ears. The highest concentration of ear parts (spikelet, fork, glume basis, rachis, culm) in the room A718 samples comes from the inner chamber of the parching oven (fig. 1, *b*), where fuel was probably put (Miller, Smart 1984; Charles 1998; Valamoti, Charles 2005). Fuel in the Ancient Near East, just like today, could be wood, chaff or dung cakes (made from a mixture of chaff and animal dung). The fact that much of this chaff is preserved suggests that dung cakes might have been used here, as further confirmed by the presence of rachis internodes of *T.* cf. *durum* (Tab. 2). Hulled (*T. dicoccon* and *T. monococcum*) and naked (*T. aestivum* and *T. durum*) wheats in fact need different crop-processing practices, as mentioned above: mixed samples with both crop by-products of the two cereal types are generally not found in domestic contexts, apart from refusal deposits (bins) and fireplace fuel/dung remains (Hillman 1981). It is noted from ethnographic examples that dried animal dung is often mixed with water and straw and made into cakes, which are then desiccated and stacked up for use mainly in winter months (Miller 1984; Yakar 2000; Zapata Peña *et alii* 2003). This is the most common and cheap fuel matter in the Near East even now (Shahack-Gross 2011), where wood sources are in short supply. The use of wood as fuel is well proven by charcoal analyses in all levels of Arslantepe (Sadori, Masi 2012) and detailed studies show the presence of several woody *taxa* in the Malatya plain during the following periods (Alvaro *et alii* 2010; Masi *et alii* 2013*a-b*). Nevertheless in the burnt room A718 only few charcoal remains were found, limited specifically to the bread oven. Dung fuel produces a consistent heat over longer periods of time than wood and tends to be more efficient for cooking and heating dwellings (Braadbaart *et alii* 2012). This use can be suggested for parching too. Many authors also identified dung-derived samples with high proportion of cereal chaff and grass seeds in the archaeobotanical records of sites from Turkey and Syria (Miller 1991; Charles 1998). In the post-Ubaid levels of Kosak Shamali (Upper Euphrates, Syria) only wheat chaff remains were recorded from hearth deposits (Willcox 2003). At Tell Brak the presence of animal dung remains in fireplace samples from household context are reported (Charles *et alii* 2001; Colledge 2003). At the same time, the high concentration of wheat grains in the fuel chamber of Arslantepe oven is not common (fig. 1, *b*), although caryopses do appear to pass through the herbivore stomach and occur in dung (Charles 1998). It is likely that some unprocessed whole ears were used for ignition of the oven.

Crop remains from the domed oven may represent mixed samples of both food product and fuel matter. The latter is likely suggested, as just argued, by the proportion of glume wheat crop by-products. Wood remains are present in low quantities. Staples were also recovered in front of the entrance of the bread oven (fig. 3). Since it is not usual to fill a passageway such as the small opening of the oven, it is possible that these grains have originally been scattered from the nearby bench. Moreover types and proportions of plant macroremains are similar in samples from both contexts.

Most interesting are the data from the bench samples. All glume wheat spikelets, culm parts and most of the glume wheat chaff were found directly on the bench: straw or fuel such as dung cakes might have originally been kept on it. Most grains and all - rare - rachis internodes of barley crop found in the kitchen come from this context. It is possible that they were fed to livestock and thus passed to the dung (Valamoti, Charles 2005). These barley grains show a very damaged surface (acid?) which might confirm this (Charles *et alii* 2001). Furthermore visible “fibre remains” were reported on the bench during excavations: was it the straw or dung fuel used to heat the ovens? In contrast, clean crops could be stored in a likely hanging structure above the bench. One cooking pot was also found there.

Finally few wheat grains were recovered in the hearth: these finds could represent spillage during cooking activities. Two pots come from the area between the hearth and the parching oven.

ANIMAL EXPLOITATION IN THE SUBSISTENCE ECONOMY OF PERIOD VIII

The investigated context

Animal bones, differently to botanical charred remains, are ubiquitous within the archaeological layers at Arslantepe. Thus whilst period VIII charred seeds mainly come from kitchen A718 and thus limited our analysis to a single context, considerations on the fauna can be generalised to the whole phase. The bones identified are all from fills within room deposits, sealed by overlying layers. All are well stratified and non contaminated contexts. There are seven main occupation levels dated to period VIII and bones come from all of these. A total of 2505 bones were identified and counted, all coming from a trench of 300m^2 on the North-Western slope of the mound.

Materials and methods

The analysis of faunal remains was based first on morphological criteria and was aimed at the identification of species.

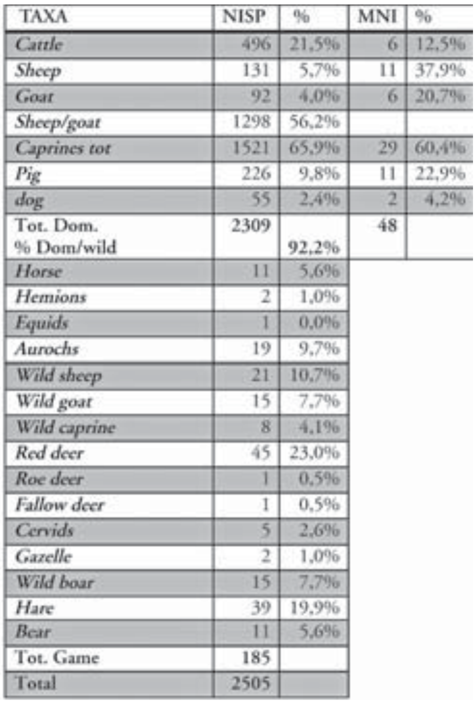
Since the 1970s Sándor Bökönyi, followed later by László Bartosiewicz, had identified a large number of bones of the site. Now as then the samples have been hand-collected, studied and analysed on site. In this paper the totality of bones found in well stratified non-contaminated period VIII levels are considered for analysis.The identification work on the period VIII animal bone assemblage has been carried out during various excavation seasons ranging from 2000 to 2011.

The data are tabulated recording the archaeological, morphological, dimensional and any other details for each bone. Most of them were broken bones. Crushing, in the vast majority of cases, was attributable to their use in food rather than other factors (e.g. trampling). Closely related species were considered in the same taxonomic unit at sub-family (e.g. Caprinae for Capra v/s Ovis) or family level (Cervidae or Equidae) because of the frequent absence of meaningful bone parts. In the last years research to distinguish species within caprines, which share many similar morphological features, has been enhanced with more osteological details: teeth provide better detail for distinguishing species (Helmer 2000; Halstead *et alii* 2002; Balasse, Ambrose 2005; Zeder, Lapham 2010; Zeder, Pilaar 2010).

In order to understand the strategies of animal husbandry an assessment of age has been made where possible, to know at what stage of animal growth individuals were preferentially slaughtered. Age assessment is based primarily on diagnostic teeth and post-cranial bones. Owing to the small number of samples, none of the techniques for determining the age at death from skeletal remains go beyond a good approximation. Here reference is made solely for the bone development of caprines (goats and sheep) taking into consideration the time sequences proposed by Silver (1969).

Results and discussion

Between the late 5th and the beginning of the 4th millennium BCE, during the Late Chalcolithic 1-2 (Early Uruk) period, Arslantepe already formed part of the network of relations between the Upper Euphrates valley, the Northern Syro-Mesopotamian world, and the Gaziantep-Antiochia region, stretching as far as the Mediterranean. The process of domestication, that had developed in Southwest Asia during the Neolithic period, when the most important progenitors of the domestic species had been present (Bökönyi 1993: 128), had long ended by the time of the Chalcolithic period. The analysis of the faunal remains shows that animal husbandry had already become firmly established and entrenched since a long time in all these regions (Bartosiewicz 2010; Issar, Zohar 2004: 68; Arbuckle 2014). The composition of the livestock in period VIII reveals that in Arslantepe, as throughout the whole of Anatolia and neighbouring regions from the Neolithic onwards, animal husbandry economy was based on caprine rearing (Tab. 3), particularly sheep, which constituted by far the majority of the flocks everywhere. Two-thirds of the flocks were made up of sheep (Ovis/Capra ratio 1.5:1), which accounted for 66% of all domestic animals. During this period, cattle raising (about 22%) and pig farming (about 10%) also acquired a certain prominence. Their importance becomes particularly evident when one considers the productive im-



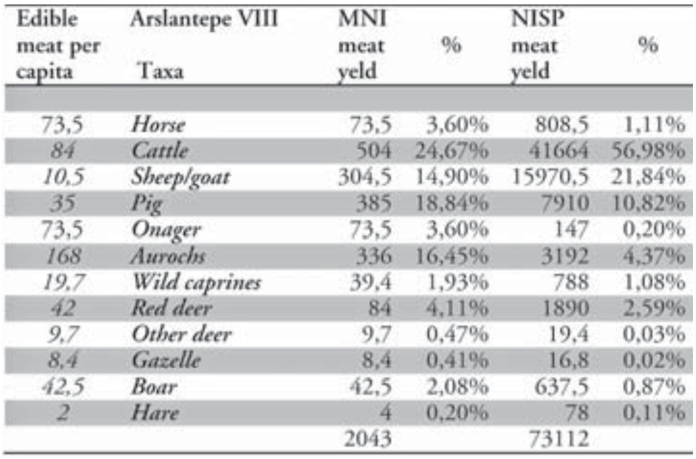
TAXA	NISP	%	MNI	%
Cattle	496	21,5%	6	12,5%
Sheep	131	5,7%	11	37,9%
Goat	92	4,0%	6	20,7%
Sheep/goat	1298	56,2%		
Caprines tot	1521	65,9%	29	60,4%
Pig	226	9,8%	11	22,9%
dog	55	2,4%	2	4,2%
Tot. Dom.	2309		48	
% Dom/wild		92,2%		
Horse	11	5,6%		
Hemions	2	1,0%		
Equids	1	0,0%		
Aurochs	19	9,7%		
Wild sheep	21	10,7%		
Wild goat	15	7,7%		
Wild caprine	8	4,1%		
Red deer	45	23,0%		
Roe deer	1	0,5%		
Fallow deer	1	0,5%		
Cervids	5	2,6%		
Gazelle	2	1,0%		
Wild boar	15	7,7%		
Hare	39	19,9%		
Bear	11	5,6%		
Tot. Game	185			
Total	2505			

Table 3 – Faunal remains of Arslantepe period VIII (Number of Identified Speciments and Minimum Number of Individuals).

portance of these three *taxa* in terms of meat production. From this point of view, the main producers were certainly cattle, which met as much as 60% of the demand, followed by caprines (22%) and pigs (11%) (Tab. 4).

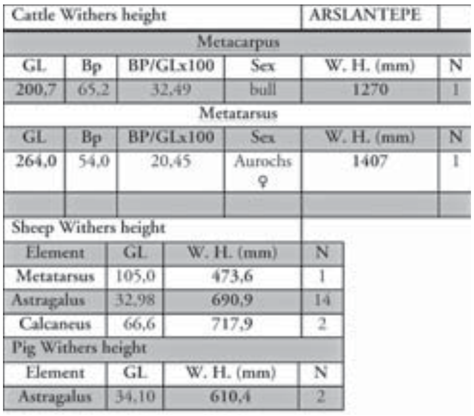
With regard to the reconstruction of the size of the animals, as far as cattle are concerned there are only two sufficiently complete bones from which to calculate the withers height (Tab. 5). Judging from the metacarpal it was certainly a domestic bull, standing about 120 cm high (Matolcsi 1970), while on the basis of the very large metatarsal there was certainly a female (Nobis 1954) aurochs whose withers height, using the same formula employed by Matolcsi (1970), was about 141 cm. The withers height of the sheep varied from between 72 cm (measured from the heels) and 47 cm (from a single metatarsal) (Teichert 1975), while the pigs were about 61 cm high judging from two *astragali* (Teichert 1969).

The synchronic analysis of different sites has shown that, in terms of size, the domestic animals raised at Arslantepe in the Chalcolithic also seem to fall within the range of the domestic animals that existed at the time throughout the Anatolian region (Boessneck, von den Driesch 1976; Zeder 2008).



Edible meat per capita	Arslantepe VIII Taxa	MNI meat yeld	%	NISP meat yeld	%
73,5	*Horse*	73,5	3,60%	808,5	1,11%
84	*Cattle*	504	24,67%	41664	56,98%
10,5	*Sheep/goat*	304,5	14,90%	15970,5	21,84%
35	*Pig*	385	18,84%	7910	10,82%
73,5	*Onager*	73,5	3,60%	147	0,20%
168	*Aurochs*	336	16,45%	3192	4,37%
19,7	*Wild caprines*	39,4	1,93%	788	1,08%
42	*Red deer*	84	4,11%	1890	2,59%
9,7	*Other deer*	9,7	0,47%	19,4	0,03%
8,4	*Gazelle*	8,4	0,41%	16,8	0,02%
42,5	*Boar*	42,5	2,08%	637,5	0,87%
2	*Hare*	4	0,20%	78	0,11%
		2043		73112	

Table 4 – Meat yield for the main edible animals of Arslantepe period VIII.



Cattle Withers height				ARSLANTEPE	
Metacarpus					
GL	Bp	BP/GLx100	Sex	W. H. (mm)	N
200,7	65,2	32,49	bull	1270	1
Metatarsus					
GL	Bp	BP/GLx100	Sex	W. H. (mm)	N
264,0	54,0	20,45	Aurochs ♀	1407	1

Sheep Withers height			
Element	GL	W. H. (mm)	N
Metatarsus	105,0	473,6	1
Astragalus	32,98	690,9	14
Calcaneus	66,6	717,9	2
Pig Withers height			
Element	GL	W. H. (mm)	N
Astragalus	34,10	610,4	2

Table 5 – Arslantepe period VIII cattle withers height.

In the animal husbandry economy optimising costs and benefits was of paramount importance. Livestock had to be kept alive for a sufficiently long time to be used on a seasonal basis for one or other of their products. The different uses of the animals are revealed by their different longevity models (Payne 1973; Hesse 1984), which can be calculated by identifying the stage of growth in the period in which the development of the skeleton had been interrupted by death.

The animal age composition in period VIII shows the earliest trends in caprine exploitation so far known at Arslantepe. Figure 3 compares the age at death of the caprines in Arslantepe period VIII against the accepted standard slaughter age trends according to whether meat, milk or wool production prevailed. The trend is most reminiscent of sheep and goat meat exploitation, with the young killed at a consistently even rate and slaughter peaking at around 3-4 years of age (Helmer, Vigne 2007).

By analysing the mortality profiles for each of the two species of caprines, one can distinguish a different distribution in the age bands (fig. 4*, a-b).* The kill-off pattern for the goats follows the traditional milk production pattern (milk type A), while evidence of the slaughter of the sheep clearly shows that their main use was for meat production although this does not exclude the possibility of wool production.

The presence of the remains of dogs is perfectly in keeping with the widespread practice of stock-raising.

We suppose that horse remains were of wild animals. The earliest evidence of domestic horse is now known from 3500 BCE in the Eneolithic Botai culture of Kazakhstan (Outram *et alii* 2009: 1335), corresponding to Arslantepe period VII. The presence of horses is important as it strengthens Bökönyi's (1983) claim on the local domestication of horse in the succeeding period VII.

Red deer were certainly the most popular game animals, but that does not mean that they were the only ones. There was a fairly large variety of species belonging to different habitats. In order to procure game, people from the end of the 5th millennium at Arslantepe had to travel to different environments ranging from the forests to the steppes. In addition to the wild animals which were certainly hunted for meat, there was a variety of other wild animals whose relations with people still have to be clarified, but are at any rate useful in that they reveal the existence of different biotopes in the Malatya area. Noteworthy among the latter are the findings of portions of bear paws showing the bite marks left by a carnivore (indication of the presence of flesh or marrow residues), suggesting that bears were not solely and unequivocally used for their fur. At all events, a rapid calculation shows that wild game played a very small part in the diet (less than 10% of the total).

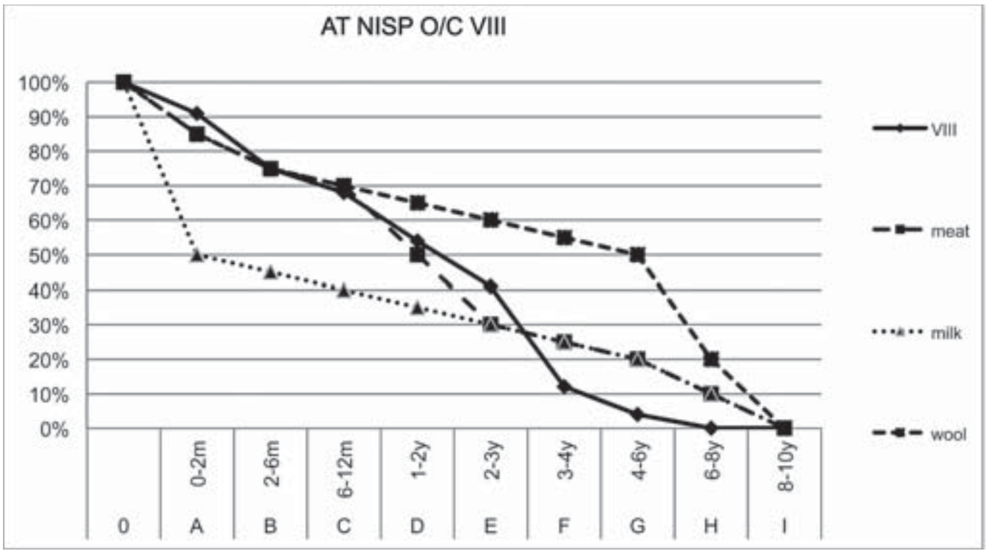


Fig. 3 – Mortality profile at Arslantepe VIII. The different age intervals have been corrected according to Helmer and Vigne (2007).

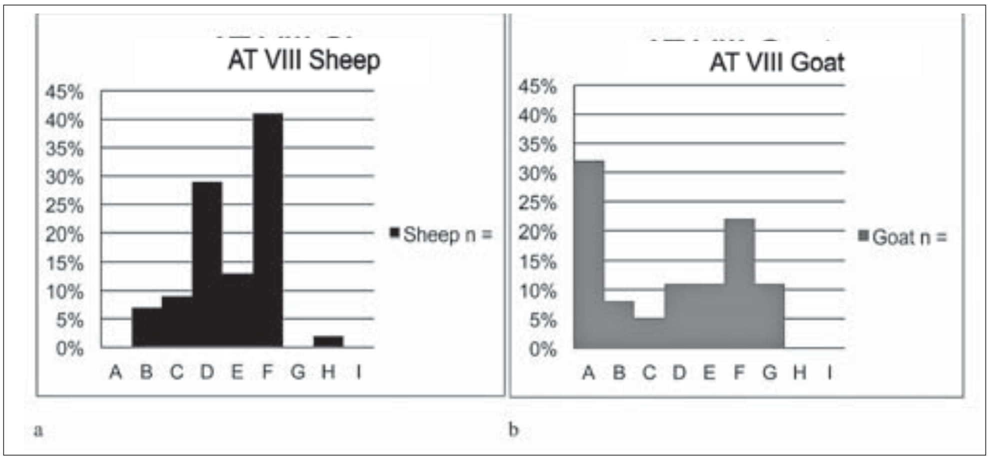


Fig. 4 – Age at death: *a*. Sheep culling profiles; *b*. Goat culling profiles. See Figure 3 for age interval legend.

In the next period VII (Late Chalcolithic 3-4, 3800-3400 BCE), the site expanded and centralisation developed. This is reflected in the diversified distribution of the livestock remains according to the function of the different areas, residential or public (Bartosiewicz 2010). Although animal husbandry still continued to be based mainly on sheep and goat in the following millennium too, in period VII, cattle remains were more frequently found in the residential areas (where they are equal to caprine specimens in terms of NISP), together with a substantial presence of pigs (Bökönyi 1983), while in the cult building (Temple C), where redistribution activities were performed, caprines, particularly sheep, prevailed (Bartosiewicz 2010: fig. VI.1). Sheep raising increase would subsequently peak in the following period VI A, when centralisation was at its height (Bökönyi 1983; Bartosiewicz 1998). This would suggest that in period VIII a self-sufficient household economy was being maintained even in the presence of a social and political organisation, which was tending toward centralisation (Bartosiewicz 1999).

CONCLUSION

Both the botanical and faunal data from Arslantepe period VIII provide interesting points of view for a comparison between domestic and early state economies.

Botanical remains from the kitchen (A718) of a private dwelling with no apparent indication of being a special residence has an abundance of *Triticum* wheat, whilst barley is rare. If we analyse this result within the context of Arslantepe's later Chalcolithic botanical distribution, we will notice though that in all domestic contexts wheat appears to be the most common crop. Barley is instead more present in period VII Temple C and in the period VI A public complex. Could this mean that during the Chalcolithic private, domestic agricultural production aimed at human consumption was mainly wheat based? The rare barley in A718 is concentrated in the samples that has been suggested could represent fuel, possibly also in the form of dung cakes. The barley present thus might derive from animal fodder.

The greater quantities of barley in Temple C and in the public area in period VI A, instead might suggest that elite/politically oriented production (or centralisation of production) was mainly concerned with barley. Such an interpretation would be in line with data from many other Mesopotamian sites, as mentioned above, as well as what testified by ancient texts, where barley is mentioned amongst the goods distributed to workers in the early state systems.

At Arslantepe VIII we have no public building and cannot tell thus if differential crop use can be suggested for this early phase too. At Tell Brak though a decrease in wheat has been noticed and associated with an increase in barley starting from LC 1-2, suggesting that changes were probably occurring already at this time (Colledge 2003). It would be extremely interesting to know from what kind of contexts are the Brak finds in order to test there too our hypothesis according to which in these early phases the human use of barley was preferably encouraged in public distribution.

Interesting is also the hypothesis that the wheat crops in kitchen A718 might come from maslin crops. The growth of different species together in the same field might thus have been tolerated or even deliberately sought. This system would help buffer risk (van der Veen 1995) minimising total crop failure in a bad year. At the same time variability is generally not typical of specialised productions, as those we hypothesise might be encouraged by elites of primary state systems who used these goods as forms of wealth, accumulating and, on occurrence, redistributing them. Crop distribution in A718 would thus suggest an origin from a family run cultivation and field.

The proportions in animal species of period VIII too suggest a mixed and balanced economy. Sheep and goat constitute the majority of animals, but not in the very high proportions that will be seen in period VI A and in the public contexts. Sheep are more abundant than goat and Siracusano hypothesises they were probably used for meat and wool. Goat instead appears to have been more oriented towards milk production. More than seeing their abundance as an influence of emerging complex societies relying on staple finance, this variability again suggests animal rearing aimed at the subsistence of single families. Proportions of caprines confirm that the exploitation of animals is similar to that of preceding Ubaid period (for example Tell Zeidan), but also to that of the Arslantepe period VII residences.

We have already pointed out that in the residential contexts, with caprine numbers remaining more or less similar, changes can be noted between LC 1-2 and LC 5 in the proportions of cattle and pig. The former appears to be more abundant in elite buildings, whilst pig is rare (see introduction). In commoners' dwellings instead pig contributes substantially to the diet. This is certainly due to the economic and social value of these two animals.

The first true indication of an increase in sheep and goat is in the period VII public building and will be then more generalised in later period VI A (Bartosiewicz 2010); then too though it is probably linked to the public use of these animals, as mobilised goods for wool production and possibly in the form of food (meat or milk products) during the distribution of rations. It is probable that the increase in these animals, initially sprung by elites' desire to centralise and control goods, gradually brought to a change in herding patterns in all contexts. Thus by period VI A, caprines constitute the great majority of animals both in public and private contexts. As with the botanical remains, the present study not only supports the idea of a different type of animal exploitation in public and private contexts of the Late Chalcolithic period, but suggests that in the early phases of social and economic complexity these two spheres might be distinguishable. We thus stress the importance of distinguishing contexts when analysing primary economy in such societies.

A last interesting aspect is that of hunting. Quantities of wild animals at Arslantepe do not vary significantly throughout the Late Chalcolithic period. LC 1-2 has approximately 8% of wild animals and LC 3-4 slightly more (10%), exactly like period VI A (Bökönyi1983, 1993). This indicates that the meat of wild animals was a regular integration to the protein diet of Arslantepe inhabitants. The species present too are always the same ones, typical of the Malatya region, with a possible slight increase in variety in period VI A (Bartosiewicz 2010). Interestingly period VIII and period VI A both have a very high presence of hare, interpreted as an indicator of an open landscape.

A look at the distribution of wild animals in different contexts though gives evidence of some variability. Whereas period VII elite residences confirm an approximate 10% of wild animals, as that of period VIII domestic contexts, in Temple C these sum up to only 5% of the fauna present. Likewise, in period VI A, Temple B, access to which was possibly limited to elites, has 9% of wild animals whilst the public store rooms only have 2%. Thus, even though wild animals were part of the typical diet, they were not included amongst the food redistributed by the elites and possibly elites did not have any control on hunting activities. The slight increase in wild animal variety in period VI A might be due to an acquired symbolic value denoting prestige of elites, but a comparison with commoners' dwellings of the same period would be needed to confirm this.

In conclusion thus, the beginning of the Late Chalcolithic period in Arslantepe shows, in the domestic contexts brought to light, a mixed primary economy possibly managed by single families with no evident interference of growing elites. Comparisons with later developments at the same site and with contemporary situations in other sites though has suggested that in the early phases of state formation and increasing central authorities two partly autonomous systems of primary economy might have co-existed: a private, family run one and a "public" one boosted by growing elites.

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CHAPTER 2

Timber exploitation during the 5th-3rd millennia BCE at Arslantepe (Malatya, Turkey): environmental constraints and cultural choices

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ORIGINAL PAPER

Timber exploitation during the 5th–3rd millennia BCE at Arslantepe (Malatya, Turkey): environmental constraints and cultural choices

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Abstract A considerable amount of charcoal remains from the archaeological site of Arslantepe (Eastern Anatolia) has been analysed. The anthracological assemblage comes from seven archaeological periods, ranging from the Late Chalcolithic 1–2 (mid-5th millennium BCE) to the Early Bronze Age III (late 3rd millennium BCE). The woody taxa exploited by the local communities appeared to have only minor changes throughout the investigated periods. For the evaluation of wood use practices, charcoal was chronologically grouped according to depositional context. The categories of depositional context identified differentiate between the uses of wood for structural parts of buildings, object manufacture, fuel, refuse, and wood found in outdoor areas or in burial contexts. Communities at Arslantepe, characterized by different cultural and socio-economic traits, appeared overall to select timber depending on its use: hydrophilous plants prevail in building material, with the exception of the 2900–2500 BCE period when environmental constraints probably motivate the dominance of woodland-steppe plants. The differential occurrence of taxa in the diverse depositional contexts highlighted cases of under/overestimation of remains, in particular in relation to the woods for construction. Finally, taxa have been attributed to different ecological groups. The interpretation of results and the comparison with other available palaeoenvironmental data point out that climatic factors play only a secondary role in the choice of wood exploitation in the area. Human choice may vary even with constant environmental records.

Keywords Charcoal analysis · Landscape use · Eastern Anatolia · Climate versus human change · Arslantepe

Introduction

The main goals of charcoal analysis from archaeological archives are the reconstruction of past vegetation, human exploitation and palaeoclimatic trend (Asouti and Austin 2005; Chabal 1994; Deckers 2005; 2016; Ludemann 2010; Marston 2009; Scott and Damblon 2010; Thiébault 2002; Willcox 1999). Archaeological charred remains from the Mediterranean region have been widely used to reconstruct past environment for prehistoric communities, implying that they used what was present nearby (e.g. Asouti and Austin 2005; Figueiral and Mosbrugger 2000). Methods to interpret the landscape using charred woods coming from archaeological settlements were developed and published by several scholars (e.g. Badal et al. 1994; Figueiral 1993).

The palaeoclimate played a crucial role in the development of human societies, and it is often pointed out as the major factor in the emergence and collapse of ancient civilization (Roberts et al. 2011; Staubwasser and Weiss 2006; Weiss 2002; Weiss et al. 1993). This might be true in particular for arid and semi-arid environments where seasonal and occasional climate fluctuations have a strong influence not only

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on plant growth, but also on their persistence. Modern studies have shown that plant growth is more closely related to rainfall than to temperature variation (Riehl 2008; Wilkinson 2003). Little rainfall changes or a lowering of water table can cause major landscape alteration. On the other hand, some populations demonstrate an incredible resilience and adaptation to climate changes (Collective 2007; Kuper and Kröpelin 2006; Marro 2009; Mercuri et al. 2011; Rosen 2007). Thus the role of environment in the changes of human organisation should be thoroughly assessed in all cases.

Palynology is widely used to investigate past flora and vegetation, and, if used together with plant macrofossil analysis, can provide interesting clues on past landscape changes and human impact (Birks and Birks 2003; Geib and Smith 2008; Mercuri et al. 2010; Nelle 2008; Nelle et al. 2010; Sabato et al. 2015; Sadori et al. 2011, 2015). Although, several palynological studies are available in Turkey (Eastwood et al. 2007; Kuzucuoğlu et al. 2011; Roberts et al. 2001, 2011; van Zeist and Bottema 1988; Wick et al. 2003), the sites are far from the Malatya area. Moreover, their resolution is temporally lower than that of cultural changes occurring at Arslantepe and thus difficult to use in detailed investigations. In arid and semi-arid regions, pollen grains are often not preserved (e.g. Neumann 1992) and on-site pollen records are rare examples (Mercuri 2008a, b). In absence of pollen data coming from continuous sediment records with adequate temporal resolution, different strategies need to be considered to reconstruct past environments.

In recent years the application of stable carbon isotope analysis to wood archaeological remains represents a reliable independent source of climate information (Aguilera et al. 2011; Hall et al. 2008; Masi et al. 2013a, b). Palaeoclimatic records associated to archaeological evidence can be advantageously used to reconstruct palaeoenvironmental changes and human forcing. Modern research aims to understand the correlation of the mentioned factors, putting them in parallel and trying to evaluate single roles and their interrelations (see Izdebski et al. 2016).

Archaeobotanical analysis of plant remains from Arslantepe (Malatya, Turkey) began in the 1980s led by Maria Follieri, whose multidisciplinary approach to archaeological contexts was greatly innovative (Follieri and Coccolini 1983). The interest of environmental sciences for historical reconstruction was just growing at that time (Hastorf and Popper 1988; Helbæk and Schultze 1981). Published charcoal analysis from the site has so far focussed on single archaeological phases and/or specific topics (Alvaro et al. 2010; Piccione et al. 2015; Sadori et al. 2006, 2008), while we here use all available data for a diachronic reconstruction of timber use. Specifically, this study is interested on wood selection and cultural choices made by the Arslantepe communities: the long settlement history (lasting more than 2000 years), the large amount of charcoal remains (about 60 kg) and the palaeoclimatic data (Masi et al. 2013a, b) from the site make it suitable for the interpretation of human-environment interaction. The availability of an independent palaeoclimate trend allows interpreting the anthracological assemblage as a cultural formation.

Environmental setting and ecological context

The investigated site of Arslantepe is located at 38° 22′ 55″ N, 38° 21′ 40″ E, 941 m a.s.l. in the modern Malatya plain (eastern Turkey), ca. 15 km West of the upper Euphrates (Fig. 1). Along the Taurus range enclosing the plain precipitations vary from 600 to 1000 mm/year (Atalay 2004), whereas in the plateau the mean annual precipitation is lower, on average 400 mm, with monthly maxima during winter and early spring seasons (Sensoy et al. 2008). Nonetheless, a large hydrogeological catchment supplies the plain reliably with surface-running water and outcropping springs (Marcolongo and Palmieri 1983). Today, the area is covered by a sequence of alluvial and colluvial sediments (Dreibrodt et al. 2014), providing fertile soils for extensive apricot orchards (Çolak et al. 2010).

Malatya lies in the Irano-Turanian floristic region (Çolak and Rotherham 2006; Yilmaz et al. 2003). Forests are present at the edge of valleys and in tectonic depressions, while steppe vegetation is widespread in the valleys (Kaya and Raynal 2001). The low summer humidity is the major limiting factor for vegetation: arboreal species are rare, except near channels, natural springs and in orchards (Yildiz et al. 2004). Despite this, biodiversity is high because the area, lying in the transition zone between the park woodland in northern Mesopotamia to the steppe of the Caucasus, shows important ranges in elevation. Taurus Mountains have most of the endemic plant species of Turkey (Yildiz et al. 2004). Present-day vegetation is strongly influenced by human activities, which have reduced forest areas (Asouti and Kabukcu 2014). Shrub steppe vegetation replaced semi-open forest, which was the potential vegetation of the plain. It consists of deciduous broadleaved woods, with mixed broadleaf (mainly deciduous/semi-deciduous oaks and rosaceans) and conifer woods; mountain coniferous woods populate the surrounding mountains. The altitude strongly influences vegetation, with red-pine (*Pinus brutia*) and maquis dominance below 1200 m a.s.l.; the occurrence of cedar (*Cedrus libani*), Taurus fir (*Abies cilicica*), and black pine (*Pinus nigra*) in the belt from 1200 to 2000 m a.s.l.; and alpine steppe vegetation over 2000 m a.s.l. (Atalay and Efe 2010; Atalay et al. 2008; Davis 1965-1988; Zohary 1973). The local hydrogeological features favour the presence of riverine gallery forest with poplars and willows.

Archaeological setting and palaeoenvironmental data

The settlement mound of Arslantepe covers an area of 4.5 ha with a height of 30 m above the surrounding plain. Its

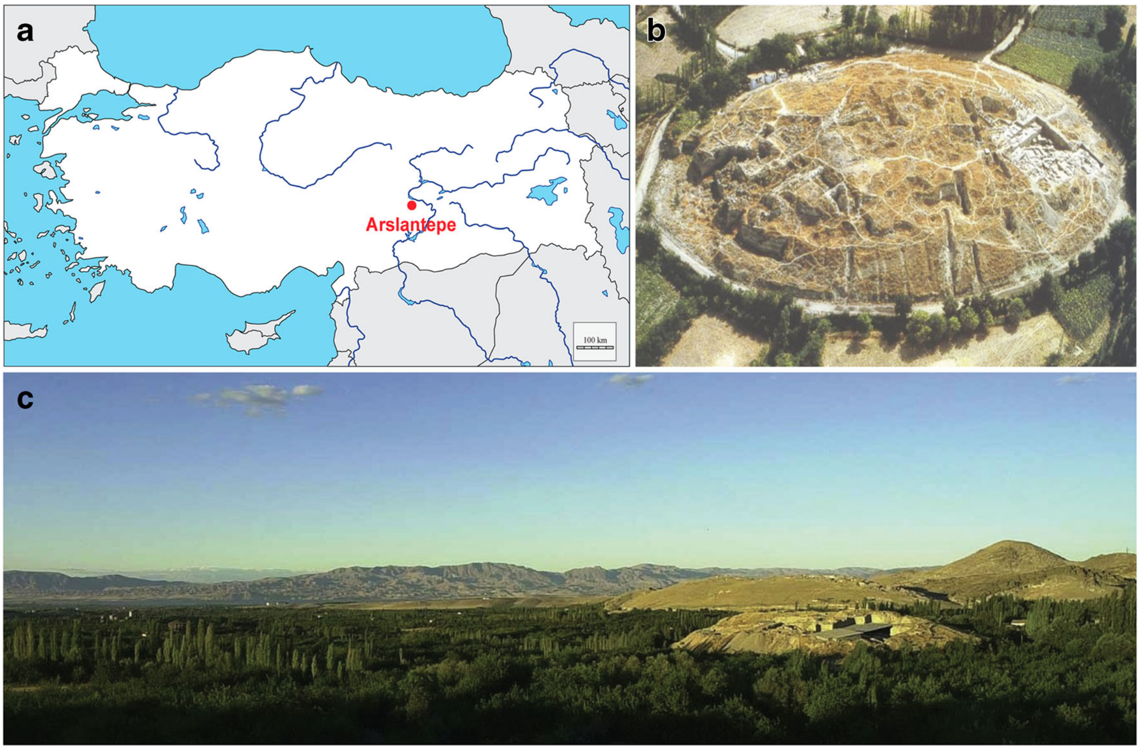

Fig. 1 Arslantepe (Malatya, Turkey). a. Site location, b. Foreground of the mound, c. The Malatya plain with the settlement mound

extraordinary occupational sequence is almost uninterrupted, starting as early as the mid-5th millennium BCE and continuing through to the Roman-Byzantine Age (Arslantepe.com). The chronological framing of archaeological periods was carried out using both archaeological comparisons and calibrated radiocarbon dates (Alvaro et al. 2010; Di Nocera 2000; Frangipane 2012a, b). The ^{14}C dates have been provided on tens of wood and seed remains, and they are expressed in calibrated calendar year. The seven oldest periods of the sequence, from the Late Chalcolithic 1–2 (Arslantepe period VIII, 4250–3900 BCE) to the Early Bronze Age III (Arslantepe period VI D, 2500–2000 BCE), have been taken into account for this study (Table 1).

The first occupational levels excavated so far (period VIII, 4250–3900 BCE) are characterised by domestic contexts, with kitchens, courtyards, small storage and living areas (Balossi Restelli 2010, 2012; Vignola et al. 2014). In the successive period VII (3900–3350 BCE) the settlement reached its maximum extension: small private dwellings have been unearthed on the slopes of the mound, while a temple and elite residential area were on the highest point of it (Frangipane 2012a). The site is well known especially for its imposing and well preserved architecture and finds related to the phase of pristine state: during the VI A period (3350–3000 BCE) an extended public structure, the so-called palace, was built (Frangipane 1997, 2010, 2012a). The excavation brought to light both monumental buildings, in which economic, religious and administrative activities were performed, and elite residences (Frangipane 1993, 2003b; Frangipane and Palmieri 1983). After the destruction of the palace by fire, several settlements, characterised by private dwellings of alternating pastoral and sedentary communities, followed each other for a couple of centuries. During the VI B1 occupation (3000–2900 BCE) semi-nomadic groups mainly lived in non-permanent wood and mud huts flanked by animal fences, but also had one monumental building at the centre of the mound (Frangipane 2014). The following VI B2 period (2900–2750 BCE) consisted in a rural village of mud-brick houses flanking streets, family storages and animal pens, butchering and chipping areas all thickly built around a massive “citadel” wall in the internal part of which we do not know what was kept (Alvaro 2010; Frangipane 2012b; Frangipane and Palmieri 1983; Piccione et al. 2015). In the last long Early Bronze Age occupations (period VI C, 2750–2500 BC and VI D, 2500–2000 BCE), the Arslantepe inhabitants first became mobile again, but settled down again into a small fortified town in the second part of the millennium (Conti and Persiani 1993; Frangipane 2012b; Persiani 2008).

Building technique deeply changed in such timeframe (4250–2000 BCE) but some common characteristics can be found. For instance, roofs from all periods had always beams and in some cases vertical central posts, similar to those found in other Near-Eastern contexts (Aurenche 1981; Moorey 1999). The structure of the roof was made of a series of wooden beams and smaller sticks, lying perpendicularly to the beams, possibly also with a straw mat used as a base for the

Table 1 Archaeological phases, chronological framing (Frangipane 2004, modified) and sources of anthracological data. In **bold characters** are the periods considered in this study

General chronological sequence of Eastern Anatolia	Arslantepe periods	Calendar years BCE	Source of anthracological data
Late Roman and Byzantine age	I		
Iron age	II - III	1100–712	
Late Bronze Age II	IV	1600–1200	
Late Bronze Age I	V B	1750–1600	
Middle Bronze Age	V A	2000–1750	
Early Bronze Age III	**VI D**	**2500–2000**	**In this article**
Early Bronze Age II	**VI C**	**2750–2500**	Sadori et al. 2006
Early Bronze Age I	**VI B2**	**2900–2750**	Piccione et al. 2015 **and in this article**
Early Bronze Age I	**VI B1**	**3000–2900**	**In this article**
Late Chalcolithic 5/Late Uruk	**VI A**	**3350–3000**	Alvaro et al. 2010**,** Follieri and Coccolini 1983**,** Sadori et al. 2008 **and in this article**
Late Chalcolithic 3–4	**VII**	**3900–3350**	**In this article**
Late Chalcolithic 1–2	**VIII**	**4250–3900**	**In this article**

final mud top (Aurenche 1992; Kramer 1982). Most of the houses, in all phases, were supplied with hearths, ovens and other domestic features (benches, mortars and other tools, drains).

The relationship between human societies and climate is an essential element for the interpretation of the development of sites, as water availability, just to cite one variable, obviously strongly conditions human choices. The stable carbon isotope content of arboreal plant charred remains has been used to estimate water availability from the end of the 4th to the 3rd millennium BCE (Baneschi et al. 2012; Masi et al. 2013a, b). Deciduous oaks and juniper remains from five succeeding periods of Arslantepe (from VI A to VI D) have been analysed. All the data where chronologically ordered using archaeological data and radiocarbon ages. The two taxa show different behaviour according to their ecological characteristics and highlight climatic fluctuations with an instability phase from ca. 3400 to 2800 BCE and more stable conditions until 2000 BCE. The stable carbon content evidences also that climate in the past was wetter than nowadays. Isotopic content of animal bones from the entire Arslantepe sequence confirm all these observations (Galli 2016 unpublished PhD dissertation). The carbon content of barley and emmer charred grains from the same periods has provided important clues for the reconstruction of past cultivation techniques (Masi et al. 2014).

The palaeoclimatic reconstruction of Eastern Anatolia was also developed using a macrophysical climate model in comparison with isotope proxy data (Arıkan 2015). From the end of the Late Chalcolithic, the decline in precipitation and the increase in temperature are confirmed (Early Bronze Age I-II, 3000–2500 BCE), followed by cooler and wetter conditions (Early Bronze Age III, 2500–2000 BCE). The effects of changing climate during the 3rd millennium BCE have been linked to changing settlement systems across the region (Arıkan 2014). In particular, computational modelling (extensive agropastoral land use modelling) was applied to the Malatya plain during the Early Bronze Age I (3000–2750 BCE) in order to estimate changes in the palaeoenvironment and to simulate the varying scale and intensity of human impact on the territory. The results highlight that the scale and intensity of anthropogenic impacts change significantly in relation to the level of social organisation, demography, and temporal length of occupation (Arıkan et al. 2015).

The correlation between a high-resolution record of slope deposits close to the Arslantepe mound and the settlement and land use history is provided by Dreibrodt et al. (2014). The authors point out that mid-late Holocene geomorphologic processes reflect responses to human impact on the surrounding landscape. From the 5th to the 1st millennium BCE well-managed land use is testified by neither deposition activities nor soil formation in the catchment area (Dreibrodt et al. 2014). Noticeably, an erosion phase seems to be associated with the collapse of the Late Chalcolithic society probably resulting in a drop of soil protection management previously provided by the local agricultural practices (Dreibrodt et al. 2014).

Materials and methods

In this paper, all the wood remains analysed for the seven periods of Arslantepe, from the Late Chalcolithic 1–2 (4250–3900 BCE) to the Early Bronze Age III (2500–2000 BCE), have been taken in consideration. Most of data included are unpublished (Table 1).

Wood assemblages in the investigated archaeological phases come from burned contexts. Only two are the exceptions: Temple C in period VII and the Royal Tomb in VI B1, whose preserved wood remains are not charred. Because of the excellent state of preservation of wood (Fig. 2), charcoal sampling was carried out in situ by archaeologists according to the archaeobotanical protocol in use for excavation campaigns carried out in several tens of years (1976–2012). Charcoals were always hand-picked when visible to the naked eye, and smaller amounts were obtained from dry-sieving of soil. No charcoals have been collected through flotation as it has been demonstrated that water at Arslantepe dissolves charred macroremains (Wright 2005), and this sampling method is thus not used.

In this perspective, a charcoal sample is the set of wood fragments recognised or interpreted as a unit during the excavation. It corresponds to (1) a single wood (even if fragmented into tens of pieces once collected from the excavation), (2) the filling of small structure like fireplace, oven, mortar, post hole, bin or vessels. As for the first case, in many cases the kind of find, the degree of preservation (Fig. 2) and the accurate archaeological excavation allowed singling out and univocal taxonomic identification of single structural elements (Alvaro et al. 2010; Sadori et al. 2008). In other cases, laboratory identification demonstrated that what had been interpreted as a single piece of wood was in fact composed by 2 or 3 taxa, thus at the minimum represented three separate wooden elements.

Due to the high amounts of charcoal, fragments were shortly sorted in laboratory according to their main anatomical features (hardwood, softwood, monocots) using a reflected light microscope. Wood structures were then observed with a differential interference contrast microscope (DIC) according to Nomarski with a magnification between 50 and 500x. The high DIC's depth of field allows identifying anatomical structures even in very small fragments of charcoal. Each piece of wood was manually fractured to observe samples along transverse, tangential and radial surfaces. Identifications were carried out using a reference collection and specialised atlases (Fahn et al. 1986; Greguss 1955, 1959; Schoch et al. 1988; Schweingruber 1978, 1990). Even if mostly identified at past subfamily level, we used the taxonomic level Rosaceae for the purpose of this work also considering that the redefinition of subfamilies is still in progress (APG III, Stevens 2009 onwards). Separate identifications are published in detailed papers (see Alvaro et al. 2010). Due to the small size of fragments, no systematic attempt to divide between deciduous (*Quercus* sect. *robur*) and semi-deciduous oaks (*Quercus* sect. *cerris*) was carried out (Cambini 1967). *Pinus sylvestris*/*montana* gr. (Greguss 1955) does not include species of Mediterranean pines. Some taxa were photographed at the scanning electron microscope (SEM) (Online Resource 1). Wood structures were still recognisable, being extreme fragmentation rather rare.

Fig. 2 VI A period, Late Chalcolithic 5 (3350–3000 BCE). An example of well preserved charred beams on the floor of the corridor in the palatial complex (photo by Missione Archeologica Italiana in Anatolia Orientale)

Samples have been divided into six depositional contexts according to the context of retrieval and reconstructed use: (1) *building* includes all the wood used as construction material, (2) *fire installation* collects the fuel found in ovens and fireplaces, (3) *domestic feature* groups all the remains from benches, mortars, tools and drains, they most probably represent objects or furniture, (4) *bin* refers to the charcoals collected within dump pits, (5) *outdoor surface* includes the remains found in open spaces outside the buildings, (6) *burial* comprehends the woods collected in funerary contexts; they could represent objects, planks or coffin like structures. Samples from other contexts (i.e. general building filling) have been classified as *uncertain* for the purpose of this work.

All the identified fragments were weighed using a digital analytical balance with 0.01 g readability. An ongoing debate exists on the quantification of anthracological remains. Counting and weighing are time-by-time pointed out as the most representative way to quantify wood remains. The amount of charcoal recovered in a site represents neither all arboreal vegetation nor the amount of wood used, due to filters introduced by combustion (Smart and Hoffman 1988) and taphonomic processes. Chabal (1990, 1994; see also Théry-Parisot et al. 2010) experimentally demonstrated that taphonomic variables, like mass loss and charcoal fragmentation, affect all plant species in the same way. In anthracological analysis counting the number of charcoals is a well-assessed method (Asouti 2003; Asouti and Austin 2005; Asouti and Hather 2001; Chabal 1992; Deckers 2016; Dufraisse 2008; Newton 2005; Popper 1988) and generally takes into account also the size of wood fragments (Carrión Marco 2005; Chabal 1997; García Martinez 2009; Heinz 1990; Uzquiano 1997). Some authors revealed the high correlation existing between charcoal counts and weights (Ludemann 2010; Miller 1985; Riehl and Marinova 2008). At Arslantepe, the sample size can vary and includes both small pieces (<1 to 5 cm in length) from fire installations and long beams (up to 2 m in length) from buildings. Obviously, this implies that there is a great variability in the relation between counts and weights of finds in different contexts. In the anthracological analyses carried out at the site in the past more than 30 years, weights of samples have been preferred to counts because of this great variability. Data available for all samples consist of weight, while both count and weight is only available for specific contexts. As a diachronic interpretation requires a univocal quantification method, we have used charcoal weight. In this way, we were able to use and compare all the data, to better estimate the size of structural elements and to compare data from different contexts. As a supplement to the use of weight (Fig. 3), relative frequency of taxa calculated through ubiquity analysis (number of samples where the considered taxon is recovered, compared with the total number of samples for each period) from the excavated deposits is reported (Fig. 4). This has a double outcome, first in correcting the minimum number of wooden elements (a single sample that results as composed by two taxa should indicate a minimum of two wooden elements) and, secondly, as it may highlight species widely spread, but present in low quantities (otherwise underestimated) or show single taxa selected for specific use in large quantities (hence overestimated) (Cowling et al. 1999; Deckers 2005; Figueiral and Mosbrugger 2000; Marston 2009; Miller 1988).

Analysis of a large number and variety of deposits, reported in multiple ways (i.e. weight and frequency), increases confidence that the observed patterning in data reflects the distribution of wood remains on site and therefore the reality of changes in woodland exploitation during the two investigated millennia.

Results

Given the huge amount of data, the taphonomic history and the complex wood assemblage as a whole, we have taken into account context groups when discussing changes in taxa representation through time. In this perspective we tried to validate our interpretation comparing it with other sites and geographical areas. A very large amount of charcoals (ca. 60 kg) was identified in the seven investigated periods (Table 2, Fig. 3). They belong to 11 taxa, with each taxon possibly comprehending several species. Only 3.7% of the samples come from the dry-sieved collection. The majority of these (19 samples) have been attributed to filling contexts. Among the last seven the following: three belong to fire installations of period VII and four to VI D contexts (2 samples from domestic features, 1 from a bin and 1 from buildings). Because of the small proportion of charcoals obtained through dry-sieving, data are discussed as a whole. As already

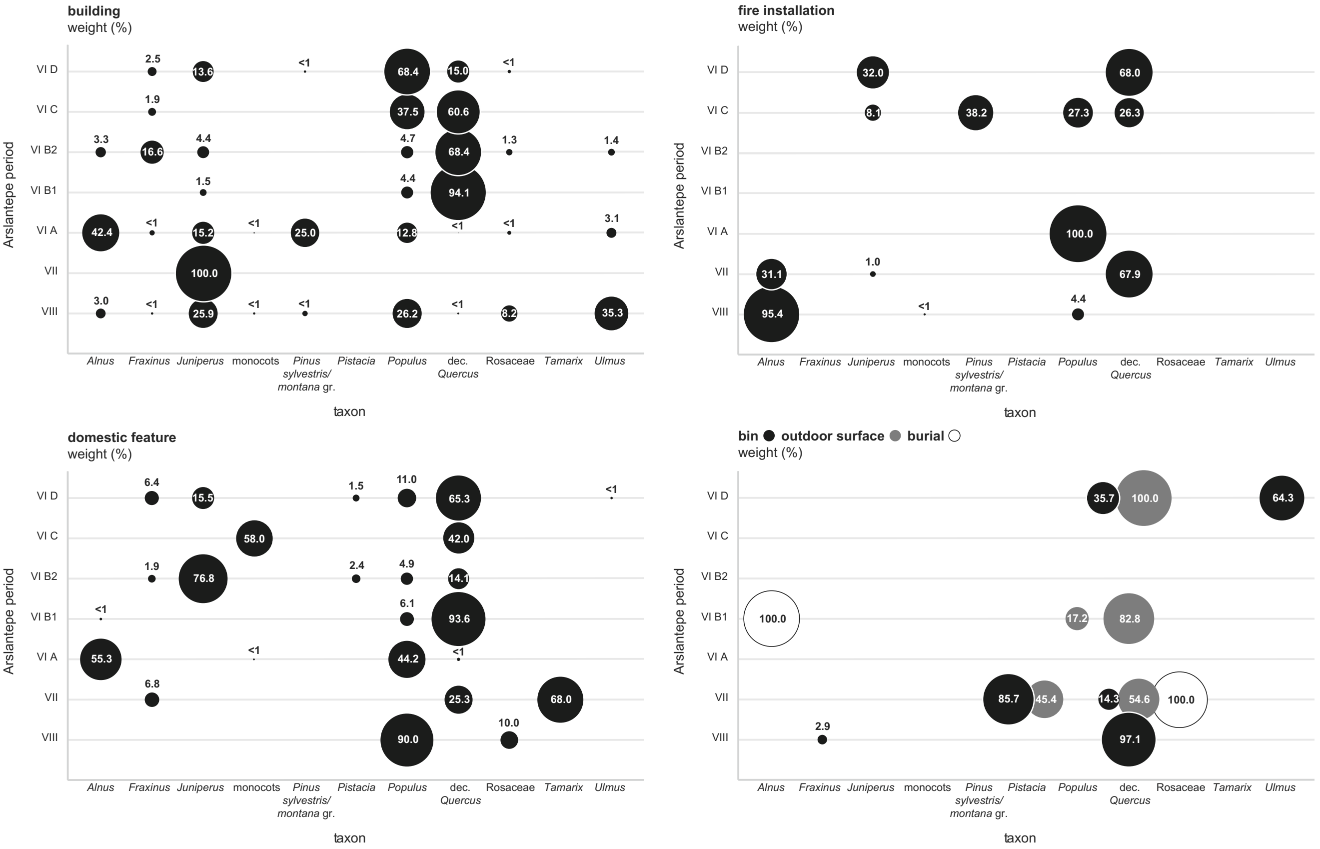

Fig. 3 Percentages of weight of plant taxa divided by depositional contexts for each archaeological period

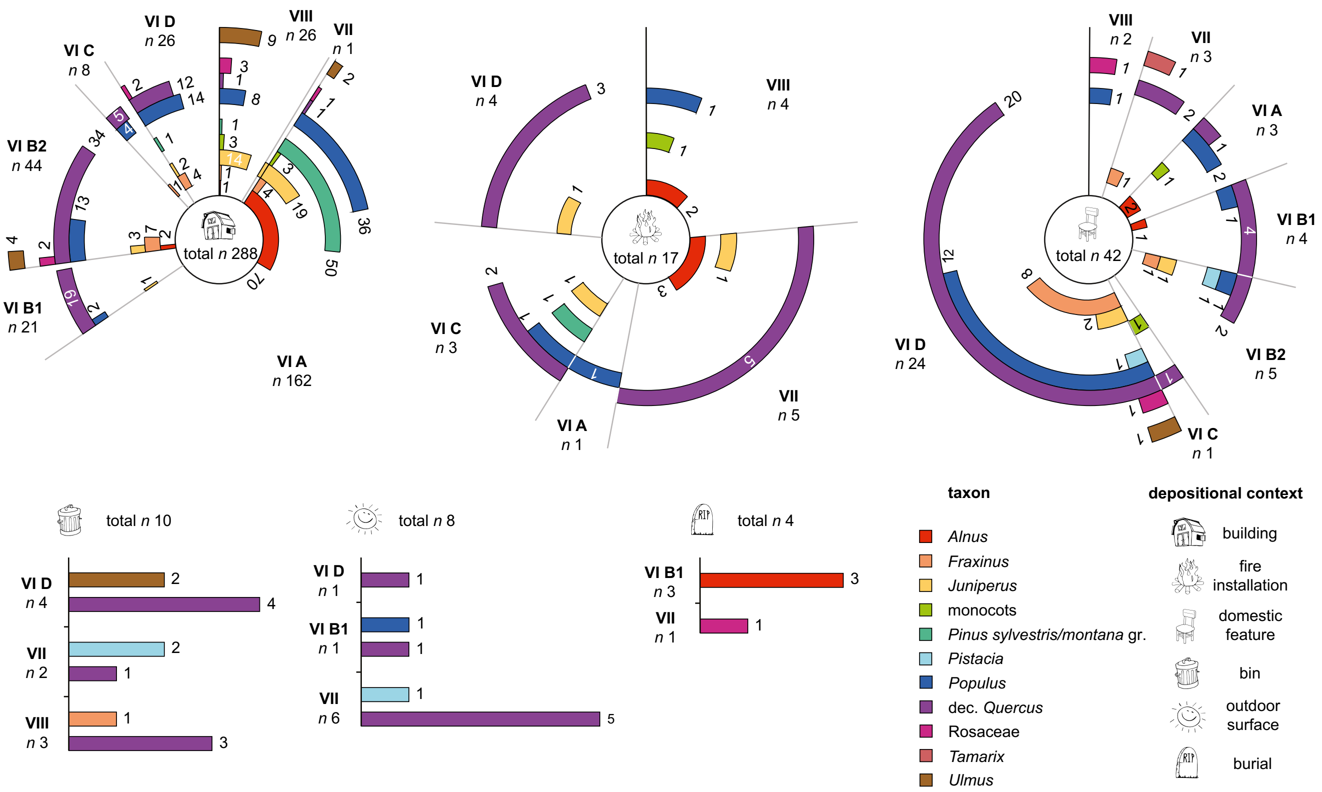

Fig. 4 Relative frequency of taxa for each depositional context and period. The total number of recovered samples for each context (total *n*) and the number of samples in which each taxon is present for each period (*n*) are shown

mentioned and just in order to evaluate changes in the use of wood resources, results of charcoal analysis were listed according to the depositional contexts already described (see Materials and methods). Analysed samples are 859, 63.1% of which are from recognisable depositional contexts. Two hundred eighty-seven were ascribed to building structures. Considering the weight of all analysed charcoals, wooden structural remains are the most common (approximately 59.7% of the total in weight). All the other depositional contexts comprehend 81 samples, which barely reach 3% of charcoal total weight (fire installations: 0.5%; domestic features: 2.4%; bins: 0.4%; outdoor surfaces: 0.2%; burials: 0.1%). All the remaining samples (490) of uncertain origin represent the 36.9% in weight of all findings. They are reported in Table 2.

At the beginning of the Late Chalcolithic (period VIII, 4250–3900 BCE) *Ulmus* (elm), *Populus* (poplar) and *Juniperus* (juniper) were the main building timber, representing the 35.3, 26.2 and 25.9% of the total finds within this typology. Riparian trees were recurring as firewood (*Alnus*–alder, 95.4%) and domestic features (poplar, 90%). On the other hand deciduous *Quercus* (deciduous oaks) were predominant in rubbish deposits (97.1%), where *Fraxinus* (ash, 2.9%) was also identified. In addition small amounts of ash remains come from the building fillings (Table 2).

In the following phase (period VII, 3900–3350 BCE), the only remain referring to building structures is the uncharred juniper wood from the basement of Temple C, even if deciduous oaks and poplar are highly present in the fill of the excavated buildings (Table 2). Deciduous oaks (67.9%) were more common than alder (31.1%) in firewood remains, while *Tamarix* (tamarisk, 68.0%) was predominant in domestic contexts for tools and furniture. Dumping remains of *Pistacia* (pistachio) and deciduous oaks were the most frequent in bin fillings and outdoor surfaces. Few amount of Rosaceae (0.9 g) is the only taxon recovered from burials under a house floor.

Approximately 39 kg of charcoals were identified so far from Late Chalcolithic 5 deposits (period VI A, 3350–3000 BCE). Most of these woods were primarily related to construction material (77.9%). In this case, hydrophilous species were prevalent (alder, 42.4% and poplar, 12.8%) followed by conifers (*Pinus sylvestris/montana* gr.–pine, 25.0% and juniper, 15.2%). The two riparian taxa were also exploited as firewood (poplar) and domestic features (alder, 55.3%; poplar, 44.2%). Other identified taxa did not reach significant percentages, but abundant ash and deciduous oaks remains from building fillings should also be noted (Table 2).

In the VI B1 period (3000–2900 BCE), the amount of charcoals was the smallest of all phases (ca. 1.2 kg) and more than 59% of the remains belonged to uncertain samples. Building remains came from posts either of huts or animal pens. These were mainly deciduous oaks (94.1%), with minor quantity of poplar (4.4%), even if its remains were abundant in building

Table 2 Weight (g) of single taxon for each archaeological period. Samples are grouped by depositional contexts (see text)

Depositional context	Arslantepe archaeological period	Samples (*n.*)	*Alnus*	*Fraxinus*	*Juniperus*	monocots	*Pinus sylvestris/ montana* gr.	*Pistacia*	*Populus*	dec. *Quercus*	Rosaceae	*Tamarix*	*Ulmus*	TOTAL
building	**VI D**	**26**	-	34.5	188.6	-	2.5	-	951.3	208.7	4.6	-	-	**1,390.3**
288 samples -	**VI C**	**8**	-	4.6	-	-	-	-	88.2	142.8	-	-	-	**235.5**
35,853.6 g	**VI B2**	**44**	101.5	510.3	134.7	-	-	-	143.5	2,100.2	38.6	-	43.7	**3,072.4**
	VI B1	**21**	-	-	6.0	-	-	-	18.2	389.0	-	-	-	**413.2**
	VI A	**162**	12,919.9	257.0	4,621.0	15.0	7,623.8	-	3,910.3	5.0	146.2	-	939.0	**30,437.2**
	VII	**1**			26.8									**26.8**
	VIII	**26**	8.3	0.5	72.2	0.5	2.5	-	73.0	0.3	22.8	-	98.3	**278.2**
fire installation	**VI D**	**4**	-	-	34.1	-	-	-	-	72.4	-	-	-	**106.4**
17 samples -	**VI C**	**3**	-	-	6.7	-	31.4	-	22.5	21.6	-	-	-	**82.3**
310.5 g	**VI A**	**1**	-	-	-	-	-	-	78.0	-	-	-	-	**78.0**
	VII	**5**	9.4	-	0.3	-	-	-	-	20.5	-	-	-	**30.1**
	VIII	**4**	13.1	-	-	<0.1	-	-	0.6	-	-	-	-	**13.7**
domestic feature	**VI D**	**24**	-	40.4	98.0	-	-	9.6	69.4	411.8	-	-	1.2	**630.4**
42 samples -	**VI C**	**1**	-	-	-	28.4	-	-	-	20.6	-	-	-	**49.0**
1,433.5 g	**VI B2**	**5**	-	7.7	310.0	-	-	9.6	19.6	56.8	-	-	-	**403.6**
	VI B1	**4**	0.1	-	-	-	-	-	2.9	44.5	-	-	-	**47.5**
	VI A	**3**	164.3	-	-	0.3	-	-	131.3	1.0	-	-	-	**296.9**
	VII	**3**	-	0.3	-	-	-	-	-	1.0	-	2.7	-	**4.0**
	VIII	**2**	-	-	-	-	-	-	1.9	-	0.2	-	-	**2.1**
bin	**VI D**	**4**	-	-	-	-	-	-	-	55.0	-	-	99.1	**154.1**
10 samples -	**VII**	**3**	-	-	-	-	-	20.6	-	3.4	-	-	-	**24.0**
182.5 g	**VIII**	**3**	-	0.1	-	-	-	-	-	4.3	-	-	-	**4.4**
outdoor surface	**VI D**	**1**	-	-	-	-	-	-	-	36.2	-	-	-	**36.2**
8 samples - 98.8 g	**VI B1**	**1**	-	-	-	-	-	-	5.0	24.0	-	-	-	**29.0**
	VII	**6**	-	-	-	-	-	15.2	-	18.3	-	-	-	**33.6**
burial	**VI B1**	**3**	5.6	-	-	-	-	-	-	-	-	-	-	**5.6**
4 samples - 6.5 g	**VII**	**1**	-	-	-	-	-	-	-	-	0.9	-	-	**0.9**
uncertain	**VI D**	**139**	0.8	633.6	162.7	1.1	9.8	29.5	3,966.4	3,345.7	77.1	-	31.2	**8,257.9**
490 samples -	**VI C**	**42**	2.6	-	17.1	-	25.2	-	143.2	2,088.3	19.9	-	-	**2,296.3**
22,076.4 g	**VI B2**	**80**	9.5	35.8	11.2	-	2.4	-	150.3	2,031.6	-	2.3	79.8	**2,322.9**
	VI B1	**21**	31.7	30.0	-	22.6	4.9	-	166.0	469.2	-	-	1.9	**726.2**
	VI A	**155**	3,094.2	265.7	878.9	3.0	500.2	-	2,617.1	811.0	83.5	-	23.5	**8,277.1**
	VII	**34**	<0.1	0.2	4.9	-	0.3	6.9	10.5	62.8	5.0	3.7	-	**94.4**
	VIII	**19**	1.3	4.6	9.0	4.8	-	-	22.1	1.1	7.3	-	51.6	**101.6**

fillings (Table 2). Only a small amount of juniper (1.5%) testifies for the exploitation of conifer timber at the beginning of Early Bronze Age. Pine remains were also identified from uncertain samples (Table 2). Deciduous oaks and poplar charcoals were also recovered from domestic features (deciduous oaks, 93.6%; poplar, 6.1%) and outdoor surfaces (deciduous oaks, 82.8%; poplar, 17.2%). Some remains from a burial (5.6 g) testify the use of alder also in this context. Ash wood exploitation is only testified by scattered remains from building fillings (Table 2).

During the following periods VI B2 (2900–2750 BCE) and VI C (2750–2500 BCE), again deciduous oaks were the most exploited timber together with a large variety of other taxa. The amount of charcoals from structures and features inside houses of the VI B2 village was approximately 3.5 kg. Besides deciduous oaks (68.4%), only ash was commonly used as building wood (16.6%). Alder, juniper, poplar, Rosaceae and elm were present, but none of them reach 5% of total remains. On the other hand the major taxon from domestic feature samples was juniper (76.8%). Also pistachio (2.4%) is used in this way. Pine and tamarisk have been identified within VI B2 charcoal remains but they come from non-interpretable samples (Table 2). Inside the house of VI C period so far investigated (Sadori et al. 2006), ca. 235 g of charcoals refer to structural elements. The overwhelming presence of deciduous oaks (60.6%) is accompanied by poplar (37.5%). Pine and juniper wood were identified from building fillings (Table 2). Domestic features were primarily made of deciduous oaks (42.0%). This is the only period in which monocotyledons reach a considerable amount (58.0%). Proportions of charcoal remains from fire installations are quite different, with 38.2% of conifer wood (pine) and similar quantities of poplar (27.3%) and deciduous oaks (26.3%).

In the latest and long lasting analysed occupational phase, covering the end of the Early Bronze Age (period VI D, 2500–2000 BCE), charcoals from clearly identified contexts amount to 2.3 kg (21.9% of VI D total charcoal weight). Poplar was the most abundant taxon (68.4%) among building woods, followed by deciduous oaks (15.0%) and juniper (13.6%). The same plants were also used in the production of a variety of domestic features but in different proportions (deciduous oaks 65.3%, juniper 15.5%, poplar 11.0%). Ash and pistachio woods could be used for the same purposes as they were recovered in the building fillings (Table 2). Only deciduous oaks and conifers (juniper) were exploited as firewood (respectively 68 and 32%). The analysis of charcoal remains from rubbish layers also testifies the use of elm (64.3%) beside deciduous oak wood (35.7%).

Discussion

Wood use at Arslantepe

The variability of the timber recovered (only 11 taxa) is not high, in particular considering the long investigated period that covers about 2250 years and the related important known cultural changes. Properties of the wood, together with source areas and technological features linked with its exploitation (Table 3), may help us discuss the complex relations existing between human choice, technical skills and environmental changes.

Nine taxa have been so far identified in the samples of period VIII (4250–3000 BCE, Fig. 3). Elm, poplar and juniper are the most common plants among the building remains. They are all easy to work and could have been used for different architectural elements (Nardi Berti 2006): beams were likely made of elm and poplar, while smaller elements could be taken from juniper shrubs/small trees. Riparian plants are used both for objects or furniture (poplar) and fuel (alder) due to their probable abundance in the Malatya plain and to their fast growth (Giordano 1971). It is interesting to note that poplar, more durable, is carefully selected for objects, while alder, liable to be deteriorated by atmospheric agents, is preferred as firewood (Nardi Berti 2006). Also ash from building fillings could be part of domestic furniture. Few branches of deciduous oaks, recovered only in the bins, were probably used as fuel.

At Arslantepe, no wood from structural parts of the buildings of period VII (3900–3350 BCE) has been preserved. Two reasons, and possibly both together, can be adduced to explain this absence: first, wood was not preserved because most of the settlement was not destroyed by fire; second, the settlement was not abandoned at the end of each architectural phase and the building elements were reused in the following constructions. Tamarisk wood was identified only in this period: its remains come from a pipe, together with deciduous oaks and ash, and are also scattered from building fillings. In contrast with the previous period deciduous oaks, above all, and alder were used as fuel. The marked increase of oaks remains could be associated to the enlargement of the catchment area up to the foothills, where deciduous oaks are widespread (Atalay and Efe 2010), due to the expansion of the settlement and the consequent requirements of wood resources. In the absence of contemporary palaeoclimatic data, some palaeoenvironmental changes in the plain due to climate oscillations may also be postulated.

The large amount of wood remains in period VI A (3350–3000 BCE) has several reasons, firstly due to the devastating fire that destroyed and accelerated the burial of structures. Buildings in this period were complex and functionally, as well as architecturally, differentiated. The timber for their construction seems to have been carefully selected, suggesting the presence of skilled carpenters: in fact, different taxa were used in different structures, and sometimes in the same room, depending on their architectural purposes (Sadori et al. 2008). In Temple B (palatial complex), in an impressive monumental room 12 × 5.7 m large, riparian trees such as alder and poplar were dominant and only two beams of pine were found. The radiocarbon dates obtained from charred beams and piles from

Table 3 Vegetation type, macroscopic features and ordinary employment of charcoal taxa. The macroscopic features and ordinary employment are from Nardi Berti (2006) and Giordano (1971) and refer to species in brackets, if specified

Taxon	Vegetation type	Source area	Macroscopic features	Durability	Ordinary employment
Alnus. (*A. glutinosa* Gaertn)	Riparian hydrophilous	River flanks and springs areas	Heartwood indistinct; freshly cut wood orange, tend to brown when seasoned; fine texture; aggregate rays; straight grain	Scarce	Easy to work and season; not easy to bend; liable to deteriorate by atmospheric agents but very durable submerged; used for pileworks, hydraulic and lathe works
Fraxinus (*F. excelsior* L.)	Riparian hygrophilous (broadleaved woodland, woodland-steppe)	River flanks and springs areas (plain)	Heartwood generally indistinct; alburnum pink-whitish or yellowish; light duramen; ring-porous; thin rays; coarse texture; straight grain	Scarce	Resilient; easy to season, but sensitive to humidity; easy to work and to bend
Juniperus	Coniferous mountain/degraded	Mountain/hill slopes	Yellowish alburnum; duramen reddish-brown; early−/late-wood transition very gradual; fine texture; uneven grain	Good	Easy to work; used for firewood, fence posts, boards, wall board and small wood Items
Monocots	Riparian	River flanks and springs areas	No wood	Scarce	mixed with mud to make roofs and wall plaster; reed matting
Pinus sylvestris /montana gr. (*P. sylvestris* L.)	Coniferous mountain	Mountain slopes	Alburnum whitish-yellowish; duramen reddish-brown; resinous; wood rings with abrupt transition, easily recognisable; medium texture; variable grain	Scarce	Easy to work and season; used for furniture, door and windows frames
Pistacia (*P. terebinthus* L.)	Broadleaved woodland, woodland-steppe	Plain, foothills and hill slopes	Alburnum whitish-yellowish; brown duramen with irregular outline; wood rings scarcely ricognisable; thin rays; fine texture; irregular grain	Good	Easy to work and polish; hard and heavy wood; used for lathe items
Populus	Riparian hydrophilous	River flanks and springs areas	Heartwood both indistinct also with whitish alburnum and duramen greenish or brown; wood rings recognisable; fine to coarse texture; straight grain	Scarce	Easy to work and season; not easy to bend; used for carpentry
Deciduous *Quercus*	Broadleaved woodland, woodland- steppe	Plain, foothills and hill slopes	Alburnum whitish-yellowish; brown duramen; ring-porous visible to the naked-eye; broad multiseriate rays visible to the naked-eye; coarse texture; straight grain	Good	Easy to work; slowly seasoned, tend to fissure; hard and heavy wood; used for building, floors, naval works, charcoals and firewood
Rosaceae	Broadleaved woodland, woodland-steppe	Plain, foothills and hill slopes	Variable	Variable	Easy to work
Tamarix	Riparian	River flanks and springs areas	Alburnum whitish-yellowwish; duramen reddish-brown; wood rings no easily recognisable; fine texture; irregular grain	Scarce	Brittle; small-sized wood; used for small items; poor quality firewood
Ulmus	Riparian hygrophilous (broadleaved woodland, woodland- steppe)	River flanks and springs areas (plain)	Alburnum pink-whitish; duramen reddish-brown; wood rings easily recognisable; fair tangential bands of parenchyma; medium to coarse texture; straight grain	Scarce	Easy to work, good resistance and life; resilient if without knots; used for furniture, chairs, counters, handles

Temple B and corridor areas show that many of the structural elements were older than the settlement's timeframe, strongly indicating a wide reuse (Sadori et al. 2008). In particular, the big pine beams were probably very precious not only due to their impressive dimension (Alvaro et al. 2010 estimated an original diameter of more than 25 cm) but also for the distance of the source from Arslantepe. In fact, the nearest pines were probably on the Taurus range, at least 30 km away (Atalay et al. 2008; van Zeist and Bottema 1988). In smaller palace rooms, as the storerooms, deciduous oaks were found, but unfortunately their context of retrieval was not such as to allow a sure interpretation of their use (811 g from uncertain samples, Table 2); nonetheless, their position in the fill suggests they might be structural parts of the roof beams or remains of wooden furniture as suggested also for ash remains. Elite houses, located to the north of the palatial complex, have a plan and architectural features as those of Temple B (Frangipane 2010). Due to the strict similarity of the private dwellings with the public structures, the high presence of alder and poplar could be attributed to the structural elements, even if these samples belong to the undefined depositional context. The dominance of these riparian trees is confirmed also in the domestic features, where they reach 99.5% of the remains. Only one sample of poplar is recovered in a fireplace.

The strong decrease of taxa variability (only 4) recorded in the Early Bronze Age I (VI B1 period, 3000–2900 BCE) was certainly partly due to the changes in the architecture and possibly also to a change in the system of timber exploitation. The inhabitants of the mound, in fact, mostly built small huts and fences (Palumbi 2010), for which a selection of long and particularly resistant wood was not necessary. Furthermore, in this period, the centralised political and economic system of the previous VI A period has collapsed; we can thus hypothesise that each family provided for its own building material. The only big, recently excavated possibly communal building in mud-bricks, technically similar to those of the Late Chalcolithic periods, was destroyed by fire and charred roof beams have been collected (Frangipane 2014). Charcoal analyses have been not carried out yet. Deciduous oaks for the first time prevail in all other building materials, also replacing the riparian taxa of previous period in domestic features and outdoor surface deposits. Anyway, all the wood taxa commonly recovered at Arslantepe are testified from uncertain samples, but their proper use as timber or domestic furniture is not attributable. Deciduous oaks can grow in woodland-steppe formations in which water is scarce. This strong change in timber use though cannot be attributed to environmental change. Asouti and Kabukcu (2014) observing the modern vegetation at the Taurus foothills in Turkey, highlight that small-sized and stunted trees still occur in open formations and as old-growth coppices near villages. The palaeoclimatic isotope record from deciduous oaks and juniper charcoals available from Arslantepe VI A to VI D periods (Masi et al. 2013a, b) furthermore indicates an increase in water availability in correspondence with VI B1 period (Fig. 5). It is thus probably the different needs and organisation of the VI B1 village that caused the change in taxa exploitation.

Burials were rare within the studied area of Arslantepe and only two have plant remains. In the oldest burial, dated to period VII, a small amount of Rosaceae wood is recorded. In the other (Royal Tomb T1) belonging to the VI B1, uncharred alder wood remains were recovered. This burial is noteworthy for the richness of the funerary supplement made up of potteries, working tools, personal ornaments and weapons of precious metals (Frangipane 2010).

Among wood remains of the VI B2 (2900–2750 BCE), not as abundant as seeds/fruits (Piccione et al. 2015), deciduous oaks still prevail in building contexts. Among trees with high

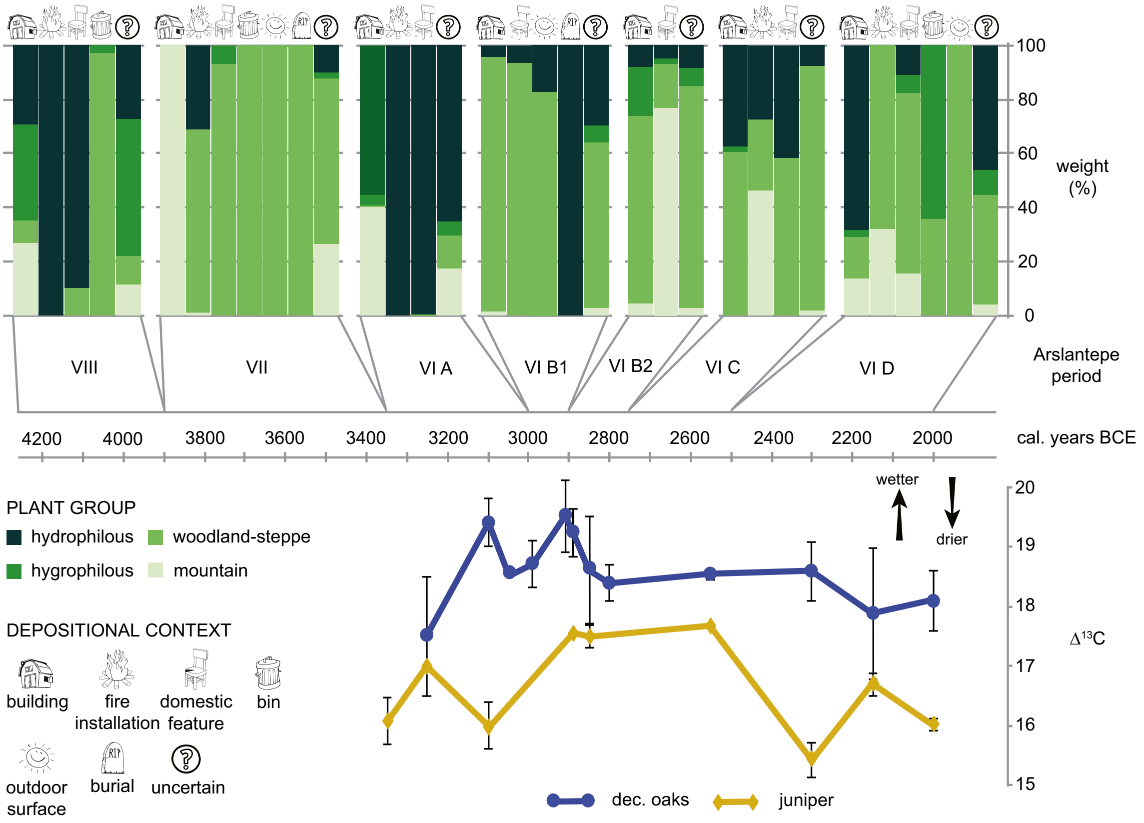

Fig. 5 Comparison between percentage diagram of plant groups from charcoal assemblage (see Table 2) and carbon stable isotopes curves from deciduous oaks and juniper remains (Masi et al. 2013a, b). Plant groups are based on vegetation zones: hydrophilous (alder, poplar, tamarisk), hygrophilous (elm, ash), woodland-steppe (deciduous oaks, rosaceans), mountain (pine, juniper)

water demand, ash seems to replace alder and poplar (recovered only in traces) in building elements. Its wood properties are quite similar to those of alder (Table 3). The needs of architecture are thus similar in both periods. Both species are fast growing and the scarcity of alder and poplar can be barely related to overexploitation. Stable isotope data reveals no abrupt palaeoclimatic changes in the Malatya region during this period (Fig. 5 and Masi et al. 2013a, b). Therefore, the use of ash could be due to the exploitation of a different, even though still near, territory or to cultural choices. The high number of woody taxa identified in the domestic features of period VI B2 is possibly linked to the strong variability of activities performed in each "family unit" (group of structurally connected rooms). Wood was employed for many tools and objects related with food storing and processing. Piccione et al. (2015) highlighted the use of deciduous oaks for making wooden lids of cooking pots and storage jars, and of juniper for handles of small tools, like knives or sickles.

All the archaeobotanical data processed until now for the VI C period (2750–2500 BCE) come from one room (Sadori et al. 2006). This is part of a small group of strongly standardised monocellular buildings (Frangipane 2012b). The high amount of deciduous oak wood comes from the single central post of the house and poplar charcoals were next to this. The characteristics of the two woods are quite different: oaks have a hard and heavy structure and are suitable for supporting the structure, while poplar, light and flexible, could have been used for the roof texture (Table 3). Scattered remains of conifer and Rosaceae woods from the fill layers also testify the use of these taxa as construction material or domestic furniture. The high amount of reeds (monocots) from the depositional context of domestic features is noteworthy. We must consider that the monocot remains are underestimated due to their small size and flammability, despite the large use of reeds in the ceiling texture. In this case, it was found not far from a wooden structure, which probably constituted a mat made object with a wooden framework (Sadori et al. 2006). Only in one of the two fireplaces wood remains of deciduous oaks were preserved. In the oven, many different taxa were used as firewood: pine (the most abundant), poplar, deciduous oaks and juniper. This is the only attestation of pine used as fuel. In previous studies, it has been postulated that the past fuel economy depended on local supply of woody resources (Ludemann 2010). As mentioned before, pines should have been quite rare, but its remains have been also identified from the filling layers of the room (25.2 g from uncertain samples, Table 2). It is therefore possible to assume that at first pinewoods were used for furniture and later for fuel. Even so, the use of pines as firewood might be justified by their capacity of increasing the temperature in the oven (see Giordano 1971, heating properties of conifer wood).

The VI D period (2500–2000 BCE) is rich in taxa, in particular poplar is the most common taxon in the structures, similarly to what found during the VI A. Deciduous oaks still are the most abundant for the domestic features and fire installation. In all these three depositional contexts, juniper is present in moderate quantities. Elm is found discarded in bins for the first time in 1400 years. In period VIII, it had been attributed to a building structure, while in VI D it was probably fuel despite its presence in the building fillings possibly suggests a specific use as timber.

Evaluation of taxa frequency

In order to better evaluate the true importance that the different taxa had, the weight of samples has to be critically analysed. In fact, as we have already stated, the sole weight might be misleading and bring to under/overestimate taxa. In Fig. 4, we present the relative frequency of taxa identified in all samples, for each period and depositional context. A comparison between relative weights (Fig. 3) and frequencies (Fig. 4) can help us comment on this too. It immediately appears that this problem mostly affects samples interpreted as belonging to building structures, due to the very large dimension of some structural elements as vertical posts and roof beams, and in particular for the monumental buildings of VI A period. In general frequencies and weights seem to be well correlated. Exceptions are those in period VIII where juniper would appear to be scarce but it is present in almost half of the building samples (14 samples on 26 totals for the period); on the contrary poplar and elm could be employed in the room structures and appear overestimated.

From the comparison between frequencies and weights, poplar appears to be underestimated both in VI B2 and VI C to deciduous oak's advantage, while the two taxa show an opposite trend during VI D. In the houses of the later period, poplar is employed for big structural elements because it is represented in a lower number of samples but in greater weight than oak. Interestingly, whilst in VI B2 deciduous oak is overestimated within the building structural elements, it is underestimated among the domestic features, in comparison to juniper. Actually, the latter comes from a single sample hypothesised elsewhere to be a tool (Piccione et al. 2015). The same behaviour is clearly visible in VI D where ash, deciduous oaks and poplar were all underestimated in comparison with juniper that, heavy, was present in only two samples. One more interesting example concerns the apparent high amount of tamarisk found in the VII period. The charred remains were discovered in a single sample coming from a sewer of a house floor. This exceptional find could be part of a tool or other domestic feature. Another interesting plant from an outdoor surface of period VII is a single sample of pistachio, a tree that is very rarely used throughout the sequence; could it represent here a wild shrub growing in the open space? This interpretation is extremely interesting as it reminds us that open spaces in the village must have had trees and shrubs providing some possible relief and a bit of shade to kids playing around and people chatting and working outdoors. The domestic feature contexts of period VIII give us another example of interpretation based on frequency. All the remains from this period come from two samples, one of poplar and one of rosaceans. The two are both circular items, probably stoppers for ceramic vessels.

Diachronic changes in charcoal assemblage and comparison with Near Eastern sites

Timber exploitation reveals different patterns throughout the analysed archaeological sequence. From period VIII to VI A, in the Malatya region, conifer and riparian woods were mostly used despite the exploitation of oak woods is widely testified from neighbouring areas (Deckers 2016). The reduced use of oaks wood is unusual in Anatolian and North Mesopotamian regions where oak forests were common since the early Holocene (Deckers 2016). At Tell Brak (north-east Syria) deciduous oaks, pistachio and Rosaceae Maloideae are reported in charcoal samples from different contexts of the early 4th millennium BCE together with some riverine taxa (according to Charles et al. 2010 riverine taxa comprehend willow/poplar, elm and ash). Also during the mid-4th millennium BCE pistachio and tamarisk woods were exploited in large quantities, while riparian trees slightly decreased (Charles et al. 2010). In contrast during the period VII at Arslantepe, pistachio and tamarisk were not recovered inside the building structures but only identified from open areas and domestic features. Their limited use could be related to lesser availability preventing the selection for timber applications. Nevertheless, it is noteworthy that Charles and colleagues (2010) associate the appearance of tamarisk remains with less frequent flood events in relation to the proto-urban management of the local waterways. Dreibrodt et al. (2014) also revealed the absence of soil deposition events near the mound during this period, relating it to a well-managed land use.

The non-substantial presence of oak among timber remains of the Arslantepe VI A palace has been already put in relation with specific architectural requirements. Comparison with timber used in other public buildings of the northern Mesopotamian region is not so straightforward, both due to different vegetational landscapes and different uses. Monumental public buildings are reported from Trench TW at Tell Brak during the Late Chalcolithic (McMahon et al. 2007; Oates et al. 2007). Later, (late 4th millennium BCE) deciduous oak wood was mainly used but the amount of pistachio remains increase together with tamarisk, as revealed by a trend starting from the previous phases (Charles et al. 2010), probably suggesting an opening of the vegetation related to the proto-urban management of lands. A completely different plant assemblage is found at the Royal Palace G of Ebla, dated to the second half of the 3rd millennium BC (Early Bronze Age III): local conifer woods (e.g. *Abies*–fir, *Cedrus*–cedar) were employed for constructions certainly due to their tall straight trunks, as hypothesised for alders, poplars and pines at the Arslantepe palace, while ash and Rosaceae Maloideae were used for luxury furniture (Caracuta and Fiorentino 2013). Only since the Arslantepe Early Bronze Age levels timber from oak forests lying in the plain and foothills prevails on the other wood taxa. Charcoals from the beginning of the 3rd millennium BCE levels of Tell Brak show an opening of woodland vegetation with equal proportions of oaks and pistachio remains, probably due to local human pressure (Charles et al. 2010). In the Late Chalcolithic-Early Bronze Age I levels of Tell Jerablus (northern Syria) no deciduous oaks remains have been found, while *Populus*/*Salix* taxon dominates the charcoal samples with tamarisk and ash, due to the location of the site near the Euphrates river (Deckers and Riehl 2007). At Kurban Höyük (south-east Turkey) oak woods were mainly used as construction timber during the early levels of the 3rd millennium BCE, followed by poplar/willow remains and few fragments of juniper, Ulmaceae and other taxa (Miller 1986). At Arslantepe, the exploitation of wood resources from the Malatya plain by the Late Chalcolithic settlements could have reduced riparian trees near the site in spite of the favourable palaeoenvironmental conditions (Marcolongo and Palmieri 1983), supporting the expansion of woodland-steppe vegetation. It is thus difficult to precisely highlight cultural choices beyond the variation in the Arslantepe charcoal assemblage between the Late Chalcolithic and the Early Bronze Age. For example, as for the VI B2 period, in the 3rd millennium BCE levels of Gegharot, in the southern Caucasus, ash was greatly exploited as construction timber together with willow (Jude et al. 2016). In both cases the availability of ash trees, combined with their good technological features, might facilitate their exploitation. At the end of the VI D period poplar starts again to be widely used in the Arslantepe settlement. The same trend is attested for juniper wood. Differently in the 3rd millennium BCE sites of Middle Euphrates region riparian trees were present in high proportions in comparison with semi-arid woodland taxa. At Emar (northern Syria) poplar/willow represents the most abundant taxon from floor and secondary ash deposits of the 3rd millennium BCE, followed by tamarisk (Deckers 2005). Deciduous oaks and coniferous woods were exploited only in very few amounts (Deckers 2005). Also at Tell Jerablus, lying near the Euphrates River, riparian trees were dominant and oak timber had a limited use (Deckers and Riehl 2007). On the other hand, from the 2700 to 2000 BCE levels of Tell Mozan (north-east Syria) deciduous oaks were largely exploited from the catchment area, while ash and poplar/willow were used to a limited extent (Deckers and Riehl 2007). Also in the Khabur region, at Tell Brak the exploitation of oak and pistachio woods continues during the Early Bronze Age occupation (Charles et al.

2010). Such a difference in timber exploitation between the Malatya plain and the adjacent areas was likely local environment-induced, due to the availability of wood resources and functional purposes. At the end of the period the stable isotope record from Arslantepe shows changes towards dryer conditions (Fig. 5 and Masi et al. 2013a, b). For this reason, the selection of taxa, testified by wood remains of the VI D settlement, might be due to architectural or specific functional purposes such as evidenced during the VI A period.

The same trend in the use of riparian and oak trees for domestic facilities during the analysed periods can be highlighted: the former prevail in the early phases (especially from VIII to VI A periods), while the later are predominant since the VI B1 levels. Whereas alder was greatly exploited in the Late Chalcolithic (VI A period), as revealed by timber remains, juniper wood became more frequent inside the houses since the Early Bronze Age (VI B2 and VI D periods). Ash wood, due to its good properties, was selected for objects and furniture as well as for smaller structural elements during all the occupations.

On the other hand, firewood remains from the Arslantepe sequence show that oaks and poplar were selected from the early to the late periods. Oaks woods are also predominant inside the bins, which can refer to refuse layers collected from fireplaces, together with pistachio, elm and ash. Charcoal analysis from refuse deposits found in open areas at the site of Çatalhöyük (south-central Turkey) reveals that, already during the Neolithic, oaks were the most exploited, with an increasing trend in the use of poplar and willow at the end of the period in relation to their local availability (Asouti and Hather 2001). In the Chalcolithic levels of Pınarbaşı (south-central Turkey) few fragments of tamarisk, ash and oak together with abundant remains of pistachio were found in deposits associated to fire installations (Asouti 2003). Oak, poplar/willow and ash were identified from similar contexts of northern Mesopotamian sites even though in different proportions than the Arslantepe ones (Charles et al. 2010; Deckers 2005; Deckers and Riehl 2007). At the 3rd millennium BCE Kurban Höyük (south-east Turkey) oak and poplar/willow were both used as fuel, with few quantities of juniper remains (Miller 1986). It is noteworthy that in the Arslantepe contexts, a gradual trend in the exploitation of juniper wood as fuel, in addition to domestic facilities, can be suggested despite its use as construction material decreases. Changes in the distribution and structure of shrub vegetation in the Malatya area through millennia could be postulated as due to human pressure.

Wood selection vs. palaeoenvironmental change

Within the building structures, the riparian trees (hydrophilous group in Fig. 5) were particularly abundant in the VI A and VI D periods (more than 50%). They decrease abruptly in the intermediate periods, from VI B1 to VI C. This change cannot be ascribed to climatic fluctuations that indicate periods VI A and VI D as the less humid of the whole sequence (Fig. 5 and Masi et al. 2013a, b), thus we have to imagine direct human choices as responsible for the abundance in hydrophilous plants. Alder and poplar have high and straight trunks even if their durability is rather scarce (Table 3) and were possibly searched for in the construction of the large monumental buildings of VI A. Length was thus preferred to durability, as suggested in other recent archaeological researches (Marston 2009; Rubiales et al. 2011). Alder is quite rare among the wood remains of riverine taxa from the Near Eastern sites, probably due to its huge water demand (Deckers 2016; Zohary 1973); even so the central élite system of VI A was able to organise expeditions to find and exploit it. In the VI D, similarly, the urban planning and standardisation of the town possibly allowed the community to exploit the less present poplar.

The increasing exploitation of riparian woodlands in central Anatolia has been linked to the need in agricultural or grazing land by Hittite society during the 2nd millennium BCE (Wright et al. 2015). At Arslantepe probably more durable and hard wood was available and the riverine vegetation not fully exploited. In particular hygrophilous plants such as elms and ashes had overall limited use: they were abundant in period VIII then almost disappeared, emerging again during the latest phases (Fig. 5). These trees grow in the outer zone of the riparian gallery forest, in water-rich soils, and their exploitation at the beginning of the 4th millennium BCE may be related to the need in arable fields by the Late Chalcolithic settlement (Balossi Restelli et al. 2010; Dreibrodt et al. 2014). In general, the exploitation of riverine forest taxa (including our two categories of hydrophilous and hygrophilous trees) is well documented since the 4th millennium BCE along the Middle Euphrates where land use was focused within the floodplains (Deckers 2016). In the south-central plateau of Turkey, hygrophilous components of past vegetation were limited to little marshes and riparian forests around springs (Asouti 2003). Wet zone trees were also exploited in the highlands of the South Caucasus region where woody resources mainly derived from subalpine open woodland (Jude et al. 2016).

Deciduous and semi-deciduous oaks with rosaceans compose the woodland-steppe plant group. They are widespread all over the considered 2500 years with the only exception of the VI A period, that is clearly due to specific human selection. Oak woodland had a wide natural distribution up to southern Turkey and northern Syria during the 4th-3rd millennia BCE (Deckers 2016). Pollen data from a Lake Van core (eastern Turkey) show the development of a steppe-forest characterised by high levels of oaks since the beginning of the Late Chalcolithic (Wick et al. 2003). A more open woodland-steppe dominated by terebinths and almonds has been suggested far west in the Konya basin, south-central Turkey (Asouti 2003). In the uplands of the central Anatolian plateau, oaks, together with pines, represented the more moisture-dependent elements of a vegetation mosaic reconstructed for the Neolithic times (Asouti and Hather 2001; Willcox 1974). It is interesting to note that semi-arid deciduous oak woodlands of Irano-Turanian region (north and east of Taurus-Zagros range) have been reconstructed as anthropogenic vegetation type modelling by human activities since the Neolithic period (Asouti and Kabukcu 2014; Curebal et al. 2015). Miller (1998) also evidenced light deforestation in the Near East from anthracological data of the 3rd millennium BCE. At Arslantepe, differences in oak exploitation were not likely due to palaeoenvironmental changes. On the contrary, the recovery of riverine plants during the second half of the 3rd millennium BCE, after the strong decrease of the previous centuries, may indicate diminished agricultural land clearance and lower human pressure on the Malatya plain.

Pine, together with juniper, composed the mountain plant group. Pine trees grow today some 10 km away from Arslantepe and the low presence of this wood in the past is certainly related to the fact that other trees were locally present and easy to collect (cf, the Principle of Least Effort: Shackleton and Prins 1992). Pollen records from southwestern and eastern Turkey reveal that mountain coniferous woods fully developed from the Chalcolithic period with some oscillations (Eastwood et al. 1999; van Zeist and Bottema 1988; Wick et al. 2003). Pines grow substantially taller than other local tree, as juniper or oak. It is not surprising that this taxa was mainly used in the palatial complex of the VI A period. Despite pinewood has a scarce durability, the difficulty of its finding may suggest that it was considered a precious timber. Juniper, which is largely growing in the Taurus slopes, is instead distributed all along the Arslantepe periods. In the Irano-Turanian region it characterises marginal areas for tree- or shrub-growth (Atalay and Efe 2010; Zohary 1973) and is reported in association with open woodland-steppe taxa since Chalcolithic times from south-central Anatolia (Asouti 2003). At the end of the Late Chalcolithic, there was an expansion of juniper in the woodlands and a peak of the arid-tolerant pistachio, as the pollen diagram of Lake Van shows (Wick et al. 2003). These have been interpreted as indicators of a dry event (Charles et al. 2010). Stable isotope values from Arslantepe records reveal local climatic oscillations during the VI A period (Fig. 5 and Masi et al. 2013a, b). In the Bronze Age, juniper has been interpreted as constituent of the oak woodlands due to the natural or human-induced deterioration of the forests, as shown by pollen data from eastern Turkey (Wick et al. 2003). Even if low size charred stems of juniper were quite common in most of the Arslantepe periods, this slow growing shrub/tree produces a particularly durable wood and big trunks were likely considered a valuable timber. It was in fact employed as beams in the Temple B entrance (Alvaro et al. 2010; Kuniholm 1996).

Conclusion

The charcoal assemblage of Arslantepe indicates that wood resources were mainly exploited from two local vegetation zones, the woody steppe (composed by deciduous and semi-deciduous oaks with rosaceans) and the riparian vegetation. The latter is from wet environments, including both hydrophilous (mainly alders and poplars with a slow amount of tamarisks) and possibly hygrophilous (elms and ashes) taxa. A considerably minor contribution is from mountain taxa (pines and junipers). Woodland-steppe elements are very abundant; they prevail in all the recovered depositional contexts especially during period VII. In particular, deciduous oaks are one of the most important taxon with the exception of VI A. This last was dominated by hydrophilous elements in building structure and, even more, in fire installation and domestic features.

If we look at ecological groups, the Arslantepe periods show important changes in plant use, that only partly respond to environmental changes. The above mentioned palaeoclimatic reconstruction helps us excluding strong climate changes from 3350 to 2000 BCE (from VI A to VI D). The different distribution of taxa along the investigated time span can be addressed not to climatic conditions but to the overexploitation and/or timber selection related to different technological and/or cultural needs.

An accurate sampling has allowed the recovery and the positioning of the woody elements during the study, essential to properly interpret plant remains and for a deeper knowledge of their exploitation. Following this protocol, the tight collaboration between archaeobotanists and archaeologists can effectively aid in the comprehension of past populations and their relations with the surrounding environment.

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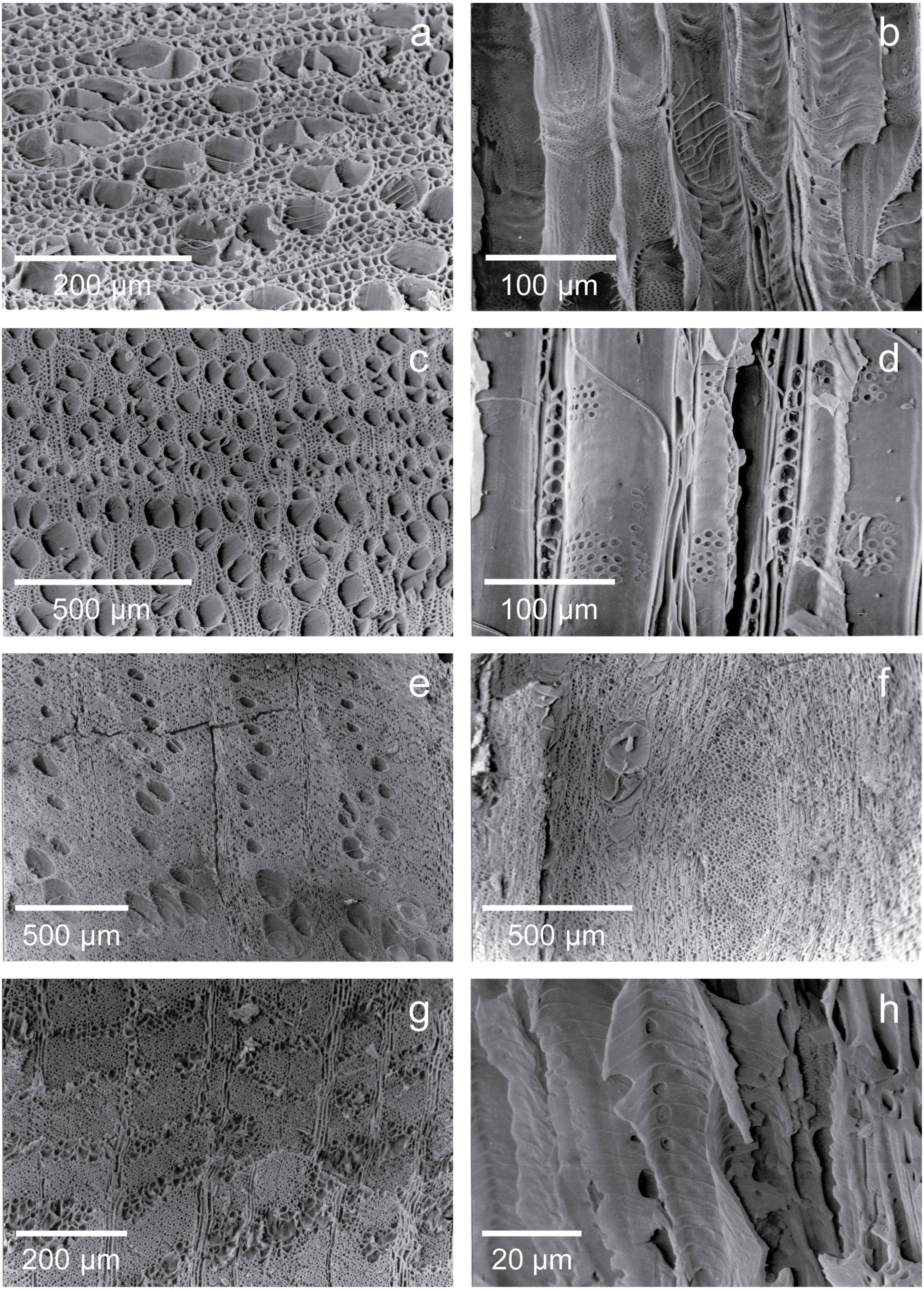
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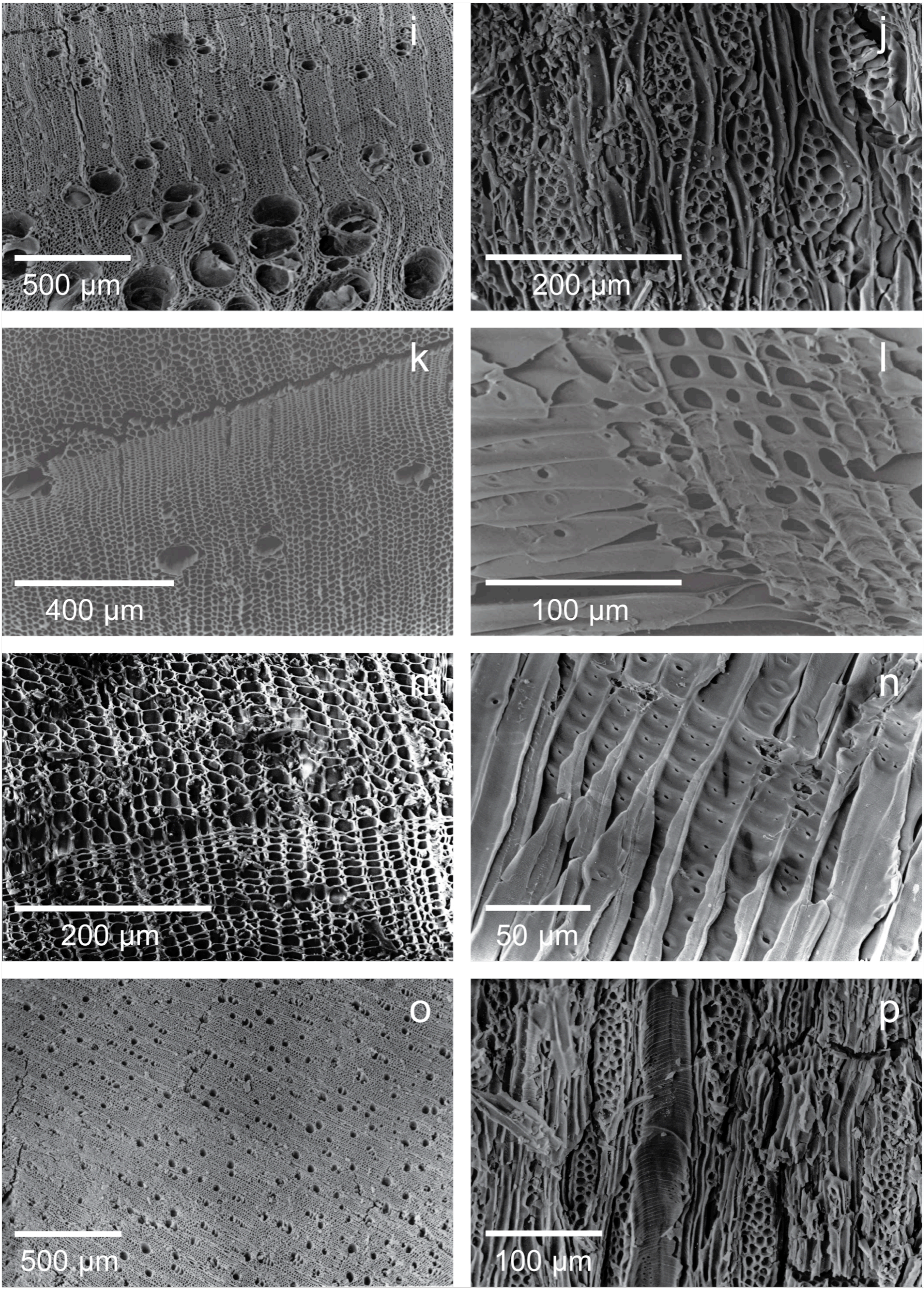
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SECTION 2

Stable isotopes: plant data in palaeoclimatic and agronomic studies

CHAPTER 3

δ^{13}C and δ^{15}N from ^{14}C-AMS dated cereal grains reveal agricultural practices during 4300-2000 BC at Arslantepe (Turkey)

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δ^{13}C and δ^{15}N from ^{14}C-AMS dated cereal grains reveal agricultural practices during 4300–2000 BC at Arslantepe (Turkey)

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ABSTRACT

In semi-arid environments of the Near East water availability and soil fertility are limiting factors for crop growing and land use is locally adjusted to environmental features. In the last decades stable carbon and nitrogen isotope analyses on archaeobotanical cereal remains have been developed in order to reconstruct water and nutrient sources for grain filling. Diachronic studies on isotope records from single archaeological sites may help distinguish palaeoclimatic changes from human choices in agricultural practices, but they are actually missing.

We have analysed ^{13}C isotope discrimination (Δ^{13}C) and N isotope composition (δ^{15}N) on barley, emmer and wheat ^{14}C-AMS dated grains from the archaeological site of Arslantepe, Malatya (South-Eastern Turkey). Our intent is to focus on the exceptionally long-term development of agricultural practices at the site from 4300 to 2000 BC.

Stable isotope values of cereals show temporal trends in water supplies and manure application. Irrigation was provided to barley crops from 4300 to 3100 BC during the rise of centralised political organisation at the site. Different locations of barley fields are suggested from 3100 to 2000 BC when domestic economies are attested. In addition, the marked increase of barley δ^{15}N values from 3350 to 3000 BC reveals manuring and/or cultivation in pasturelands due to the deposition of animal urea and dung. Wheat could have been grown close to the site, where irrigation water from natural springs was available. Emmer and wheat seem to have been cultivated in the same areas or directly in the same fields. During 3000–2500 BC intercropping cultivation is inferred by low δ^{15}N values. The evidence of mixture crops confirms the increase of pasturelands during herders' occupations and the concentration of crop fields possibly around the site.

1. Introduction

The study of crop growing conditions and farming practices is an essential step in the reconstruction of socio-economic changes in past societies. The rise and decline of ancient civilizations, especially in the Near East, are thoroughly tied to agricultural production and its varying developments in relation to both environmental constraints and social structure (Feynman and Ruzmaikin, 2007). However, the knowledge of changes in agricultural systems at a local scale, including water availability and soil fertility enhancement, is still limited. In particular the role of climate and field management strategies in agricultural production has been variously considered in analysing ancient Near Eastern societies (Riehl, 2012).

In the Eastern Mediterranean region several palaeoclimatic records clearly evidenced mid-Holocene climate oscillations (Roberts et al., 2011). Above all climatic and agricultural data suggest that past and present climate affected agricultural yields (Olesen et al., 2012). In the last decades the use of stable carbon isotope analysis of cultivated plant remains proved essential to directly link palaeoclimatic fluctuations and crop production (Ferrio et al., 2005; Aguilera et al., 2012; Araus et al., 2014; Riehl et al., 2014; Fiorentino et al., 2015).

^{13}C/^{12}C ratio in cereal grains is a proxy of the amount of water they received during the grain-filling period. The stable carbon isotope analysis is in fact used to reconstruct environmental conditions for crop growth especially in semi-arid environments (Masi et al., 2014; Mora-Gonzáles et al., 2016). Parallel studies of the stable nitrogen

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isotope ratio evidence that N cycle in soils and plants can be conditioned by anthropogenic activities at different scales (Bol et al., 2008). Since manure has a clear effect on crop production, the reconstruction of ancient manuring practices may highlighting different agronomic conditions (Bogaard et al., 2013; Araus et al., 2014; Kanstrup et al., 2014; Styring et al., 2017). Information on ancient crop management can be achieved by combining ^{13}C and ^{15}N abundances (Kanstrup et al., 2011; Fiorentino et al., 2012) since water availability is the main factor conditioning cereal production in non-fed agriculture and, in turn, ^{15}N abundance of cultivated plants integrates field conditions during growth.

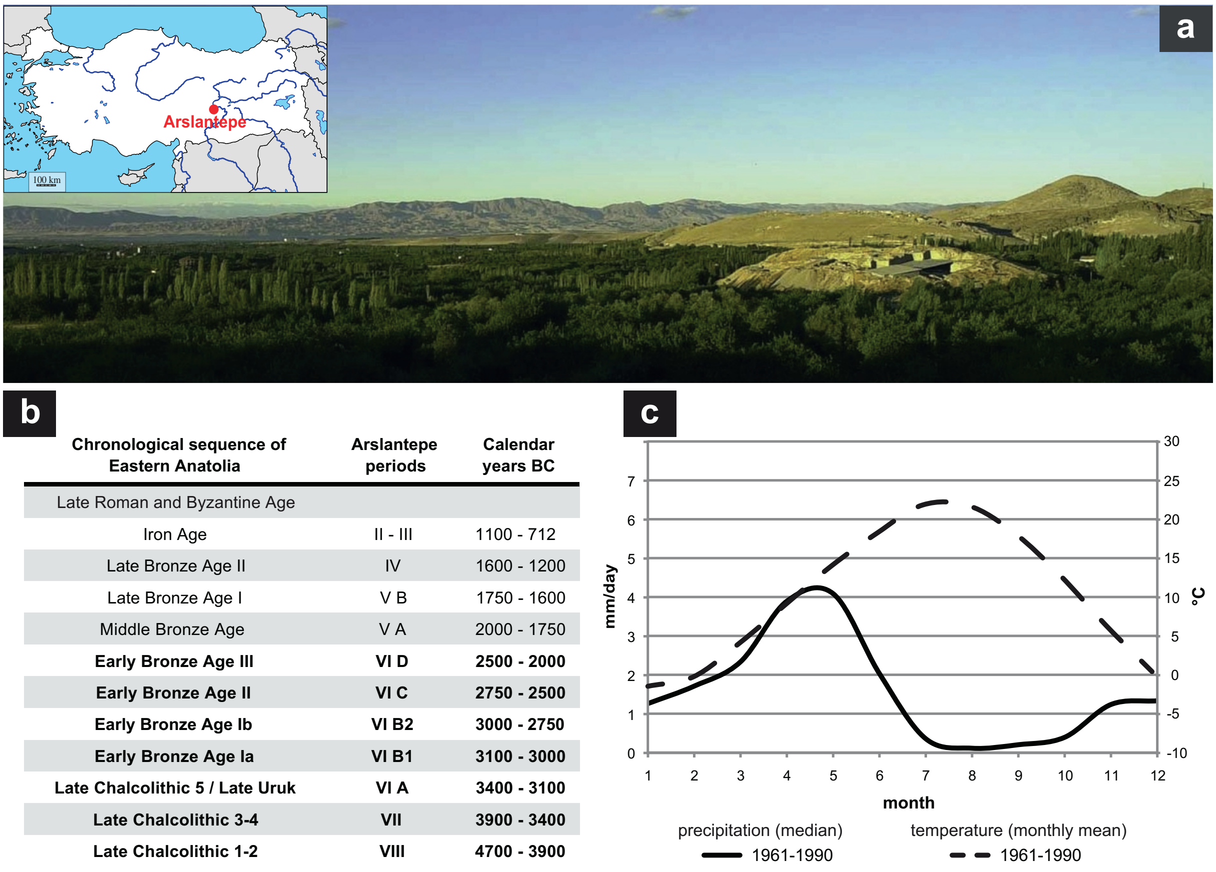
Ancient systems of land use might have adopted a great variety of different cultivation and field fertility techniques, among which intercropping must have been one of the most common practices. Cultivating two or more crop species (i.e. both cereals and legumes) in the same field at the same time matched crop needs with available growth resources (Sullivan, 2003; Tsubo et al., 2005). Intercropping can improve soil fertility through N-fixation by legumes allowing reduced manuring and increasing the efficiency of soil resource use (Matusso et al., 2014).

The stable carbon isotope analysis on charcoal remains from the archaeological site of Arslantepe (South-Eastern Turkey) has already turned out essential in understanding the exploitation of wood resources (Masi et al., 2017). The study was based on carbon and nitrogen isotope analysis of a large collection of charred cereal grains from successive occupational phases, from the beginning of the Late Chalcolithic, hence LC (period VIII, 4700–4100 BC) to the end of the Early Bronze Age, hence EBA (period VI D, 2500–2000 BC). Due to the novelty of this methodological approach and to the long occupation of the site, our research represents the first attempt to apply stable isotope analysis to a large assemblage of plant material from a single well-dated archaeological site reflecting more than 2000 years of agricultural history. We aim to elucidate long-term agricultural practices in the region and to firmly support the use of ^{13}C and ^{15}N abundances as a direct source of information on the development of crop production in the ancient Near East.

2. The investigated site

The multi-period settlement of Arslantepe has been excavated since 1961 by the Italian archaeological expedition in Eastern Anatolia of Sapienza University of Rome. The site is located in a plateau at ca. 940 m a.s.l. in the Malatya region (South-Eastern Turkey). The settlement lies at the edge of a wide alluvial plain enclosed by the Anti-Taurus Mountains on the east, south and west and is situated along the western banks of the Upper Euphrates river (Fig. 1a).

The investigated sequence of settlements at Arslantepe starts as early as 4700 BC and continues with very limited hiatuses in cultural levels until historical times (Fig. 1b). Archaeological phases are dated according to related archaeological contexts and radiocarbon ages (Di Nocera, 2000; Alvaro et al., 2010; Balossi Restelli, 2012; Vignola et al., 2017 and in this article). This study focuses on the occupational levels from 4300 to 2000 BC. Along this quasi-uninterrupted sequence, social, cultural and economic changes are testified. The earliest phase (period VIII: LC 1–2, 4700–3900 BC) was characterised by small domestic units with kitchens, storages and living areas for each household (Balossi Restelli, 2012). Gradually the settlement grew and social differentiation developed (period VII: LC 3–4, 3900–3400 BC): elite residences and an imposing temple building lied on the top of it (Frangipane, 2016). Then the site changed, becoming the centre of a new pristine state (period VI A: LC 5, 3400–3100 BC): this huge palatial



Chronological sequence of Eastern Anatolia	Arslantepe periods	Calendar years BC
Late Roman and Byzantine Age		
Iron Age	II - III	1100 - 712
Late Bronze Age II	IV	1600 - 1200
Late Bronze Age I	V B	1750 - 1600
Middle Bronze Age	V A	2000 - 1750
Early Bronze Age III	**VI D**	**2500 - 2000**
Early Bronze Age II	**VI C**	**2750 - 2500**
Early Bronze Age Ib	**VI B2**	**3000 - 2750**
Early Bronze Age Ia	**VI B1**	**3100 - 3000**
Late Chalcolithic 5 / Late Uruk	**VI A**	**3400 - 3100**
Late Chalcolithic 3-4	**VII**	**3900 - 3400**
Late Chalcolithic 1-2	**VIII**	**4700 - 3900**

Fig. 1. Arslantepe (Malatya, Turkey). a) The Malatya plain with the settlement mound (site location, top left) (Masi et al., 2017, modified); b) Archaeological periods (in bold the investigated ones) and new chronological framing combining old radiocarbon dates, stratigraphic sequence and new ^{14}C–AMS radiocarbon dates, this paper; c) Monthly mean temperature (°C) and precipitation (mm day^{-1}) values in the Malatya area for period 1961–1990 (Masi et al., 2013b, modified).

complex, with administrative and religious structures and elite residences, has been destroyed by a fire that ended the centralised system forever (Frangipane, 2016). Later mobile groups with links to Transcaucasian cultures occupied the site (period VI B1: EBA Ia, 3100–3000 BC) and short-lived occupations occurred (Frangipane, 2014; Palumbi et al., 2017). As a proof of the alternating dominance of different communities in the plain, a farmers' village was built up on the mound in the following VI B2 period (EBA Ib, 3000–2750 BC). Short- and long-term settlements succeeded respectively during VI C (EBA II, 2750–2500 BC) and VI D (EBA III, 2500–2000 BC) periods but the presence of fortification walls deeply revealed the persistence of conflicts in the region (Frangipane, 2012).

3. Interpretative framework

3.1. Modern climate and palaeoenvironmental background

The site is located in a semiarid environment. The mean precipitation rate for 1961–1990 is reported in Fig. 1c. The rainfall season occurs in spring, followed by the driest and hottest months of July–October (Sensoy et al., 2008). The Taurus range, where precipitations are higher and mostly in the form of winter/early spring snow, is the large hydrogeological catchment that provides surface-running water and outcropping springs for the plain (Marcolongo and Palmieri, 1983; Atalay, 2004). Low summer humidity limits tree growth to the edge of valleys while steppe vegetation is widespread (Yildiz et al., 2004). Nonetheless in the plain a sizeable biomass is fed by aquifer and alluvial sediments that provide fertile soils for orchards (Çolak et al., 2010; Dreibrodt et al., 2014).

Several regional records provide hints for the palaeoenvironmental reconstruction of the Malatya area. In Gölhisar Lake, South-Western Turkey, the comparison of oxygen isotope ratios and palynological analyses revealed wetter conditions for the LC (since 4000 BC) and the onset of drier ones after 3100 BC (Eastwood et al., 2007). The drop in humidity between LC and EBA is also evident from isotope and pollen data of Lake Van in Eastern Turkey (Wick et al., 2003). In Central Anatolia, the sediment cores of Tecer Lake have reported peaks of aridity from 4000 to 3000 BC (Kuzucuoğlu et al., 2011). Also from the oxygen isotope analysis of Lake Eski Acıgöl and Lake Nar Gölü, in the Cappadocia region, the gradual transition from wetter to drier climate in the mid-Holocene have been evidenced (Roberts et al., 2001; Dean et al., 2015).

The local palaeoclimatic trend has been estimated through stable carbon isotope analysis on charcoal remains from the site (Masi et al., 2013a, 2013b). The deciduous oaks (*Quercus*) record especially allowed inferring water availability and aquifer level in the plain relating to summer droughts (Masi et al., 2013a). Deciduous oaks stable isotope values reveal climatic instability from ca. 3200 to 2800 BC. A dry event is recorded during the VI A period (3200 BC) while wetter signals are evidenced in the late VI A and VI B1 periods (3100–2900 BC). Atmospheric humidity abruptly decreases at ca. 2800 BC (VI B2 period), remaining unchanged until the late VI D period. At ca. 2150 BC even drier conditions are attested.

The Arslantepe stable isotope records have also been compared with the MCM (Macrophysical Climate Model) reconstruction of the Upper Euphrates basin (Arıkan et al., 2016). At 4300–3000 BC the region experienced cool and wet conditions followed by a decline in precipitation and an increase in temperature (3000–2500 BC). Then a progressive improvement is suggested (2500–2000 BC), contrary to what Arslantepe records locally. Nonetheless the Upper Euphrates basin showed a gradual but continuous decline in rainfall during all EBA periods (Arıkan et al., 2016).

3.2. Field and livestock management

Changes in precipitation and temperature were critical for societies relying heavily on dry farming. Probably local communities adjusted the level of intensity in land use and field management time by time. At Arslantepe subsistence strategies, evidenced by archaeobotanical and archaeozoological data, refer to a “staple” economy with a possibly equal contribution of crop production and herding practices since LC. A selection due to context preservation has to be postulated (Vignola et al., 2014) for the whole record.

In period VIII levels emmer and einkorn are the most abundant crops, while few specimens of legumes have been identified. Barley grains prevail among plant remains of the period VII assemblage. During the palatial phase (period VI A) the ubiquitous presence of multi-row barley, which has higher water requirements than two-row species, suggests a centralised management of economic system with direct impulse on agricultural techniques (Balossi Restelli et al., 2010). Opposite evidences have been postulated for VI B2 period, when especially two-row barley was cultivated in the Malatya plain (Piccione et al., 2015). In the investigated context of VI C period a concentration of chickpeas has been recovered (Sadori et al., 2006). In VI D settlement remains of wheat and faba bean/grass pea prevailed (Sadori and Masi, 2012). A well-managed land use is also testified by a slope deposit record near the mound (Dreibrodt et al., 2014). An erosion phase is only dated to ca. 3000 BC, suggesting a drop of soil protection in the plain previously safeguarded through the agricultural activities.

Considering the barley and emmer carbon isotope content from Arslantepe, cereal growth conditions in the plain don't completely match with the palaeoclimatic reconstruction provided by charcoals (Masi et al., 2014). In particular, a change in agronomic conditions has been clearly identified from 3000 to 2800 BC: while the barley isotope ratio revealed a dry phase, the emmer one gradually suggested higher humidity, explainable by human intervention (Masi et al., 2014).

Also the variability in composition of livestock could be affected by different strategies in land use across the Malatya region. Animal husbandry is directly connected with agricultural practices in terms of forage crop, manure and pasture availability. Since period VIII domestic economy was based on caprine rearing (Vignola et al., 2014). At the end of period VII the prevalence of caprines in the monumental area of the site indicates a change in the role of these species, possibly connected with the emergence of the centralised organisation of period VI A (Palumbi, 2010). A similar animal husbandry model based on the key role of caprines has been reconstructed for the VI B1 pastoralist settlement (Siracusano and Bartosiewicz, 2012). A gradual increase in beef consumption is reported in the VI B2 rural village (Piccione et al., 2015). Archaeozoological analysis is still ongoing for the following periods.

4. Materials and methods

4.1. Archaeobotanical samples

Hulled barley (*Hordeum vulgare* L.), emmer (*Triticum dicoccon* Schrank) and naked wheat (*Triticum aestivum* L./*durum* Desf.) grains were selected for stable carbon and nitrogen isotope analysis. Due to intraspecific and intrasample variability of $\delta^{13}C$ and $\delta^{15}N$ (see Section 4.2), that is expected in plants grown under the same agronomic conditions (Bogaard et al., 2007; Heaton et al., 2009), five kernels of the three crop taxa per contextual unit were selected following Masi et al. (2014).

$\delta^{13}C$ values of 68 cereal grains from 11 contexts were analysed and joined with 53 previously published (Masi et al., 2014) to provide isotopic data on barley, emmer and wheat. Barley and emmer grains were selected from the three oldest periods of Arslantepe in order to extend the carbon record to 4300 BC. In addition, new data from wheat are provided for all the investigated sequence, except period VII that has no such find. Contexts from which samples were selected are those described by Masi et al. (2014), plus the deposits list below. For period VIII (Vignola et al., 2014), kernels were recovered from soil samples of room A718 (kitchen). For period VII, kernels were selected from room A849 (elite residences) and rooms A900–A932 (temple building). Due to the limited availability of plant remains, emmer grains refer only to A849 and wheat has been never identified. The 2013–2014 field campaigns brought to light new cereal remains from a VI A room (A1358) of the palace complex (Frangipane, 2016), allowing to enlarge the isotope data set for the period. Lastly, for period VI B1 wheat kernels were recovered from soil samples of an outdoor area (A1325, Frangipane, 2012).

A total of 102 cereal grains from 14 contexts were measured for $\delta^{15}N$. The same specimens were analysed for both $\delta^{13}C$ and $\delta^{15}N$, except for contexts published by Masi et al. (2014) where new kernels were selected.

^{14}C dates were performed on 10 plant remains: 5 grains of *Triticum dicoccon*, 1 *Triticum* sp., 1 fruit of *Sorbus* sp., 2 charcoal fragments of deciduous *Quercus* wood and 1 of *Juniperus*. In the case of wood, the last one or two rings of young branches were collected.

4.2. Radiocarbon dating and stable isotope analysis

Measurements of ^{14}C, $\delta^{13}C$, $\delta^{15}N$ and mass% N were carried out at CIRCE Laboratory, University of Campania. For natural abundances and fractionation mechanisms of stable carbon and nitrogen isotopes refer to Farquhar et al. (1989) and Fry (2006). Isotopic composition in charred kernels is not affected by carbonization process between ca. 200–400 °C (Styring et al., 2013). The slight increase registered by mass% N is negligible (Fraser et al., 2013).

All samples were treated according to Passariello et al. (2007) and milled into a powder for isotope analyses, since chemical treatment has no effects on C and N composition (Fraser et al., 2013). Moreover, for ^{14}C dates, samples were combusted and graphitized according to Marzaioli et al. (2008) and $^{14}C/^{12}C$ ratios were measured by means of an AMS system (Terrasi et al., 2008). Then ^{14}C abundances were converted to Radiocarbon (RC) ages (Stuiver and Polach, 1977). Calibrated age values were obtained by the CALIB7 code (Stuiver et al., 2017) via INTCAL13.14c data set (Reimer et al., 2013).

An elemental analyser (FLASH 1112 series EA-CHNS; Thermo Fisher) coupled to an isotope ratio mass spectrometer (Termo Fisher Delta V) via Thermo Fisher CONFLO III interface was used for $\delta^{13}C$ and $\delta^{15}N$. IAEA and laboratory standards (IAEA-C3, IAEA-C6, VR2) were measured for calibrating carbon isotope data on the absolute isotope scale for ^{13}C (VPDB) according to Farquhar et al. (1989). A minimum of two replicates per kernel was analysed, whose standard deviations averaged at 0.2‰. Since changes in atmospheric CO_2 concentration over time need to be taken into account, carbon isotope discriminations ($\Delta^{13}C$) were calculated according to Farquhar et al. (1989) by the CU-INSTAAR/NOAA-CMDL database (Ferrio et al., 2005). The data set is available at http://web.udl.es/usuaris/x3845331/AIRCO2_LOESS.xls where $\delta^{13}C_{air}$ values are reported (Indermuhle et al., 1999; Eyer et al., 2004).

IAEA and laboratory standards used for calibrating nitrogen isotope data included IAEA-N2, IAEA-NO3, VR2. Isotope ratios are reported as $\delta^{15}N$ values (‰) referring to Fry (2006). Due to the scarcity of material, it was no possible to analyse two replicates per kernel. The overall analytical precision was about 0.4‰. Few outliers, diverging in both $\delta^{13}C$ and $\delta^{15}N$ values, were detected and excluded.

Mass% N was estimated by utilising signals obtained over the stable measurement run through m/q peak amplitude 28. Isotope calibration standards were used to build a response function relating mass% N to signal 28 and unknown values were calibrated by means of the observed function.

4.3. Statistics

Differences in mean values of $\delta^{13}C$ and $\delta^{15}N$ within the three crop taxa in relation to archaeological periods were tested by a permutational multivariate analysis of variance (PERMANOVA), significant if $P < 0.05$ (PAST 2.0). The correlation between emmer and wheat stable isotope values was evaluated through a Spearman's rank analysis. Pearson's correlation coefficients (r) between $\delta^{15}N$ and %N were determined in order to define the relationship between isotope composition and concentration.

5. Results

5.1. Chronological improvement

Results of 10 ^{14}C-AMS dates are listed in Table 1. Most of the archaeological contexts selected in this study had previously been dated (100 ^{14}C dates) using charcoal remains. The new AMS RC dates are from seeds and fruit remains, whose age is closer to depositional processes and chronologically represent the last use of the buildings they were found in. The chronological framework resulted improved, distinguishing sub-phases within periods (Vignola et al., 2017). Particularly, three sub-phases of period VII have been dated (Table 1 and Fig. 1b). LC 3–4 represents one of the more long-lasting periods in the development of the site (Frangipane, 2016). Changes in the chronological boundary between VI A and VI B1 periods have been critically determined (Table 1 and Fig. 1b). In addition, providing dates on the same kernels of isotope records was useful to settle overall trends in $\delta^{13}C$ and $\delta^{15}N$ values.

5.2. Variability in $\delta^{13}C$, $\delta^{15}N$ and %N values

$\delta^{13}C$ mean values with standard deviation (SD) are presented in Table 2 and Fig. 2. The value of emmer $\delta^{13}C$ for period VIII is −23.3‰, whereas barley and wheat reach respectively −24.3‰ and −24.2‰. In period VII, a large degree of isotope variation is attested between the mid- and the late sub-phase with barley $\delta^{13}C$ values ranging from −23.5‰ to −24.9‰. Also intrasample variability is high (late VII SD: ±0.9). Emmer isotope signals are similar to the barley ones. Both VIII and VII barley and emmer $\delta^{13}C$ values are statistically different from those of all the other periods (Table 2). In period VI A barley kernels reveal a lower value (−23.8‰), while *Triticum* values tend to be higher (wheat: −23.1‰; emmer: −22.7‰). In the succeeding period VI B1 wheat $\delta^{13}C$ value decreases (−23.9‰), but increase again in later EBA (VI B2 period: −22.9‰; VI C period: −22.2‰). Differences between VI B2/VI C and LC 1–2 wheat $\delta^{13}C$ values are significant (Table 2). At the end of the investigated sequence wheat yields the lowest value of the record (VI D period: −24.5‰), being statistically similar to LC values (Table 2).

%N and $\delta^{15}N$ mean values are listed in Table 2 and Fig. 2. Samples show a relative small isotope variation in the three cereal taxa between VIII and mid-VII periods (where present), with $\delta^{15}N$ values only slightly higher than 4‰. On the other hand, in late period VII the barley isotope signal markedly increases reaching the highest value of the whole record (7.2‰). In the VI A period barley yields higher value (6.0‰) than the *Triticum* taxa, but a difference between wheat and emmer grains is also attested (respectively 5.2‰ and 4.0‰). The strongest variability in isotope values of the three cereal types is recorded in period VI B1, ranging from 8.5‰ of barley to merely 0.9‰ of wheat. In particular, VI B1 wheat $\delta^{15}N$ values statistically diverge from those of all the other periods, apart from VI C (Table 2). In the succeeding periods $\delta^{15}N$ of all the cereal taxa gradually decreases. The lowest value is recorded from the emmer kernel analysed for VI C period (0.2‰). Barley $\delta^{15}N$ values for both VI B2 and VI C periods and emmer values for VI B2 period are statistically different from those of all the other periods (Table 2). At the end of the investigated sequence an increase is testified once more, with $\delta^{15}N$ values similar to those of the earliest periods (barley: 3.5‰; emmer: 4.4‰; wheat: 4.7‰). In fact, the difference between LC 1–5 and VI D stable isotope values is not statistically significant (Table 2).

%N values greatly differ between the LC and EBA periods in all of the crop taxa (Table 2). The lowest N concentration (0.0%) is attested by late period VII barley grains, which showed on the contrary a high $\delta^{15}N$ value. The highest N concentration (10.8%) is recorded in the VI C emmer grain, which reached the lowest $\delta^{15}N$ value of analysed kernels. Correlations between $\delta^{15}N$ and %N values are negative and significant in the three cereal taxa, except for VI A when wheat grains show an opposite relationship (Table 2).

Table 1
^{14}C-AMS dates provided on samples from the same contexts investigated by stable isotope analysis.

Arslantepe period	Sub-phase	Contextual unit	Taxon	Plant remain	Laboratory ID	^{14}C date BP	^{14}C cal. BC (2σ)
VII	Middle	A849	*Triticum dicoccon*	Grain	S05/17-DSH7981	4679 ± 31	3622–3369
	Late	A850	*Triticum dicoccon*	Grain	S05/17-DSH7977	4751 ± 31	3636–3382
		A932	*Triticum* sp.	Grain	DSH6515	4546 ± 30	3367–3104
VI A		A206	*Triticum dicoccon*	Grain	S05/17-DSH7980	4556 ± 35	3485–3104
			Triticum dicoccon	Grain	DSH6455	4541 ± 39	3368–3099
		A1358	*Triticum dicoccon*	Grain	DSH6456	4584 ± 49	3512–3101
VI B1	Middle	A1369	*Sorbus* sp.	Wild fruit	D28/15-DSH7047	4600 ± 33	3507–3128
	Middle/Late	M223	dec. *Quercus*	Charcoal	D28/15-DSH7017	4559 ± 21	3369–3119
	Late	A1336	dec. *Quercus*	Charcoal	D28/15-DSH7017	4552 ± 21	3366–3117

6. Discussion

6.1. Water availability for crops

The intraspecific grain variation in δ^{13}C is attested with variable magnitude in the different periods (Table 2). Looking at each period, the intrasample variation of isotope composition is critical and should be even more so taken into account when comparing isotope evidences from the same archaeological site throughout time. Despite a certain grain variability is expected in plants grown under the same environmental conditions (see Heaton et al., 2009), Arslantepe barley displayed a higher offset in carbon composition from 3350 BC (Fig. 2) and in general δ^{13}C values are more variable than in the two *Triticum* taxa (Table 2 and Fig. 2). Emmer and wheat show the highest offset during VI A. This variability can be related to the provenience of crops from different fields. In fact, storing and redistribution activities were well attested during the palatial phase (Frangipane, 2016).

The carbon isotope discrimination (Δ^{13}C) of the three cereal types is plotted in Fig. 3. It is evident that emmer and wheat values turn out being remarkably well-correlated across the Arslantepe sequence (Spearman's rank correlation coefficient of 0.94, Fig. 3). Modern grains of different *Triticum* species displayed differences in isotope composition, but show a uniform behaviour in the increase/decrease of values when grown under the same environmental conditions (Heaton et al., 2009). Our data correspondence may suggest that emmer and wheat ripened in the same areas or were directly cultivated in the same fields as mixed crops (see “maslin” cultivation in Jones and Halstead 1995). Archaeobotanical Δ^{13}C values of wheat (*T. durum* type) recorded by well-irrigated grains are >17‰ (Wallace et al., 2013). Comparable data for emmer harvests are unfortunately not available in the literature. The same environmental conditions have to be postulated for the similarity in behaviour of emmer and wheat. Wheat Δ^{13}C values are never below the threshold of not irrigated condition (Wallace et al., 2013) pointing out that irrigation practices and/or location of fields in mature soils near springs (Marcolongo and Palmieri, 1983) could be suggested for *Triticum* cultivation. The combination with isotopic data from herbivore bone remains at the site revealed a markedly humidity phase during period VIII, well corresponding to the high Δ^{13}C of wheat grains (Galli, 2016). In 3100 BC, palaeoclimatic data from both deciduous oak wood and animal bone remains evidenced an aridity phase (Fig. 3 and Galli, 2016). These signals might have weakened the effect of irrigation activities on wheat Δ^{13}C. During period VI A, Arslantepe experienced the climax of socio-economic development with the huge palatial complex (Frangipane, 2016) that suggest well-developed cultivation technique. A similar scenario was present in other Northern Mesopotamian sites (Styring et al., 2017). In the following VI B1 period emmer and wheat Δ^{13}C high values correspond with an increase in water availability pointed out by the trend of deciduous oaks. The oxygen isotope record from human bones of VI B1 reveals the same trend (Galli, 2016). Crops seem in general to have benefitted of the increasing underground water availability in the plain (for interpretation of such behaviour see Masi et al., 2013a, 2013b) and not necessarily from irrigation. Thereafter *Triticum* carbon records abruptly decrease around 2500 BC (Fig. 3). In period VI C, mobile groups occupied the mound (Frangipane, 2012). The reduction of the settlement size matches the inflexion of wheat signals and possibly changes in the agricultural system. Isotope records of contemporary EBA sites of other Near Eastern regions show that irrigation activities were continually

Table 2
δ^{13}C, Δ^{13}C, δ^{15}N and %N mean values for barley, emmer and wheat grains for the investigated archaeological periods.

	Arslantepe period	Contextual unit	Kernels (*n*)	δ^{13}C (‰)	*s* of δ^{13}C (‰)	Δ^{13}C (‰)	δ^{15}N (‰)	*s* of δ^{15}N (‰)	N (%)	*r*
Hordeum vulgare	VI D	A516	4	−23.2 ± 0.5	2.8	17.2 ± 0.5^{bcf}	3.5 ± 0.8^{bcd}	4.0	2.2	−0.9
	VI C	A607	5	−22.6 ± 0.7	3.8	16.7 ± 0.7^{bcdef}	0.6 ± 0.1	0.9	1.7	−0.8
	VI B2	A736	5	−21.8 ± 0.5	2.8	15.9 ± 0.6^{de}	3.0 ± 0.4^{d}	1.5	2.5	−0.9
	VI B1	A772	4	−21.8 ± 0.7	2.3	15.8 ± 0.7^{d}	8.5 ± 0.9^{bc}	3.0	2.4	−1.0
	VI A	A206-A1358	8	−23.1 ± 0.3	2.8	17.2 ± 0.3^{bc}	6.0 ± 0.3^{c}	3.0	0.2	−0.7
	Late-VII	A900-A932	6	−24.9 ± 0.4	1.9	19.0 ± 0.4^{a}	7.2 ± 0.5^{bc}	1.7	0.0	−0.7
	Mid-VII	A849	6	−23.5 ± 0.3	1.4	17.5 ± 0.3^{b}	4.3 ± 0.4^{ab}	1.4	0.1	−1.0
	VIII	A718	6	−24.3 ± 0.2	1.5	18.5 ± 0.3^{a}	4.5 ± 0.3^{a}	1.6	0.2	−0.5
Triticum dicoccon	VI D	A516	5	−22.2 ± 0.4	2.4	16.1 ± 0.4^{bcd}	4.4 ± 0.2^{abcf}	1.2	2.7	−0.7
	VI C	A607	1	−20.1 ± 0.7	1.4	14.1 ± 0.7	0.2 ± 0.1^{abcdef}	-	10.8	-
	VI B2	A736	4	−21.7 ± 0.2	1.5	15.7 ± 0.2^{bcd}	1.1 ± 0.3^{e}	1.6	3.7	−1.0
	VI B1	A771	3	−21.9 ± 0.3	1.2	15.9 ± 0.3^{bc}	3.3 ± 0.4^{acd}	1.2	3.9	−0.6
	VI A	A206-A1358	9	−21.7 ± 0.3	2.9	15.8 ± 0.3^{b}	4.0 ± 0.2^{ac}	1.6	0.2	0.2
	Mid-VII	A849	7	−23.4 ± 0.1	0.5	17.5 ± 0.1^{a}	4.8 ± 0.1^{ab}	0.6	0.1	0.2
	VIII	A718	6	−23.3 ± 0.2	1.3	17.4 ± 0.2^{a}	4.3 ± 0.5^{a}	2.7	0.2	−0.8
Triticum aestivum/durum	VI D	A516	4	−24.5 ± 0.3	1.5	18.7 ± 0.3^{abc}	4.7 ± 0.1^{ab}	0.6	3.1	−0.6
	VI C	A607	5	−22.2 ± 0.3	1.3	16.2 ± 0.3^{b}	1.5 ± 0.4^{c}	2.6	3.6	−1.0
	VI B2	A170	5	−22.9 ± 0.1	0.7	16.9 ± 0.1^{b}	3.7 ± 0.2	1.0	2.7	−0.9
	VI B1	A1325-E120	3	−23.9 ± 0.5	1.7	18.0 ± 0.5^{abc}	0.9 ± 0.2^{c}	0.8	2.2	−1.0
	VI A	A206-A1358	13	−23.1 ± 0.2	2.2	17.2 ± 0.3^{ab}	5.2 ± 0.3^{ab}	1.8	0.2	0.9
	VIII	A718	9	−24.2 ± 0.1	0.7	18.3 ± 0.1^{a}	4.7 ± 0.3^{a}	1.8	0.2	−0.8

Key: *s* = sample variation (max-min values); *r* = Pearson's correlation coefficient between δ^{15}N and %N; light grey characters: data from Masi et al. (2014); lower-case superscript letters: archaeological periods whose differences are not statistically significant (PERMANOVA).

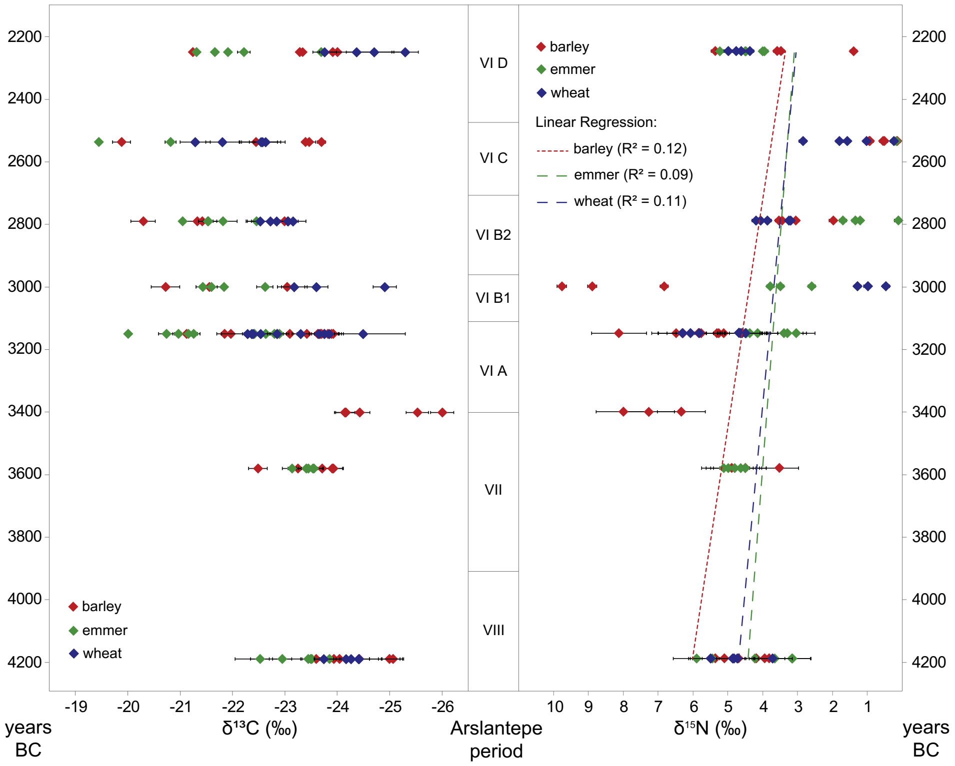


Fig. 2. δ^{13}C and δ^{15}N values of barley, emmer and wheat kernels in the chronological framing. Error bars for SD.

necessary for both emmer and wheat cultivation (Fig. 4). A significant increase of water supplies is recorded in period VI D when abundant charred wheat remains were recovered in the settlement (Sadori and Masi, 2012). Deciduous oaks curve indicates reduction in water availability, suggesting that the increased values of wheat and emmer are due to irrigation practices. Both isotope and archaeobotanical evidences confirm

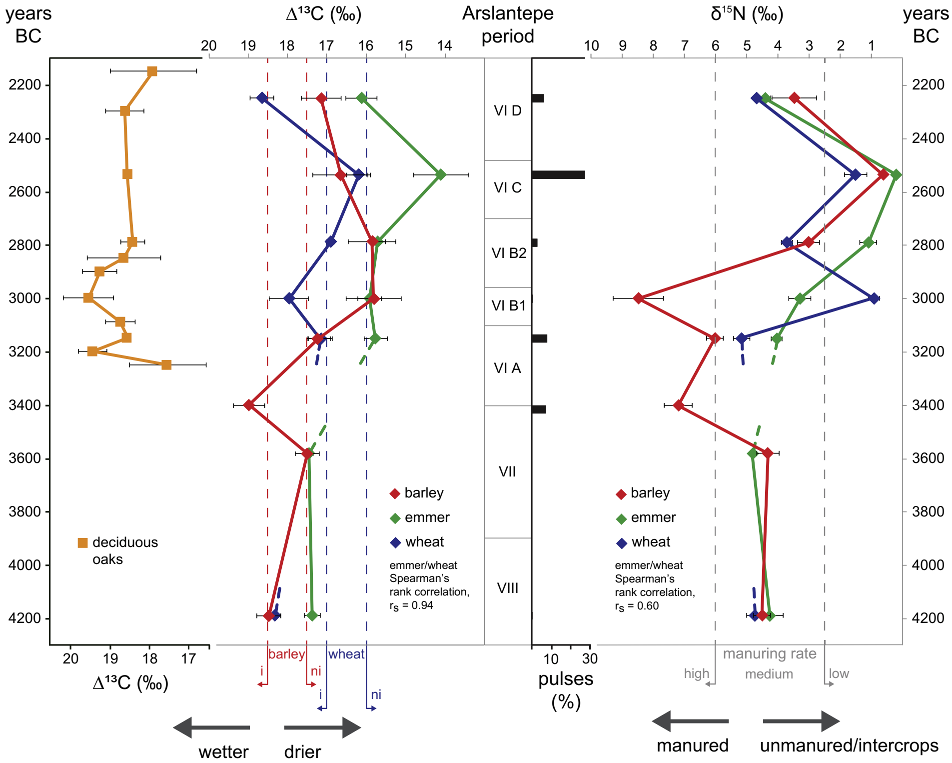


Fig. 3. Δ^{13}C and δ^{15}N mean values of barley, emmer and wheat grains, Δ^{13}C values of decicuous oaks woods (Masi et al., 2013b, modified) and % values of pulses remains in relation to archaeological periods. Δ^{13}C dotted lines represent thresholds of irrigated (i) and not irrigated (ni) isotopic values for barley and wheat (Wallace et al., 2013). δ^{15}N dotted vertical lines represent limits of manuring rates (Bogaard et al., 2013). Error bars for SD. Spearman's rank correlation coefficients significant at 99% confidence.

the development of an agricultural system based on selected naked wheat crops across the Malatya plain from 2500 to 2000 BC.

The Arslantepe barley remains showed a $\Delta^{13}C$ trend opposite to wheat. In particular barley fields were probably irrigated during period VIII and in the last sub-phase of period VII, when the stable carbon isotope ratio reaches its highest value (>18.5‰, Fig. 3; see the irrigation range values proposed by Wallace et al. (2013). Crop water availability was higher in the Malatya area than in other Near Eastern sites (Fig. 4). We want to highlight once more that this was possibly due to favourable hydrogeological conditions that made the plain attractive for millennia. Considering the evolution of the settlements through times, the irrigation of barley crops well corresponded to the maximum extension reached by Arslantepe during period VII, when an increase of social complexity is also testified by monumental buildings on site (Frangipane, 2016). We can argue that also during period VI A some water supply was provided for barley crops, since the pristine state centralised the production (Balossi Restelli et al., 2010). The societal organization probably balanced the reduction of atmospheric humidity shown by the deciduous oaks isotope record providing either irrigated or wet fields to barley and wheat crops (Fig. 3). A major change in water management of barley fields is recorded in period VI B1: since that time $\Delta^{13}C$ will in fact lie below the limit of poor irrigation activities (even though increasing slightly again in period VI D) until 2000 BC (< 17.5‰, Fig. 3). Indeed barley is harvested before wheat species (end of April/beginning of May) and is therefore not affected by the quickly reduced moisture of late spring/early summer in the Malatya region (Fig. 1c). For this phenological reason (i.e. the seasonality of grain ripening period), barley $\Delta^{13}C$ is expected to be higher than the other crops in a rain-fed agricultural regime (Masi et al., 2014). Between 3000 and 2000 BC, at Arslantepe, barley fields were not water-supplied or they might have been relocated in areas with lower water status. The hypothesis that the first-rate fields were reserved for the *Triticum* crops was already advanced by Masi et al. (2014) and is now confirmed by the intra-sample variability of EBA samples.

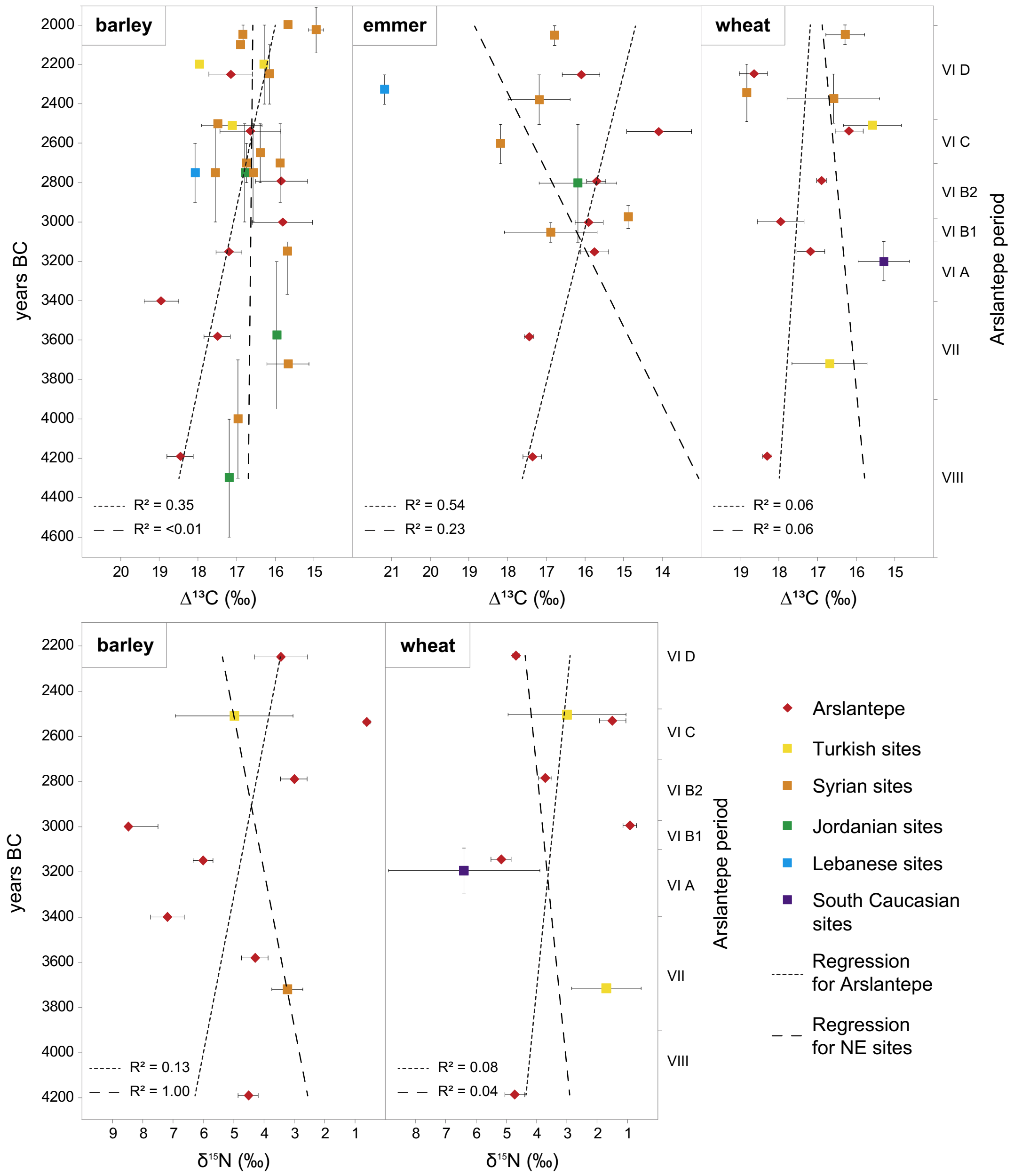


Fig. 4. Comparison of $\Delta^{13}C$ and $\delta^{15}N$ mean values for barley, emmer and wheat grains from Arslantepe and other Near Eastern sites. Data from Fiorentino et al. (2008); Araus et al. (2014); Riehl et al. (2014); Messager et al. (2015). Error bars for SD.

If, starting with EBA (period VI B1), barley fields were no longer irrigated as they had been in LC periods (from VIII to VI A), the grains might record fluctuations in rainwater. As shown by the barley $\Delta^{13}C$, the local modelling of palaeoclimate in the Upper Euphrates basin also distinguishes LC from EBA periods in terms of temperature and precipitation values (Arıkan et al., 2016). Thus a human-induced change in agronomic conditions of barley crops across the Malatya plain, as partial response to the EBA climatic trend, was possible (Roberts et al., 2001; Wick et al., 2003; Eastwood et al., 2007; Bar-Matthews and Ayalon, 2011; Dean et al., 2015).

In terms of agro-archaeological perspectives, the carbon discrimination is also used in assessing 'water use efficiency' (total absorbed carbon per unit of transpired water; Hartman and Danin, 2010). Thus low values for $\Delta^{13}C$ could reflect, for example, high water use efficiency that is related with crop selection (Araus et al., 2003). Ancient farmers systematically selected plants with physiological imprinting (i.e. the genotype ability to output low transpiration rate) to optimise the environmental sources, as water availability. At Arslantepe the decrease in EBA isotope values, especially for barley grains, could have been tied to the development of crop selection.

6.2. Soil fertility: manuring and intercropping practices

Sample variation of grain $\delta^{15}N$ in the Arslantepe periods range between 0.6 and 4‰ (Table 2). The natural nitrogen isotope variability is expected to be higher in modern grains from fertilised fields than in natural ones (1.3‰ vs. 0.1‰; Bogaard et al., 2007). ^{15}N abundances differ more in plants treated with farmyard manure (~2‰; Fraser et al., 2013). It is therefore undeniable that selected crops, cultivated within agricultural regimes, provide forms of nitrogen addition. However, as already evidenced by $\delta^{13}C$, *Hordeum* $\delta^{15}N$ displayed a higher variation than the *Triticum* crops (Table 2). This diversity could reflect several growing conditions for barley. Once again, we can reconstruct that barley fields were located in different areas of the Malatya region with less suitable soils.

As plotted in Fig. 3, the selected crops comply with rather similar trends of $\delta^{15}N$. It has been experimentally proved that different cereal species grown under the same soil conditions have similar $\delta^{15}N$ values regardless of grain sizes (Fraser et al., 2011). Barley showed a marked enrichment of $\delta^{15}N$ during late-VII, VI A and VI B1 periods in comparison to *Triticum* signals. The hiatus in emmer and wheat records in period VII must be anyway contemplated (Fig. 3). Since modern $\delta^{15}N$ higher than 6‰ reveals cereal cultivation with intensively applied manuring (Fraser et al., 2011), the Arslantepe barley grains seems harvested from manured fields at 3350–3000 BC. The increase in caprine flocks is testified at the site exactly since late period VII, when the husbandry of a wide amount of animals and the cultivation of forage crops could have been managed by the centralised institutions (Palumbi, 2010). Interestingly, a positive relation between $\Delta^{13}C$ and $\delta^{15}N$ (Fig. 5) was detected in periods VII ($R^2 = 0.53$) and VI A ($R^2 = 0.27$). Using data from present-day crops grown in semi-arid environments (Araus et al., 2013), this association confirms that ^{14}N losses through volatilization increase with full water availability enhancing the manuring effect on $\delta^{15}N$ in spite of the plant/climate relationship with natural environments (Amundson et al., 2003). Additionally, the positive relationship between $\delta^{15}N$ and %N in VI A wheat grains ($R^2 = 0.73$) confirms better growing conditions, with an increase in N content (Fig. 5). In conjunction with the main socio-economic development of the site (Frangipane, 2016), barley cultivation may have been supported by systematic manuring practices within an intensive agricultural production. It is feasible that to population increase in the Arslantepe region since period VII corresponded a larger cropping area as evidenced in Upper Mesopotamia during the Bronze Age (McCorriston and Weisberg, 2002). Since emmer and wheat have a high water requirement, cultivation in marginal areas may have been used for barley crops. New soils were more fertile than the overexploited fields close to the settlement. A similar relationship between early urban development and forcing barley cultivation in marginal areas was also suggested for LC 3–4 Tell Brak (South-East Syria) (Styring et al., 2017). On the other hand, the location of farmed lands within the Malatya region is also relevant for the period VI B1. Marginal areas were usually used as grazing lands. In semi-arid environments, herbivores urea and dung directly enhance atmospheric losses of ^{14}N through volatilization or denitrification increasing $\delta^{15}N$ (Seagle et al., 1992). Since pastoral groups occupied the Arslantepe mound after the destruction of the VI A palace and large areas for animal stocking are testified (Frangipane, 2014), the high $\delta^{15}N$ in barley kernels could indicate that fields were located in pasturelands. The negative relations between $\delta^{15}N$ and %N confirm that denitrification processes occurred in the plain (Fig. 5). In addition, VI B1 barley grains differed in their relationship with $\Delta^{13}C$ and $\delta^{15}N$ compared with other periods (Fig. 5). This negative relation ($R^2 = 0.99$) reflects the natural trend of plant nitrogen composition (Amundson et al., 2003) and highlights that barley crops were harvested from N-rich but not water-supplied fields, as already proposed for carbon composition. Isotopic data from stock-breeder settlements on the South Caucasus Mountains show a similar pattern (Fig. 4). Looking at palaeofauna as indicative of different habitats, deforestation process due to the need of grazing lands in the Malatya plain was testified by the increase of hare remains and the decrease of red deer during the VI B1 period (Siracusano and Bartosiewicz, 2012). Forest clearance was also evidenced by an erosion phase occurred after the VI A collapse (Dreibrodt et al., 2014).

Emmer and wheat $\delta^{15}N$ values are notably well correlated, as suggested by $\delta^{13}C$, except in VI B1 period (Spearman's rank correlation coefficient of 0.60, Fig. 3). Modern data (Fraser et al., 2011) indicate that the Arslantepe *Triticum* records usually refer to a medium level of nitrogen inputs with $\delta^{15}N$ ranging between 2.5–6‰. In traditional agriculture, the slight ^{15}N enrichment of cereal grains could reflect the application of little manure over the long-term and/or the effects of a previous intensive manuring on harvests (Bogaard et al., 2007). Taking into account the variability of agronomic conditions, such correspondence may suggest that emmer and wheat crops were sown in the same areas. On the other hand the opposite relationship between $\Delta^{13}C$ and $\delta^{15}N$ measured in VI B1 period from emmer ($R^2 = 0.71$) and wheat ($R^2 = 0.81$) kernels reveals better growing conditions for the latter crop (Fig. 5). Considering the extension of pasturelands in the plain (evidenced by barley isotope composition), it is likely that wheat fields have been located in the irrigable areas near the natural springs by VI B1 herders.

VI B1 $\delta^{15}N$ of wheat kernels tend to 0‰ as happens for all crops in VI C period. Regression coefficients point out a tendency towards the decrease of cereal $\delta^{15}N$ across the investigated sequence (Fig. 2). In particular the lowest value of VI C emmer corresponds exactly to the highest %N (Table 2). Leguminous plants have a $\delta^{15}N$ close to 0‰ because they host root bacteria capable to converse the atmospheric N_2 ($\delta^{15}N = 0‰$) to ammonia (Marshall et al., 2007). Different forms of intercropping cultivation may have been performed in the above-mentioned periods. Annual legumes (seeds and forage) may be cultivated as sole crops or in mixtures with cereals. The latter represents one of the most traditional ways of production in Mediterranean agricultural regimes (Duc et al., 2015). Additionally, the advantage of a legume intercrop in terms of N-source is the direct transfer of nitrogen by excretion from the legume nodules to the cereal in the field (Naudin et al., 2010). As the N_2-fixation involves little isotopic fractionation, ^{15}N is strongly discriminated and the ^{14}N-enriched ammonia are taken by cereal plants whose $\delta^{15}N$ decreases up to 0‰ (Virginia and Delwiche, 1982). The presence of mixture crops during the VI B1 occupation could confirm the decrease of farmed lands at the expense of pasturelands and the concentration of crop fields in a small area, probably around the site. The production of forage from grain legumes on arable lands may have contributed to reducing distance between plant and animal production in the socio-economic system of pastoral communities. Some species, e.g. *Cicer arietinum* (chickpea), are considered to be a good alternative to summer fallow using them as green manure or forage crop (Duc et al., 2015). Looking at the charred pulses recovered at

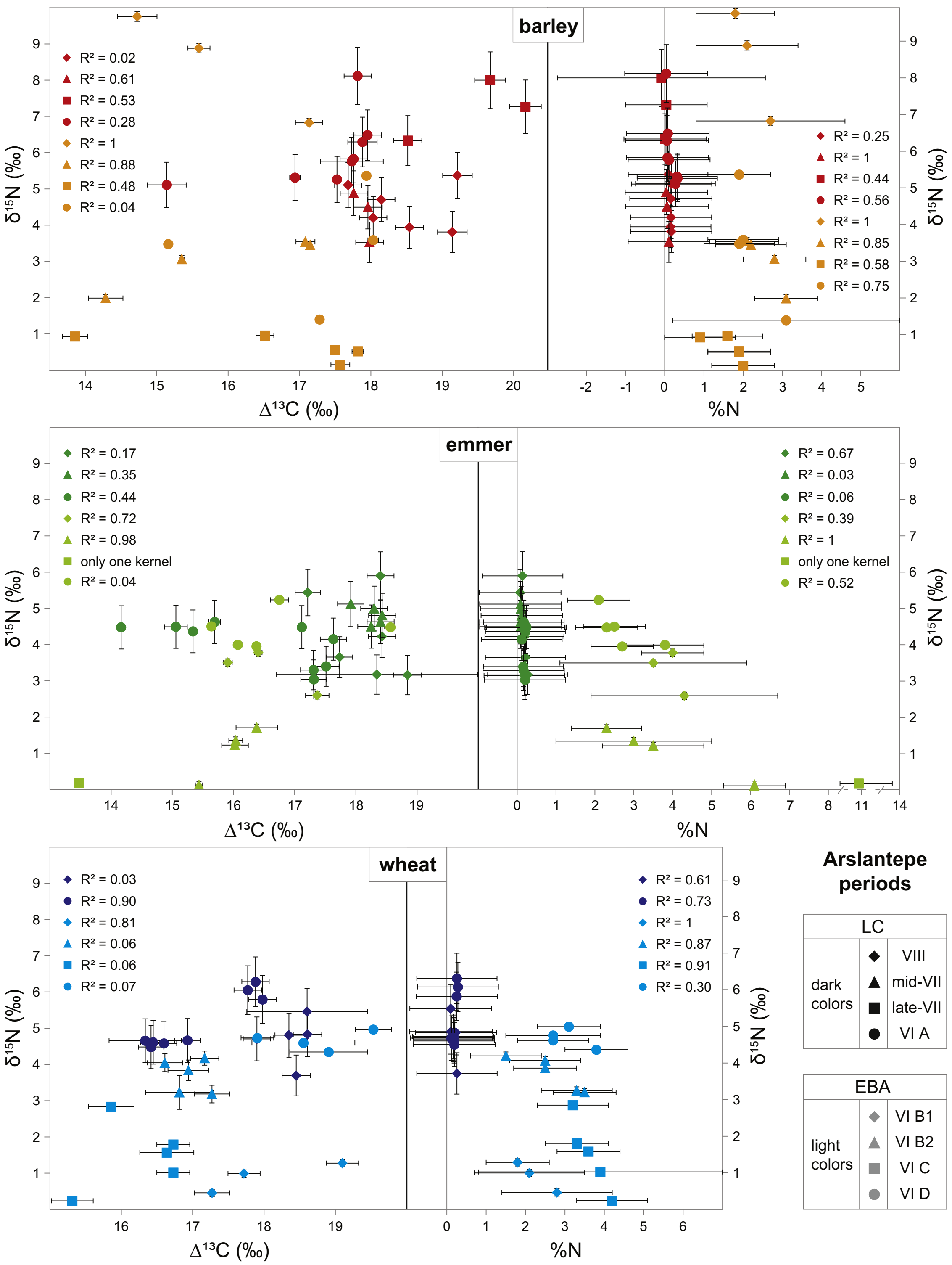


Fig. 5. Relationship between Δ^{13}C and δ^{15}N (left) and δ^{15}N and %N (right) values of barley, emmer and wheat kernels grouped by archaeological periods. Error bars for SD.

Arslantepe during VI C period (Sadori et al., 2006), the high proportion of chickpea seeds recovered (Fig. 3) exactly corresponds with the decrease of δ^{15}N of all of the cereal taxa. In addition, a significant negative relationship between δ^{15}N and %N of wheat kernels ($R^2 = 0.91$) could confirm that the increase of grain nutrients has been fostered by leguminous plants (Fig. 5). Since mobile groups settled on the mound at 2500 BC (VI C period), as had occurred in VI B1 period, the adoption of mixed cereal and legume crops may have been tied to the pattern of seasonal occupations. The natural N-enrichment provided by leguminous plants does not demand manuring during summer, when herders moved to the mountain pastures on the Antitaurus range.

7. Conclusions

Within the exceptional continuum of agricultural history at Arslantepe, isotope differences due to water supply and manure application reveal consistent temporal trends despite the degree of natural variation. Although the range of agronomic conditions under which crops were grown is a complex issue to solve, our interpretation was successfully because based on aligning archaeological, isotopic and palaeoenvironmental evidences.

Since 4300 BC agriculture in the Malatya plain was characterised by irrigation and fertilisation practices at different levels. With the emergence of social elites and the change in settlement layout towards a monumental development during late period VII and VI A (LC), an intensification of agricultural production was testified by barley isotope composition. High-level irrigation and manuring activities have been carried out when the VI A palatial complex was built on the mound. In comparison with other regions of the Near East, growing conditions in the Malatya plain benefitted from hydrogeological features due to karst activity. Since 3100 BC the pristine state system collapsed and pastoral groups of a Transcaucasian-linked culture established new agronomic practices. For the more resistant barley crops they may have used fields in marginal grazing lands with less water availability but with increased soil fertility due to the N-enrichment provided by animal pasture. On the other hand, wheat could have been harvested close to the site, where water from natural springs was easier to use (Δ^{13}C > 16‰) and fields hosted cereal-legume mixture crops (δ^{15}N < 1‰). The management of lands in the Malatya plain could have been shared by different communities living contemporarily in the region and agronomic practices changed again by 3000 BC. Around 2500 BC, the integrated system of mixed crops was fully established by new mobile groups. N-supply to fields was safeguarded, contrary to water regime that may have been not improved. While irrigation activities were pointed out in EBA sites from Turkey and Northern Syria, the agronomic development in the Arslantepe area was not conditioned by water availability as indicated by the deciduous oaks Δ^{13}C record. Cultural changes influenced the agricultural production from 2500 to 2000 BC, when the recovery of ancient cultivation techniques was testified. The importance of wheat in primary economy of the local communities is testified both by isotope and seed/fruit records. Arslantepe wheat grains yield higher Δ^{13}C and δ^{15}N than the other Near Eastern sites. If we propose that the importance of emmer was restricted to “maslin”, the similar agronomic trend along the millennia of both *Triticum* crops may be explained.

From the present study it appears clear that the combination of isotope data and archaeobotanical analyses from Arslantepe deeply contribute to the understanding of the cereal production in South-Eastern Turkey during LC and EBA.

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Author contributions

The manuscript was conceived and written by C. Vignola with contributions of F. Balossi Restelli, M. Frangipane, F. Marzaioli, A. Masi, L. Sadori and F. Terrasi. C. Vignola, F. Marzaioli, I. Passariello, L. Stellato and F. Terrasi were responsible for data production. C. Vignola, A. Masi and L. Sadori were responsible for data management and interpretation. Figures were elaborated by C. Vignola.

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CHAPTER 4

$\delta^{13}C$ values in archaeological ^{14}C-AMS dated charcoals: assessing mid-Holocene climate fluctuations and human response from a high-resolution isotope record (Arslantepe, Turkey)

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δ^{13}C values in archaeological ^{14}C-AMS dated charcoals: Assessing mid-Holocene climate fluctuations and human response from a high-resolution isotope record (Arslantepe, Turkey)

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Rationale: Past climate has always influenced human adaptation to the environment. In order to reconstruct palaeoclimate fluctuations and their role in the evolution of Near Eastern societies during the mid-Holocene, high-resolution Δ^{13}C records from fossil wood remains at the archaeoloical site of Arslantepe (eastern Turkey) have been developed.

Methods: After chemical treatment, δ^{13}C values were measured by sample combustion flow using a FLASH EA-CHNS instrument interfaced with a Delta V isotope ratio mass spectrometer via a CONFLO III. Two replicates per sample were analysed. The measurement precision was evaluated by propagating variations of the δ^{13}C values of samples and V-PDB standards, whereas the accuracy was checked by a quality control sample. To account for changes in atmospheric CO_2, Δ^{13}C values were calculated. In addition, ^{14}C/^{12}C ratios were measured by means of an AMS system (3 MV tandem accelerator).

Results: Mean Δ^{13}C curves of deciduous *Quercus* and *Juniperus* from archaeological levels between 4700 and 2000 BC (Arslantepe periods VIII-VI D) were produced, where the isotope values were ordered by the available Radiocarbon ages. Interspecific variations of evergreen vs deciduous plants were postulated for the juniper Δ^{13}C values being higher than 3‰. The seasonal rainfall amount was recorded by the juniper remains, while the water table levels were obtained from the oak samples.

Conclusions: The local climate experienced times of enhanced/reduced precipitation in concert with regional trends. Anomalies in the air mass circulation from the Mediterranean basin also produced oscillations of rainfall amount. In such a frame the Rapid Climate Change dry events had a consistent signature in the Arslantepe Δ^{13}C record, thus potentially contributing to social or organisational changes at the site.

1 | INTRODUCTION

The Mediterranean region is considered highly sensitive to climate change.[1] As a current research topic, the effects of climate fluctuations on the development of ancient societies have been highlighted by an array of palaeoclimatic proxies.[2,3] In particular, the semi-arid regions of the eastern Mediterranean, where early state centres arose, are suitable for exploring critical interactions between climate, environment and complex societies.[4,5] All ages are indicated as years before Christ (BC), even if age scales in years before present (BP) are also shown in the figures. Climatic, environmental and cultural reasons have all been invoked to explain the increase in social complexity from

5000 BC.[6] Nonetheless, the roles of nature- or human-forced changes at the local scale are difficult to disentangle in the absence of on-site and/or high-resolution palaeoenvironmental data.[7]

The demand for mid-Holocene climate reconstruction from Near Eastern archaeological sites has steadily increased over times and several proxy records have been built.[8] First, plant assemblages have been used for palaeoenvironmental reconstruction. In particular, archaeobotanical analyses have focused on anthracological studies since charcoals are available in large amounts from archaeological contexts.[9] In fact in semi-arid environments the most significant factor limiting wood growth is precipitation. Charcoal assemblages though may reflect also human selection of some species, rather than solely humidity and vegetation changes.[10] Secondly, regional pollen,[11-13] lake sediment[14] and speleothem[15] records have provided a useful framework for palaeoenvironmental reconstructions. However, information on spatial variability for past climate trends is still demanded.

Within such a framework, the recent use of stable carbon isotope analysis on archaeological wood remains provides a direct approach to solve this need. Indeed the physiological relation between stable carbon isotopes in fossil plants and atmospheric humidity has widely been used as a tool for the inference on the "free-from-human-influence" palaeoclimate.[16] In recent years, several researchers have helped to clarify topics such as precipitation regime,[17,18] rainfall seasonality,[19,20] irrigation practices,[21] land use and the impact of human activities.[22]

As a methodological issue, the stable carbon isotope composition ($\delta^{13}C$ value) in C3 plants is influenced by several processes.[23] During the atmospheric CO_2 fixation through photosynthesis, different isotope fractionations occur: (1) the first step takes place during the air collection when stomata opening affects the CO_2 concentration and assimilation rate in the leaves; (2) another process is tied to the activity of the RuBisCO enzyme during the photosynthesis.[24] If water stress occurs, plants close their stomata preventing water loss by leaf transpiration. The abrupt reduction in stomata conductance causes a decrease in the CO_2 concentration within leaf intercellular spaces. Consequently, ^{13}C discrimination also decreases and the $\delta^{13}C$ values of synthetic organic compounds increase.[24] These external and internal factors contributing to the isotopic signature in plant tissues are also affected by other environmental variables such as temperature, solar radiation, relative humidity, vapour pressure deficit and soil moisture.[25-27] Nevertheless, it is the physiological interaction between the concentration of atmospheric CO_2 and water availability which mainly influences the $\delta^{13}C$ values of wood.[28]

The archaeological site of Arslantepe is an outstanding long-term settlement in the modern Malatya region (south-eastern Turkey). It provided evidence of one of the first state systems in the Near East dated back to 3400 BC.[29] Huge amounts of charred plant remains were analysed, accounting for land use in the region during the 4300–2000 BC interval, namely in the Late Chalcolithic (henceforth LC) and Early Bronze Age (henceforth EBA).[10] In very recent years, stable isotope records at local scale have been established in order to describe climatic conditions behind social transformations at the site. Deciduous *Quercus* (oak) and *Juniperus* (juniper) $\delta^{13}C$ values from 3200 to 2000 BC have been analysed in order to investigate the response of plant taxa to climate variability.[18,20] Moreover, C and N stable isotope analyses have been applied on cereal grains assessing the irrigation footprint of crops from 4700 to 2000 BC.[30,31] Physical models were also compared with charcoal isotope data, enhancing the palaeoclimate reconstruction for the study area.[32]

The present study aims first to extend the time interval of the stable carbon isotope analysis by including charcoal remains from the earliest Arslantepe occupational periods. Secondly, it aims to improve the chronological framework through new ^{14}C-AMS dating carried out on the same plant remains. As a whole, we achieved the first high-resolution isotope records from an archaeological site for the period 4700–2000 BC, displaying more than 2500 years of uninterrupted climate changes and tracing back to the first steps of early state, possibly led by climate constraints.

2 | EXPERIMENTAL

2.1 | Environmental background

The multi-period settlement of Arslantepe is located at the edge of the alluvial Malatya plain along the Euphrates River in south-eastern Turkey (38°22′55″N, 38°21′40″E, 940 m a.s.l.; Figure 1A). The Anti-Taurus Mountains enclose the plain having the highest peak in the southern Doğanşehir district (2660 m a.s.l.). The regional climate is marked by extreme continental conditions that are mediated to varying degrees by different water resources and geomorphological heterogeneity (Figure 1B). Moisture mainly derives from the Atlantic and the Mediterranean basins.[33] At present, the plain has an annual mean precipitation of 400 mm/year and a mean monthly temperature between −1°C and + 22°C.[18] Rainfall occurs mainly in April–May followed by the driest and hottest months of July–October[34] (Figure 1C). The plain is rich in water, with many streams and springs.[35] The hydrogeological catchment is recharged by precipitation on the Anti-Taurus, that amounts to 600/1000 mm/year and is mostly in the form of winter/early spring snow.[36]

Altitude strongly influences vegetation cover in the region.[37] *Pinus sylvestris* L. (Scots pine) forest is widespread in cold and sub-humid conditions between 2000 and 2700 m a.s.l., together with mountain steppe and grassland vegetation.[38] In addition, *Fagus orientalis* Lipsky (beech), *Alnus* spp. (alder), *Castanea sativa* Mill. (chestnut) and *Cedrus libani* A.Rich. (cedar), *Abies cilicica* Antoine & Kotschy (Taurus fir) occur in broadleaved and conifer forest, respectively, on the belt up to 2000 m a.s.l.[38] The semi-open forest of deciduous broadleaved trees (deciduous and semideciduous *Quercus*; Rosaceae with many species of *Crataegus* L.) and conifers (*Pinus brutia* Ten., red pine; *Pinus nigra* J.F. Arnold, black pine), spaced out by *Juniperus* spp. maquis, dominates from 1200 to 2000 m a.s.l.[38] The semi-arid climate leads to the presence of shrub-steppe vegetation in the valleys and lowlands. However, the particular hydrogeological features of the Malatya plain favour riverine gallery forest, with water-demanding trees, such as *Populus* spp. (poplar), *Salix* spp. (willow) and *Alnus* spp. (alder). Alluvial sediments also provide fertile soils for crop production as in the past, influencing modern vegetation which is mainly characterised by apricot orchards.[39,40]

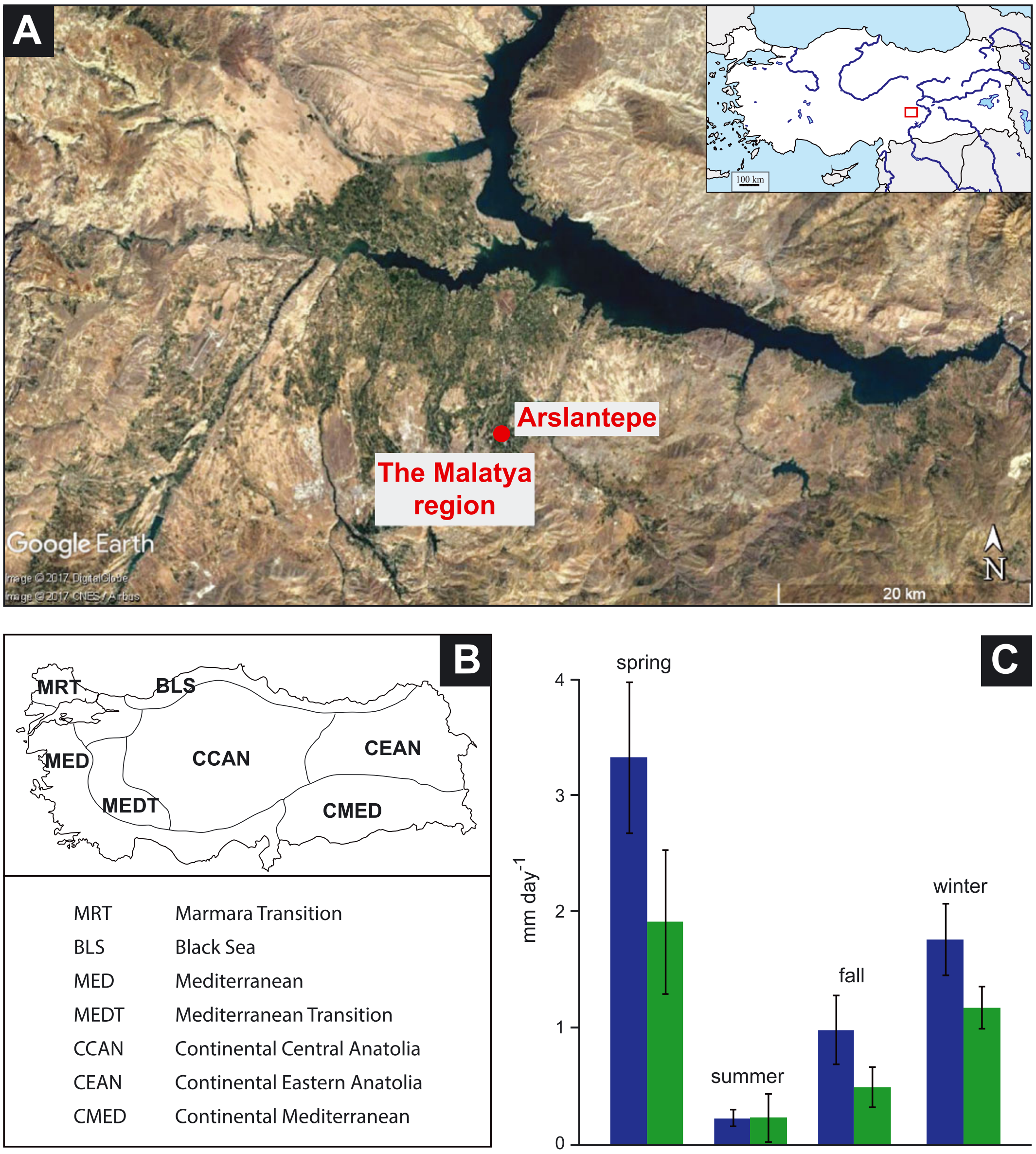

FIGURE 1 Arslantepe (Malatya, Turkey): (A) The Malatya plain with the Arslantepe site (area location top right); (B) modern climate zones of Turkey;[33] and (C) seasonal precipitation amounts in the study area: in blue for the period 1961–1990, in green for 2008[18] [Color figure can be viewed at wileyonlinelibrary.com]

2.2 | Site setting

The archaeological site of Arslantepe has been excavated by the Italian Archaeological Expedition in Eastern Anatolia, of the Sapienza University of Rome, since 1961. Chronologically, the site can be placed as early as 4700 BC, to which date the first settlement so far extensively investigated has been dated (see section 3.1).[41] The occupation of this site is exceptionally long and continued until historical times. A recent paper of Vignola et al[31] has reviewed and improved the chronology of the site that has been modelled through the interpolation of the sequence of archaeological levels and 98 radiocarbon dates (Table 1). Specifically, the present work focuses on the contiguous levels from 4700 to 2000 BC. During this timespan, the site gradually developed from rural settlements of LC 1–2 (Arslantepe period VIII, 4700–3900 BC) to the religious and elite centre of LC 3–4 (period VII, 3900–3400 BC) up to the early state centre of LC 5 (period VI A, 3400–3100 BC).[42] At ca 3100 BC the VI A palace, built by the gradual addition of administrative and religious structures and private residences, was destroyed by an extensive fire that ended the centralised system. During EBA I an alternating dominance of different communities occurred in the Malatya plain, with herders' short-lived occupations and a farmers' village (period VI B1 and VI B2, 3100–2750 BC).[42,43] After a short abandonment but a remarkable cultural break, new short- and long-term settlements succeeded during EBA II-III (period VI C, 2750–2500 BC and VI D, 2500–2000 BC).[42]

The archaeobotanical research at Arslantepe has been carried out for more than 35 years. Several studies have focused on charcoal remains.[10,44-46] Architectural woods were abundant since roof structures, and sometimes walls, were made of beams and smaller sticks. Moreover, some of the buildings were supplied with hearths, ovens and other domestic features, in which wood remains were preserved by charring. Archaeobotanical analysis especially revealed

TABLE 1 The investigated archaeological periods and the new chronological framing obtained by the interpolation of old Radiocarbon (RC) ages, stratigraphic sequence and new AMS RC dates (see section 3.1)

Chronological sequence of eastern Turkey	Arslantepe period	Years BC
Early Bronze Age III	VI D	2500–2000
Early Bronze Age II	VI C	2750–2500
Early Bronze Age Ib	VI B2	3000–2750
Early Bronze Age Ia	VI B1	3100–3000
Late Chalcolithic 5	VI A	3400–3100
Late Chalcolithic 3–4	VII	3900–3400
Late Chalcolithic 1–2	VIII	4700–3900

that the wood resources were exploited from two main vegetation zones: the plain, where deciduous oaks probably grew, and the surrounding mountain and hill slopes, where juniper trees were available.[10]

2.3 | Archaeobotanical samples

A total of 34 charcoal samples, 23 of deciduous *Quercus* and 11 of *Juniperus* spp., were recovered and analysed for this study, joining with 123 samples previously reported by Masi et al.[18,20] They were mainly selected from the 4700–3400 BC levels (VIII and VII periods) in order to extend back in time the previously available stable carbon isotope records to the earliest LC 1–4 occupation. In addition, charcoals from new deposits of 3400–3100 BC levels (VI A and VI B1 periods) were recovered and selected during the 2012–2015 field campaigns.

Each sample comes from one well-sealed contextual unit, represented by a bin, a fire installation or a wooden structure. The selected samples consist in fragments of young (only few-years old) branches or small sticks. Huge beams from ceilings/roofs, with a high number of tree rings, were avoided since the stable carbon isotope ratio refers to the $\delta^{13}C$ values of atmospheric CO_2 at the time of plant growth.[24] These could have been misleading since the architectural woods might have been in use for a long period of time, thus far later than the time of growth of the tree.[47] Each fragment was carefully cleaned and the last tree-ring was separated using a scalpel. The whole tree-rings were submitted for carbon isotope analysis since several studies point to the preservation of palaeoclimatic signal in the whole tree-ring rather than solely in the latewood, in both soft- and hardwood species.[48,49]

In order to obtain high-resolution isotope records, charcoals from dated contexts have solely been preferred. For this reason, ^{14}C-AMS dating was additionally performed on four selected plant remains. With regard to early period VIII, the remains of a juniper tree branch was selected. In addition, fragments of one juniper branch and two small oak woods were recovered from VI A and VI B1 contextual units, respectively. In these cases, the charcoal fragments were submitted for both ^{14}C and stable isotope analyses.

2.4 | Chemical treatment

Radiocarbon (RC) and stable carbon analyses were performed at the CIRCE Laboratory (University of Campania 'Luigi Vanvitelli', Caserta, Italy). Non-structural materials were removed from the selected specimens by an Acid-Alkali-Acid (AAA) treatment.[50] Samples were soaked in 3% HCl and 3.2% NaOH for 1 h alternately at 80°C, ending with an additional acid attack (to remove the CO_2 absorbed during the alkali attack) and rinsing the charcoals repeatedly with distilled water. In order to prevent the loss of material, especially during the alkali and demineralised water steps, each fragment was kept in hot-sealed Teflon envelopes. Nevertheless, in some cases, the chemical treatment prevented us from having enough material for the analysis. All the samples were then oven-dried at 70°C overnight before being milled to a powder for isotope analyses.

2.5 | Radiocarbon dating

In order to obtain RC determinations, four selected AAA-treated samples were combusted and graphitised[51] and the $^{14}C/^{12}C$ ratios were measured by means of an AMS system based on the 3 MV tandem accelerator pelletron 9SDH-2. A detailed description of the ultrasensitive accelerator system of the CIRCE Laboratory is reported in Terrasi et al.[52] The ^{14}C abundances were then converted into RC ages.[53] Calibrations were carried out through CALIB7[54] using the INTCAL13.14c dataset.[55]

2.6 | Stable isotope and statistical analyses

As reported by Hall et al,[56] the climatic signal recorded by $\delta^{13}C$ values in wood tissues is not affected by the carbonisation process between 100 and 475°C. Moreover, during the charcoalification process, biomolecules (cellulose, hemicellulose and lignin) disappear, changing into a new chemically C-enriched material. For this reason no intrinsic differences in the chemical composition of charcoal are expected and the whole wood can be suitable for isotope analyses.[57] In addition, diagenetic degradation of the graphite-like phase in fossil charcoal is not significant and oxidation products can be removed through chemical treatment.[58]

Charcoal (0.30 mg) was weighed into tin capsules and combusted using a FLASH EA-CHNS 1112 elemental analyser (Thermo Fisher, Bremen, Germany) interfaced with a Delta V isotope ratio mass spectrometer (Thermo Fisher) via a CONFLO III (Thermo Fisher). The isotopic composition is expressed in the $\delta^{13}C$ notation relative to V-PDB (Vienna-Pee Dee Belemnite):

$$\delta^{13}C = \frac{^{13}R_{sample}}{^{13}R_{V\text{-}PDB}} - 1$$

where ^{13}R is the $^{13}C/^{12}C$ ratio.[59]

Two replicates per sample were analysed. The standard deviation (SD) of replicate measurements averaged 0.1‰. The accuracy of measurements as the SD of the $\delta^{13}C$ values of the quality check sample (tobacco leaves) was 0.3‰ after sample raw $\delta^{13}C$ normalisation and linearity offset error propagation during normalisation.

In order to compare plant remains from different archaeological periods, all changes in $\delta^{13}C$ values of atmospheric CO_2 during the Holocene have to be taken into account.[60] For this reason, the carbon isotope discrimination ($\Delta^{13}C$) was calculated as follows:

$$\Delta^{13}C = \frac{\delta^{13}C_{air} - \delta^{13}C_{plant}}{1 + \delta^{13}C_{air}}$$

where $\delta^{13}C_{air}$ and $\delta^{13}C_{plant}$ represent the atmospheric and plant $\delta^{13}C$ values, respectively (adapted from Farquhar et al[61]).

Past $\delta^{13}C_{air}$ values were inferred by interpolating data from ice-core records[62,63] and the CU-INSTAAR/NOAA-CMDL database of modern stations.[64] According to the available $\delta^{13}C$ curve of atmospheric CO_2 (http://web.udl.es/usuaris/x3845331/AIRCO2_LOESS.xls), the values applied to the Arslantepe charred woods ranged between −6.29‰ (4700 BC) and − 6.40‰ (2000 BC).

Differences in the $\Delta^{13}C$ values of the selected taxa in relation to the archaeological periods were tested through a permutational multivariate analysis of variance (PERMANOVA), significant if $P < 0.05$ (PAST 2.0).

3 | RESULTS

3.1 | Improved chronological framework

The results of four ^{14}C-AMS dates on the selected charcoals are reported in Table 2. They have, together with other recent AMS ages from charred cereal grains, been published and discussed by Vignola et al,[31] and have allowed us to distinguish phases within the site's periods. The improved chronological framework, based on old RC ages, stratigraphic sequence and new AMS dates,[41] was used to develop the high-resolution isotope records discussed further in this work.

Looking at the RC ages here presented, the first phase (LC 1) of the earliest occupation at Arslantepe (period VIII) has been dated for the first time.[65-67] The RC age of sample D-DSH7173, ranging from 4720 to 4560 BC (2σ), proves that the LC 1 settlement was established before this date, as already suggested by comparisons with archaeological evidences of other Near Eastern sites.[68]

Despite its recovery in the VI A palace, the calibration range of sample S05/17-DSH7982 from 3639 to 3386 BC (2σ) reveals that this charcoal is archaeologically pertaining to the late-VII period. Indeed it was part of an older piece of furniture, probably a wooden throne, re-used during the LC 5.[69] This attribution was applied to chronologically order the sample within the juniper isotope record.

Finally, significantly the two deciduous *Quercus* RC ages entail continuous short-term occupations at the site after the destruction of the LC 5 settlement (the VI A palace was destroyed around 3100 BC). In fact three phases within the succeeding VI B1 period have been identified, spanning between 3100 and 3000 BC. Such a new chronology of Arslantepe, moreover, has produced new data on the early beginning of the EBA I in the Near East.[41]

3.2 | Carbon isotope composition

The $\delta^{13}C$ values with SD of each analysed sample of deciduous *Quercus* and *Juniperus* spp. are displayed in Figure 2, whereas the mean $\delta^{13}C$ values with standard errors grouped by archaeological periods and phases are reported in Table 3.

The $\delta^{13}C$ values of oak samples from three contemporary contextual units of the early-VIII period average at −24.7 ± 0.4‰, and during the late-VIII period the $\delta^{13}C$ value is −24.2 ± 0.2‰. In the early-VII period, the mean $\delta^{13}C$ value is established at −25.0 ± 0.2‰. From four selected contextual units of the late-VII period the $\delta^{13}C$ values average − 24.5 ± 0.2‰. The mean $\delta^{13}C$ value displayed by 19 samples of the VI A period is −24.3 ± 0.2‰. At the beginning of the VI B1 period the $\delta^{13}C$ value is −25.5 ± 0.3‰, but during the mid-VI B1 period the selected 19 charcoal samples display a mean $\delta^{13}C$ value of −24.6 ± 0.2‰. At the end of VI B1 the mean $\delta^{13}C$ value from the small oak remains is established at −24.2 ± 0.4‰ on average. The statistical analysis shows that the oak samples from all the investigated periods are similar to each other (Table 3).

The juniper samples, from the early-VIII period charcoals, display a mean $\delta^{13}C$ value of −22.4 ± 0.5‰ whereas at the end of the period the $\delta^{13}C$ value is established at −23.2 ± 0.2‰. Different wood fragments from the same unit of the early-VII period record a mean value of −22.2 ± 0.3‰ and at the same time the $\delta^{13}C$ value of the sample of the late-VII period is −22.1 ± 0.0‰. Finally, the $\delta^{13}C$ values from 13 fragments of juniper wood recovered in contextual units of the VI A period average at −22.2 ± 0.1‰. As reported in Table 3, statistical analysis shows that the VI C values significantly differ from those of all the other archaeological periods.

4 | DISCUSSION

4.1 | Differences in deciduous *Quercus* and *Juniperus* $\delta^{13}C$ values

The first points to discuss are tied to the variation of the stable carbon isotope ratios in different woody plants and the different ecological behaviours of an evergreen conifer such as juniper and of a mesophilous tree such as deciduous oaks.

The intraspecific variation of $\delta^{13}C$ values in all the site periods ranges from 0.4 to 3.7‰ for deciduous oak and from 0.6 to 1.7‰ for juniper remains (Table 3 and Figure 2). These values largely fit for the intra-population variability that is expected for plants of the same species growing at the same site (over 1.5‰ in arid regions).[70] Nonetheless, the main differences have been found within deciduous oak charcoal samples since this taxonomic group gathers together

TABLE 2 ^{14}C-AMS dates provided on samples from the same contextual units investigated by stable isotope analysis (data from Vignola et al[31] and this study)

Arslantepe period	Phase	Taxon	Plant remain	Laboratory ID	^{14}C date BP	^{14}C date BC (2σ)
VI B1	Late Middle/Late	deciduous *Quercus* deciduous *Quercus*	Charcoal Charcoal	D28/15-DSH7017 D28/15-DSH7017	4552 ± 21 4559 ± 21	3366–3117 3369–3119
VI A		*Juniperus* sp.	Charcoal	S05/17-DSH7982	4767 ± 28	3639–3386
VIII	Early	*Juniperus* sp.	Charcoal	D-DSH7173	5801 ± 21	4720–4560

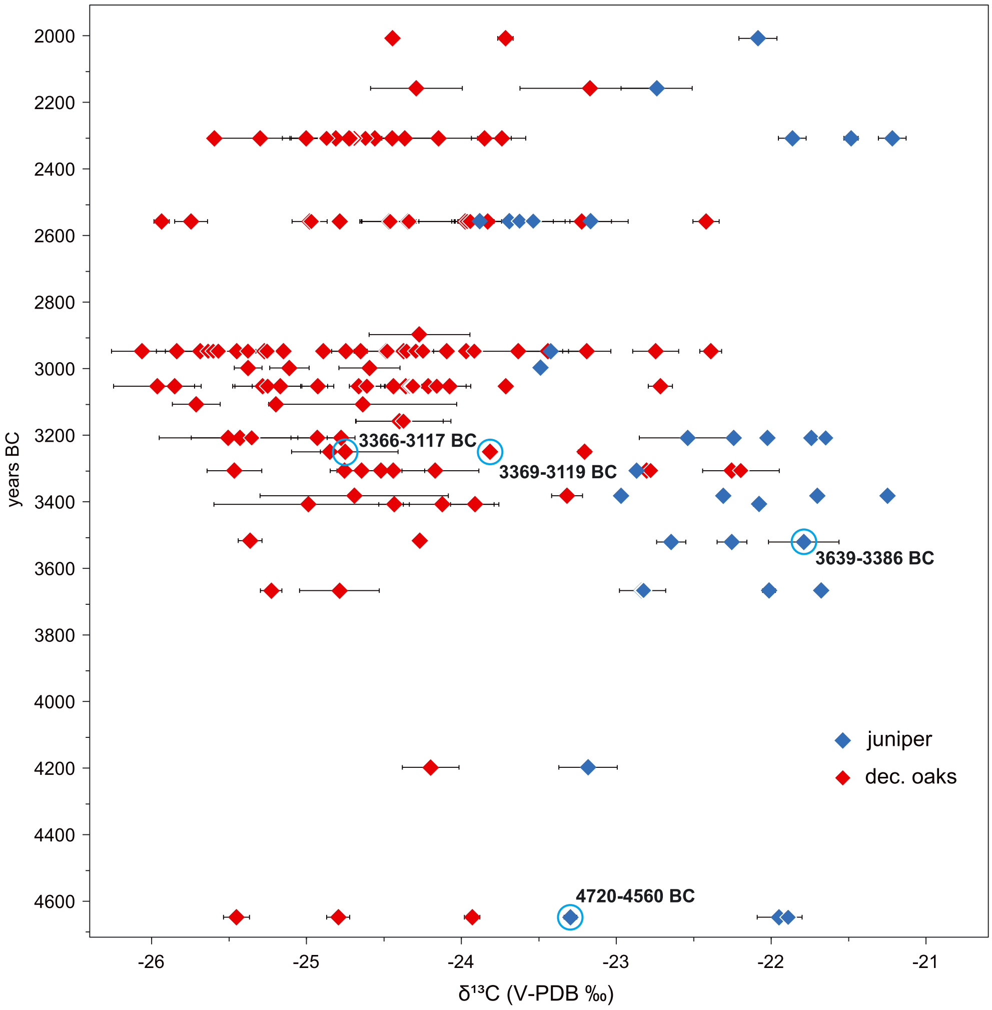

FIGURE 2 $\delta^{13}C$ values of deciduous oak and juniper charcoal samples in the chronological framing. Within circles, samples ^{14}C-AMS dated with their RC ages (Table 2). Error bars for standard deviation (SD) [Color figure can be viewed at wileyonlinelibrary.com]

TABLE 3 $\delta^{13}C$ and $\Delta^{13}C$ mean values with standard errors of deciduous oak and juniper charcoal remains for the investigated archaeological periods

	Arslantepe period	Phase	Sample (*n*)	$\delta^{13}C$ (‰)	*s* of $\delta^{13}C$ (‰)	$\Delta^{13}C$ (‰)
Deciduous *Quercus*	VI D	Late	4	−23.9 ± 0.3	0.7	18.1 ± 0.4^{a,b,c,d,e,f,g,h,i,j,k}
		Middle	16	−24.6 ± 0.1	1.9	18.7 ± 0.1^{a,b,c,d,e,f,g,h,i,j,k}
	VI C		15	−24.4 ± 0.2	3.5	18.5 ± 0.2^{a,b,c,d,e,f,g,h,i,j}
	VI B2	Late	29	−24.6 ± 0.2	3.7	19.2 ± 0.3^{a,b,c,d,e,f,g,h,i}
		Early	3	−25.0 ± 0.2	0.8	18.8 ± 0.2^{a,b,c,d,e,f,g,h}
	VI B1	Late	4	−24.2 ± 0.4	1.6	18.3 ± 0.2^{a,b,c,d,e,f,g}
		Middle	19	−24.6 ± 0.2	3.3	18.7 ± 0.2^{a,b,c,d,e,f}
		Early	3	−25.5 ± 0.3	1.1	19.3 ± 0.0^{a,b,c,d,e}
	VI A		19	−24.3 ± 0.2	3.3	18.4 ± 0.3^{a,b,c,d}
	VII	Late	6	−24.5 ± 0.2	1.5	18.6 ± 0.2^{a,b,c}
		Early	2	−25.0 ± 0.2	0.4	19.1 ± 0.2^{a,b}
	VIII	Late	1	−24.2 ± 0.2	-	18.3 ± 0.2
		Early	3	−24.7 ± 0.4	1.6	18.9 ± 0.5^{a}
***Juniperus* sp.**	VI D	Late	2	−22.4 ± 0.3	0.6	16.4 ± 0.3^{a,b,c,d,e}
		Middle	3	−21.5 ± 0.2	0.7	15.5 ± 0.2^{a,b,e}
	VI C		5	−23.6 ± 0.1	0.7	17.7 ± 0.1^{d}
	VI B2	Late	1	−23.4 ± 0.2	-	17.5 ± 0.2
		Early	1	−23.5 ± 0.0	-	17.6 ± 0.0
	VI A		13	−22.2 ± 0.1	1.7	16.2 ± 0.1^{a,b,c}
	VII	Late	1	−22.1 ± 0.0	-	16.1 ± 0.0
		Early	3	−22.2 ± 0.3	1.1	16.2 ± 0.4^{a,b}
	VIII	Late	1	−23.2 ± 0.2	-	17.2 ± 0.2
		Early	3	−22.4 ± 0.5	1.4	16.5 ± 0.5^{a}

Light grey characters: data from Masi et al.[18,20] Lower-case superscript letters: archaeological periods whose differences are not statistically significant (PERMANOVA)

s = sample variation (max-min values).

remains of both deciduous and semi-deciduous *Quercus* spp. (a difference between plant species up to 4‰ is reported in the literature).[70] In addition, deciduous oak specimens exhibit a larger offset in $\delta^{13}C$ values from 3400 to 2000 BC (LC 5-EBA III), where samples from several contextual units were collected (Table 3).

Furthermore, the interspecific variation between the Arslantepe deciduous oak and juniper $\delta^{13}C$ values reflects different physiological features for plant growth (deciduous vs evergreen trees). Indeed environmental factors, and above all water availability, differently influence photosynthesis rates, stomata conductance and RuBisCO activity between the two taxa.[71] In particular, the lower conductance of conifers than of deciduous broadleaved trees may cause the higher juniper $\delta^{13}C$ values presented here (Lloyd et al[72] reported a $\delta^{13}C$ value increase of 3‰). The two selected trees do not anyway show parallel $\Delta^{13}C$ curves as might be expected considering the physiology and autoecology of modern plants, and some isotopic effects reported for plants growing in different altitudinal transects and exposures (slope/plain)[18,27,73] are not enough to explain the asynchronicity between the two curves (Figure 4).

A possible mechanism explaining the delay in the deciduous oak $^{13}C/^{12}C$ curve compared with the juniper one was hypothesised by Masi et al.[20] In the Arslantepe record, contrasting ratios in juniper and deciduous oaks suggest that, in addition to seasonality in rainfall distribution, aquifer recharge played a complex role as the Malatya plain is in a karst system. Junipers were probably growing on the slopes surrounding the plain where oaks were widespread. Junipers used late winter/early spring rainwater, while deciduous oaks mostly water recharged from the aquifers during late spring and early summer. As the time needed to recharge the water table in a karst area can be estimated at some decades, the water or part of the water that the two species used for photosynthesis had a different age.

Thus, the present study confirms that the Arslantepe juniper record is mainly influenced by local precipitation during rainy seasons, whereas the Arslantepe oak one, being tied to summer droughts, registers the water isotopes content of some decades before.

This behaviour in confirmed by the investigation of the co-occurrence patterns of the carbon isotope discrimination in deciduous oak and juniper remains. Samples of the two taxa recovered from the same contextual unit (i.e. the same time period) have been plotted in Figure 3. It is clear that the relationships between $\Delta^{13}C$ values of deciduous oaks and juniper from 4700 to 2000 BC are positive and statistically significant only in few cases (*r* from 0.69 to 1). As confirmed by modern samples (*r* = 0.17), the isotopic content of the two plants must be interpreted in a different way.

4.2 | Changes in local precipitation and cultural developments

The second guideline of the discussion is focused on the palaeoclimate reconstruction in the study area and the comparison with archaeological evidence.

The mean $\Delta^{13}C$ values of the two selected taxa from all the investigated sequences are plotted in Figure 4. The carbon isotope composition of the fossil woods compared with the modern ones indicates that the past climate was generally wetter than the climate recorded in 2008 (350 mm/year, Figure 1C). This difference, already

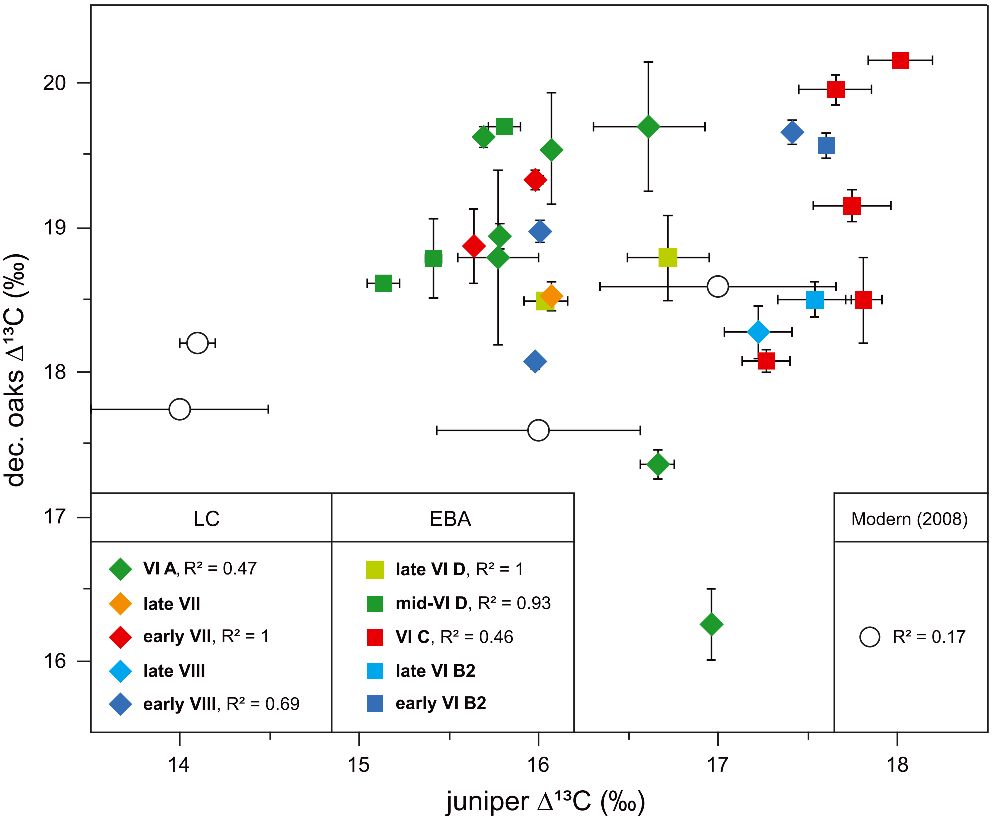

FIGURE 3 Relationship between deciduous oak and juniper $\Delta^{13}C$ values of charcoal samples from the same contextual unit, grouped by archaeological periods. Error bars for standard deviation (SD) [Color figure can be viewed at wileyonlinelibrary.com]

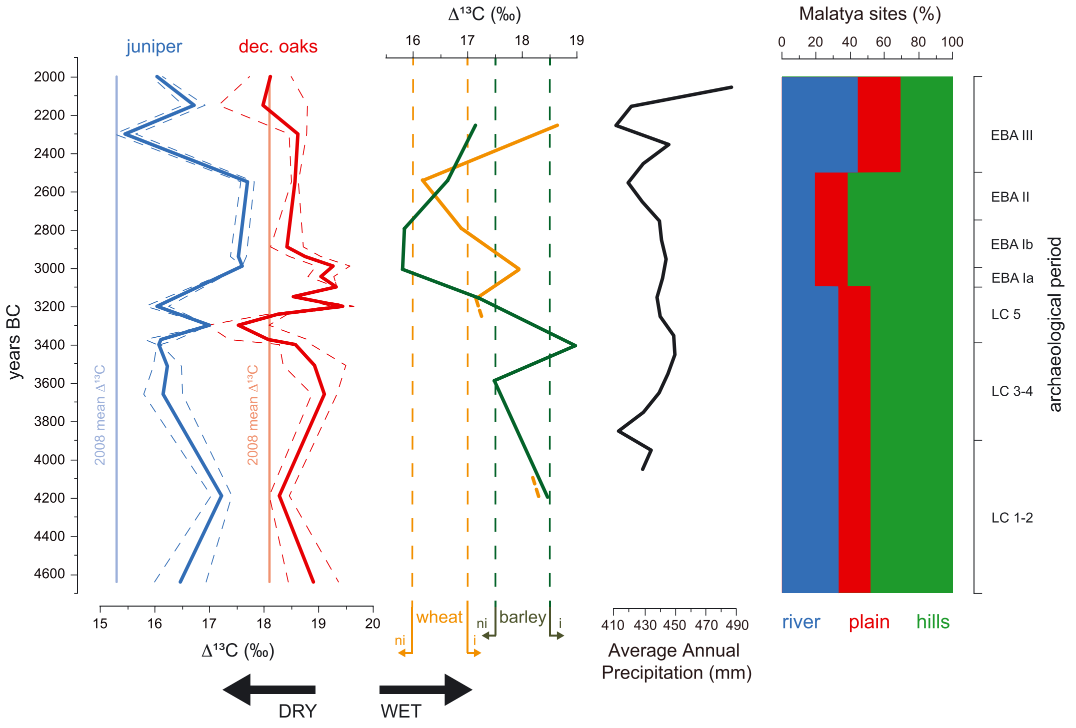

FIGURE 4 From left to right: $\Delta^{13}C$ mean values with standard errors of deciduous oak and juniper charcoal remains from Arslantepe (vertical dotted lines represent mean isotope values of modern samples; data from this paper and Masi et al[18,20]); AAP (Average Annual Precipitation) values from macrophysical model of the Malatya area;[32] $\Delta^{13}C$ mean values of barley and wheat grains from Arslantepe with thresholds for water availability (n.i. for not irrigated, i. for irrigated); [31]% values of site distribution in the Malatya plain[74] [Color figure can be viewed at wileyonlinelibrary.com]

reported by Masi et al[18,20] for 3400–2000 BC, is here confirmed as being since around 4700 BC, with the only exception of the period around 2300 BC, when oaks registered more aridity than today.

As stated by Masi and colleagues,[20] water sources, precipitation pattern and hydrogeological features at the local scale influenced the isotope composition. Differences in $\Delta^{13}C$ trends of the Arslantepe deciduous oaks and juniper, previously reported, have been confirmed here. Significantly, the importance of the dataset and the methodological approach are validated.

Since the growth of deciduous oaks occurs at spring/summer when the local precipitation rate is low, their high rooting-depth supplies them with effective uptake of groundwater in the plain during dry months. In a karst environment such as the Malatya area, the differences in plant auto-ecology and distribution (deciduous oaks probably grew in the plain fed by karst aquifers, whereas juniper in the slopes of the surrounding mountains) account for the time lag existing between rainfall amount and aquifer recharge, leading to a quasi-regular shift in the deciduous *Quercus* isotope signal (Figure 4).[20]

In the Malatya area water availability resulted therefore in dependence on (1) the seasonal distribution of rainfall, having its climax between March and June (Figure 1C) and (2) the several karst springs in the plain.

We should therefore suppose that the curve directly linked to rainfall is the juniper one, while the one for the deciduous oaks shows a delay of some decades due to the time needed for water recharge.

The AAP (Average Annual Precipitation) macrophysical model for the Malatya plain, applied by Arıkan et al,[32] displays no overall wetter conditions in the first half of EBA (Figure 4).

From 4640 to 4200 BC, a transition toward wet conditions is indicated by the juniper $\Delta^{13}C$ values. A high moisture level is also testified by isotope data from herbivore bone remains[75] (Figure 4).

Later, from 3700 to 3400 BC, when social complexity gradually grew at the site,[29] a decrease in precipitation marked by the juniper $\Delta^{13}C$ values was balanced by the increase in aquifer level reported by the deciduous oak $\Delta^{13}C$ values. The reduced precipitation water is also confirmed by the fact that barley was probably irrigated (we have so far no wheat remains between 4200 and 3200 years BC) (Figure 4).

Soon after 3400 BC both oak and juniper experienced an abrupt change followed by an instability phase established between 3400 and 2900 BC (LC 5-EBA Ia, Figure 4). This period corresponds to the early state at Arslantepe, which thus certainly had to face such fluctuations. It is noteworthy that the abrupt increase in the deciduous oak $\Delta^{13}C$ values was precisely recorded in the LC 5, when drier and wetter periods have also been pointed out in quick succession by the juniper and hare bone isotope records[75] and the concurrent increase in agricultural pressure on the plain has been reconstructed.[31] Looking at the past crop production in the Malatya area, both barley and wheat fields were always supplied with agricultural practices (such as reserving better fields) when the decrease of rain water is recorded by juniper $\Delta^{13}C$ values[31] as testified by definite thresholds of cereal $\Delta^{13}C$ values as reported by Vignola et al[31] (Figure 4). A crop production managed by the centralised institutions of Arslantepe[31] would have been able to balance the climate fluctuations in the plain. Notwithstanding this, at the end of the LC 5 period the state system lapsed into decline; causes for this are to be sought in long existing social tensions.[29]

A stability phase with enhanced late winter/early spring precipitation is suggested for the 3000–2500 BC period (EBA Ib-II, Figure 4). Considering the occupational patterns outlined for the Malatya plain during the investigated sequence, the highest juniper Δ^{13}C values exactly correspond with the establishment of new settlements on the natural hills[74] (Figure 4). Probably, the seasonal variation (= more water available also outside the karst lain) fostered mobility and transhumance of the VI B1 and VI C herder groups.[76] It is noteworthy that the differences between the VI C Δ^{13}C values and all the other Arslantepe periods are significant (Table 3).

Finally, a consistent dry event is recorded at 2300 BC (EBA III) when the past climate was similar to the present one (Figure 4) and wheat fields were water supplied. This aridity phase, with minimum AAP, has been also highlighted by the stable oxygen isotope ratios from animal remains.[75] This might have been a central factor stimulating the concentration of settlements nearer to the river, into the Euphrates floodplain, as testified by the settlement system of the Malatya plain[74] (Figure 4).

4.3 | Regional palaeoclimate fluctuations

The interpretation of the Arslantepe isotope data in comparison with other proxies, aimed at an overall reconstruction of the past regional climate, is the last focus of this study.

During the mid-Holocene the eastern Mediterranean has been sensitive to changes in rainfall and vegetation parameters, while temperature has remained approximately unvaried.[77] In particular, after 5000 BC, a transition phase, leading to aridification, emerged.[3,15] Regarding changes in precipitation, we have to locally consider the juniper isotope record since it has previously been shown that the Arslantepe juniper Δ^{13}C values are influenced by the precipitation pattern (see sections 4.1 and 4.2). Thus, changes to wetter/dryer conditions are highlighted by the juniper Δ^{13}C values from 4700 to 1900 BC (Figure 4).

How climate fluctuations have varied in amplitude and duration throughout the history of the Arslantepe site is, however, hard to assess in detail because we have a good, but not always high-resolution record.

The Sofular Cave stalagmite record, reflecting hydrological conditions over the southern Black Sea coast (NW Turkey), shows high rainfall amount, particularly until 4150 BC.[78] This wet period falls within the time frame of warm conditions found in the northern latitudes, referred as 'Holocene climatic optimum' (from ca 7050 to 4050/3050 BC),[79] when the organic-rich sapropel S1 sediments were deposited in the eastern Mediterranean.[80] At Lake Sünnet (W Turkey), after high δ^{18}O values suggesting hot summers and dry conditions, more humid climatic setting was established from ca 4700 to 4050 BC.[81] In SW Turkey, the δ^{18}O record from Gölhisar Lake shows a reducing trend until ca 4100 BC, with a precipitation/evaporation ratio considerably higher than at present[82] (Figure 5). Furthermore, positive variation in the eastern Mediterranean sea-level confirms high rates in the fluvial flow feeding the basin from ca 5000 to 4000 BC (W Turkey and Israel coastline).[88] From the Soreq Cave speleothem (Israel) δ^{18}O values record the peak of wet climate at ca 4550 BC, when the annual precipitation probably exceeded 700 mm[15] (Figure 5).

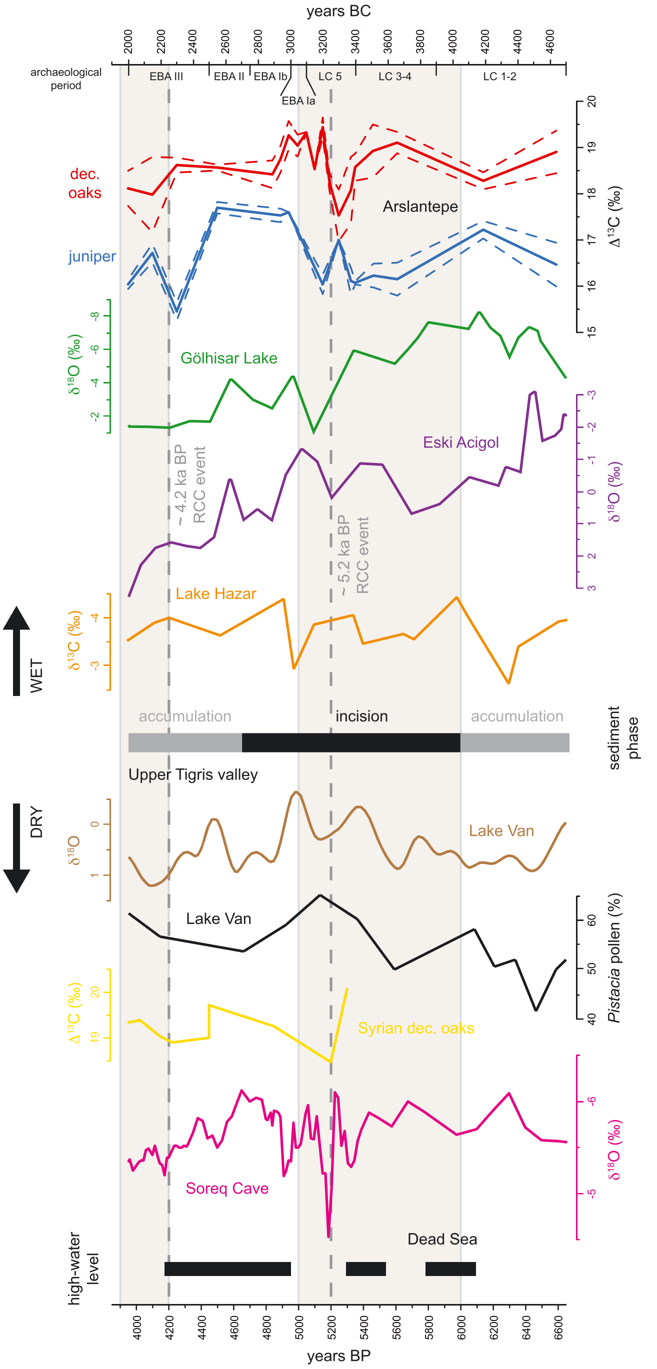

FIGURE 5 Comparison between Near Eastern palaeoclimate proxies. From top to bottom: Δ^{13}C mean values with standard errors of Arslantepe deciduous oak and juniper charcoal remains; δ^{18}O values from Gölhisar Lake;[82] δ^{18}O values from Eski Acıgöl Lake;[83] δ^{13}C values from Lake Hazar;[84] fluvial sedimentation phases from Upper Tigris valley;[85] δ^{18}O and *Pistacia* pollen % values from Lake Van;[11] Δ^{13}C mean values of deciduous oak charcoals from northern Syria sites;[22] δ^{18}O values from Soreq Cave speleothem;[15] high-water level of Dead Sea basin.[86] Shaded rectangles and vertical dotted lines indicate the Rapid Climate Changes (RCC dry events) as singled out and described by Mayeski et al[87] [Color figure can be viewed at wileyonlinelibrary.com]

From 4150 to 3400 BC a decrease in moisture is recorded in both the Arslantepe area and the Van region (E Turkey), where Wick et al[11] have confirmed the sensitive relationship between relative humidity and the carbonate oxygen-isotope signal from the Lake Van laminated sediments. In particular, at ca 3850 BC, the Malatya AAP reached its lowest value (Figure 4). The increase in δ^{18}O values after 4050 BC in the Gölhisar record has been interpreted as resulting from gradually increasing drier conditions (Figure 5). Considering the contemporary positive shift in the δ^{18}O signal from Lake Sünnet, combined with the reducing lake level,[81] a parallel climate evolution can be envisaged from the south-eastern to western regions. In addition, a long dry period is evident from Jeita Cave, Lebanon.[89] The water-level record from the Dead Sea basin also shows lower depth from around 3800 to 3600 BC with regard to the later sequence, when the lake level grew consistently[86] (Figure 5).

Between 3400 and 3100 BC, when the Arslantepe pristine state rose, oscillations in the regional precipitation pattern occurred. In particular, episodes of greatest isotope variability with large-scale switches in the stable oxygen and carbon isotope ratios appear to represent centennial-scale shifts in the rainfall amount from Soreq Cave and precipitation/evaporation balance at Gölhisar Lake (Figure 5). This suggests marked effects of climate fluctuations on the regional environments. Interestingly, oak charcoal remains from the north Syrian sites display the highest and lowest Δ^{13}C values during LC 5 in strict accordance with the Arslantepe juniper signals from the same timespan[22] (Figure 5). As in regions not subject to a karst system, the oaks trend are in agreement with the juniper one, this is further evidence of the anomaly of the deciduous oaks curve at Arslantepe. The delay was explained by the time needed for the water recharge.

The high-resolution records from Soreq Cave and Arslantepe clearly indicate climate fluctuations at the end of the LC (3400–3100 BC), not apparent from other low-resolution proxies. This climate instability involved the whole Near East, possibly having a significant impact upon local societies.[8] A drop in humidity at the end of LC/beginning of EBA (3400–3000 BC) is also shown by *Pistacia* pollen and isotope records of Lake Van, eastern Turkey.[11] In the Mediterranean basin, Mayewski et al[87] identified a major arid RCC (Rapid Climate Change) event between 4050 and 3050 BC, with a peak at 3250 BC (Figure 5). Some scholars have already related the dry event of 3250 BC (5.2 ka BP event; ka stands for kiloyears) to a consistent drought-triggered social change in the Late Uruk culture of the Great Mesopotamia.[6] This climate instability could have played a role in exacerbating the crisis of the Arslantepe LC 5 society, as already pointed out.

Despite the Bronze Age aridity trend in the eastern Mediterranean,[3] increasing moisture is initially indicated by the Arslantepe, Gölhisar and Sofular isotope records, between 3000 and 2500 BC, together with minor oscillations due to local influences[78] (Figure 5). At Soreq Cave the δ^{18}O values indicate wetter climate conditions from 2850 to 2750 BC with a mean annual precipitation of ca 700 mm.[15] The elevation of the Dead Sea level also confirms significant water inputs (above 390 m a.s.l. at 3000–2250 BC, Figure 5).

The climate oscillations that occurred at around 2250 BC are differently invoked in the historical reconstruction of the EBA III societies of the Mesopotamian regions.[90-92] The Arslantepe juniper Δ^{13}C minimum at 2350 BC is framed in the aridity trend evidenced at Eski Acıgöl,[83] Lake Van and Soreq Cave oxygen isotope curves (Figure 5). The increased oxygen isotope signal matches with the inflection in the Lake Van oak forest and high micro-charcoal values.[11] Similar forest openings have been highlighted in the pollen records of Mirabad and Zeribar lakes (E Iran) at ca 2200 and 2050 BC, respectively.[93,94] South of Turkey, the Δ^{13}C values from Syrian oaks also reveal drier conditions around 2500–2300 BC. At Soreq Cave a 2200 BC dry event occurred at the end of a long trend towards aridity that started at 2750 BC (Figure 5). Here, although the positive peak of the δ^{18}O values does not indicate such a severe aridity, the corresponding δ^{13}C values suggest a significant change in magnitude.[15] This falls within the global-scale RCC event (the so-called 4.2 ka BP event)[95] that has a consistent signature in the Arslantepe record, leading to the highest water deficit (Figure 5). Staubwasser and Weiss,[6] referring to this event as a 'Collapse as Adaptation to Rapid Climate Change', proposed a relationship between low rainfall and the collapse of the Akkadian Empire. At Arslantepe and in other Near Eastern sites, however, a continuity of the societal developments between the EBA III and MBA (Middle Bronze Age) periods is now clearly attested.[96] No evidence of a consistent cultural break has been highlighted in the site in the Malatya plain at the end of the EBA III period.[97] The tracking of more favourable habitats into the Euphrates floodplain of the Malatya area in this period may, however, be regarded as a consequence of the drought displayed by the AAP model at 2250 BC (Figure 4). In addition, Arıkan[98] confirms that human communities used high-risk landforms across the Upper Euphrates basin during the EBA III aridity.

Finally, the last marked increase in precipitation at the site (2150 BC) has been traced out in western (Sofular Cave) and central (Nar Gölü)[99] Turkey as well as in the southern regions (Figure 5). Interestingly, Benito et al[100] report extreme flooding events of the eastern Mediterranean rivers since 2150 BC.

It is worth mentioning that the precipitation pattern in the Malatya region also shows similarities with the western Turkey proxies during the wet phases. On the contrary, the trend of reduced moisture is mainly shared with E Turkey and the southern regions. The eastern Mediterranean climate, as a result of the interaction between European, Asian and North African patterns, is mainly affected by the Siberian High Pressure System in winter.[1] Thus, a strong exposure to this system favours cyclogenesis and rainfall from western Russia.[101] Nonetheless, areas of Turkey north of the Taurus range can have experienced influences by the NAO (North Atlantic Oscillation) from the western Mediterranean, following preferred tracks eastward as evidenced by several studies.[102] In addition, Roberts et al,[103] focusing on the climate signals during historical times, have shown that there is no single mode that accounts for the association of Atlantic-Mediterranean fronts in the precipitation regimes. For this reason we propose that the changes in rainfall at Arslantepe might have been influenced by oscillations in the atmospheric circulation in the Mediterranean basin, even if driven by the Atlantic circulation. While the wettest phases could have been tied to anomalies of the North Atlantic Oscillation (NAO) forcing,[104] the driest ones could have been caused by the high-pressure system from the eastern regions. Looking at the *Pistacia* pollen record from Lake Van, the increases in percentage of the pistachio pollen grains mostly corresponds with the events of reduced moisture at Arslantepe (Figure 5). On the other hand, when the wettest conditions are recorded in the Malatya area from 3000 to 2500 BC, depletion of the pistachio shrubland is evident around the lake (Figure 5). Since pistachio shrubs are drought-tolerant but frost-sensitive, changes in the precipitation pattern with increasing late winter snow potentially suggested by the Arslantepe juniper record is confirmed.

The aquifer recharge pattern in the Malatya plain, shown in the possible delay in the Arslantepe deciduous oak Δ^{13}C values, interestingly matches with other palaeoenvironmental proxies. In particular, the carbon isotope record from Lake Hazar (Elaziğ region) close to the study area reveals resemblance in recording palaeoclimate variability (Figure 5). This correlation is probably due to the presence of the karst phenomenon also in that site of the Anti-Taurus region.[84] In addition, fluvial sedimentation phases from neighbouring areas can be compared with the climate changes in the Upper Euphrates valley.[105] In particular, in the Middle Euphrates region the formation of a fluvial terrace, stabilised by dense vegetation, marked the mid-Holocene until 4000 BC, when incision occurred.[106] It is also noteworthy that the low groundwater levels in the Malatya plain correspond with sediment deposition activities of the Upper Tigris valley, suggesting dry phases. On the contrary, the precipitation increase caused the incision on the riverbed and possibly the growth of the local water table[85] (Figure 5). In fact, during wet winters the intra-seasonal soil moisture loss is reduced, fostering effective river flows and discharge into the aquifers.[104]

5 | CONCLUSIONS

It is clear from the present work that interdisciplinary research can help in identifying and understanding how palaeoclimate has influenced social response to palaeoenvironmental changes. Stable carbon isotope analysis on archaeobotanical wood remains from the site of Arslantepe (Malatya, Turkey), where one of the earliest state systems appeared, has successfully led to climate reconstruction during the mid-Holocene. In particular, we have developed Δ^{13}C records from two plant taxa, deciduous *Quercus* and *Juniperus*, from 4700 to 2000 BC. High-resolution chronology has been obtained by joining the available chronological framing, improved with new ^{14}C-AMS dates, and the outstanding archaeological sequence.

The Malatya region experienced times of enhanced/reduced precipitation in concert with regional trends, but anomalies in the Mediterranean atmospheric circulation were also involved in the local climate oscillations.

From 4700 to 4200 BC wet conditions have been recorded, followed by a slight reduction in moisture. At that time an increasing social complexity was gradually testified at the site. From 3400 an instability phase occurred until 3000 BC, with possible important influence in the evolution of the LC 5 pristine state. We have suggested in particular that the crisis of the Arslantepe centralised organisation could have been heightened by the 3250 BC (5.2 ka BP) peak in the RCC arid event in the Mediterranean basin, resulting in the intensified effort of the political and economic leaders to improve the land productivity, thus probably increasing the pressure over the population and thereby exacerbating the crisis.

From 3000 to 2500 BC the increase in the late winter/early spring rainfall coincided with the mobile occupation of pastoral groups and the increased number of the archaeological sites settled on the natural hills across the Malatya plain. Finally, at ca 2300 BC (the so-called 4.2 ka event), the RCC dry event of the eastern (and central) Mediterranean, having a high signature in the Arslantepe records, coincided with and possibly had a role in the movement of the local communities into the Euphrates floodplain. This was, however, also related to a new cultural and political change, resulting in the establishment of more sedentary communities living in small towns surrounded by walls, and probably competing with each other. There was evidence that the crop production was clearly fostered with irrigation practices/favourable locations in the surrounding plain when the decrease in rainwater has been recorded by the isotopic signal. Finally, a substantial continuity in the cultural development of the EBA III and MBA societies has been documented at Arslantepe and in the Upper Euphrates region, when we see again a strong arid event; not a dramatic crisis, but rather a re-arrangement of the political and economic organisation of the local communities is attested there at the end of the 3rd millennium BC.

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CONCLUSIONS

It is clear from this PhD research project that palaeoclimate influenced social response to palaeoenvironmental changes in south-eastern Turkey during the mid-Holocene. On the other hand, the range of agronomic conditions revealed by ancient crops was forced by the interaction between palaeoenvironmental and cultural changes. The candidate has been able to propose a consistent interpretation of archaeobotanical data at the site of Arslantepe, aligning isotopic, palaeoenvironmental and archaeological evidences. Such a goal was primarily backed up by the new ^{14}C-AMS dates, which improved the long-term site chronology. Thus, the first high-resolution archaeobotanical records from an archaeological site of the Near East has been established.

The charcoal assemblage of Arslantepe revealed important changes in plant use, responding only partly to past climate and environment evolution. In fact the different distribution of tree taxa along the investigated sequence mainly addressed to the overexploitation and/or timber selection related to different technological and cultural needs. Wood resources were exploited from the forest-steppe and riverine gallery forest in the plain, with minor contribution from the surrounding mountain.

On the contrary the area, where the site is settled, experienced times of enhanced/reduced precipitation in concert with regional trends. Anomalies in the Mediterranean atmospheric circulation probably influenced local climate oscillations. As carbon isotopes on charcoals have shown, stormtracks from North Atlantic regions seemed to occur during the wettest phases, whilst the high-pressure system from eastern regions was implicated especially in low rainfall patterns. From 4700 to 3400 BC, when social complexity increased at the site, wet conditions were recorded and followed by a slight reduce of moisture. Agriculture in the plain was characterised by irrigation and fertilisation practices at different levels since 4300 BC and was mainly wheat based. Interestingly both botanical and faunal data in the domestic contexts of 4700-3900 BC referred to a mixed primary economy, managed by single families with no evident interference of growing social elites.

Then, an instability phase occurred until 3000 BC, influencing the evolution of the Arslantepe early state. With strengthening of political and economic power of local elites, an intensification of agricultural production was especially testified by barley isotope composition. Remains of barley grains were present in large quantities from archaeological contexts at the site. Such evidences suggested that centralisation of production was mainly concerned with this crop. This interpretation is in line with data from other Mesopotamian sites as well as from contemporary ancient texts. Particularly high-level irrigation and manuring activities were carried out at 3400-3200 BC, when a huge palatial complex was built at the site. Although a contemporary decrease of groundwater level was recorded by charcoal isotope signal, crop production was fostered with irrigation practices. Anyway of course, in comparison with other regions of the Near East, growing conditions in the study area benefitted from hydrogeological features due to karst activity. At the end of this period, the Arslantepe centralised organization suddenly collapsed. Its fall coincides with the 3250 BC peak of RCC (Rapid Climate Change) dry event in the eastern Mediterranean basin. Other Near Eastern regions experienced a hard drought, trigging widespread social changes.

From 3000 to 2500 BC variation in seasonal precipitation pattern enhanced the mobile occupation of pastoral groups and supported the establishment of a number of settlements on natural hills across the plain. As stable isotopes from cereal grains have revealed, these communities of Transcaucasian-linked culture also established new agronomic practices. For barley crops they probably used fields in marginal grazed lands with less water availability but with increased soil fertility due to the N-enrichment provided by animal pasture. On the other hand wheat was possibly harvested close to the site, where water from natural springs was abundant due to the increased late winter/early spring rainfall. At the same time fields seemed to host cereal-legume mixture crops. Thus N-supply to fields was steadily safeguarded, contrary to water regime that might be not improved due to the advantageous climatic conditions. In fact, while irrigation activities were pointed out in other sites from Turkey and Northern Syria, the agronomic development in the Arslantepe area was not conditioned by water availability.

Finally at ca. 2300 BC another RCC arid event across the Mediterranean basin, having a high signature in the Arslantepe charcoal records, caused the movement of local communities into the floodplain of the Euphrates River. The high climate oscillations also caused the necessary enhancement of irrigation practices around the site and the choice to save it for the high-yield crop, i.e. wheat. Indeed, Arslantepe wheat grains recorded higher carbon and nitrogen signal than the other Near Eastern sites, suggesting their importance in the local primary economy. The social instability, triggered by palaeoclimate and testified by fortification walls around the settlement, was at large scale. The simultaneous collapse of Mesopotamian agricultural cultures was already inferred.

In conclusion, the multi-proxy approach for an integrated archaeobotanical reconstruction is clearly successful. An additional goal of this PhD project confirms it. Within the exceptional continuum of agricultural history at the site, a specific crop management practice has been proposed: the growth of different *Triticum* species together in the same fields, or “maslin”. Cereal grain analysis from 4300 BC domestic context suggested it since this system helped buffer risk minimising total crop failure for a family in a bad year. Then the similar agronomic trend of wheat crops along the millennia, highlighted by stable carbon and nitrogen analyses, has validated such agricultural practice.

Paper contributions

1. Vignola C., Balossi Restelli F., Masi A., Sadori L., Siracusano G., 2014. Investigating domestic economy at the beginning of the Late Chalcolithic in Eastern Anatolia: the case of Arslantepe period VIII. *Origini* 36: 7-36

The candidate wrote the botanical section, being responsible for data production. He also contributed to data management and interpretation of the whole paper.

2. Masi A., Balossi Restelli F., Sabato D., Vignola C., Sadori L., 2018. Timber exploitation during the 5th-3rd millennia BCE at Arslantepe (Malatya, Turkey): environmental constraints and cultural choices. *Archaeol Anthropol Sci* 10: 465-483

The candidate wrote the manuscript in collaboration with all of the authors. He contributed to data production with the analyses carried out for his PhD research. He was also responsible for data management and interpretation together with the co-authors. Figures were substantially elaborated by the candidate.

3. Vignola C., Masi A., Balossi Restelli F., Frangipane M., Marzaioli F., Passariello I., Stellato L., Terrasi F., Sadori L., 2017b. $\delta^{13}C$ and $\delta^{15}N$ from ^{14}C-AMS dated cereal grains reveal agricultural practices during 4300-2000 BC at Arslantepe (Turkey). *Rev Palaeobot Palyno* 247: 164-174

The manuscript was conceived and written by the candidate. He was responsible for data production, management and interpretation in collaboration with all of the authors. Figures were elaborated by the candidate.

4. Vignola C., Masi A., Balossi Restelli F., Frangipane M., Marzaioli F., Passariello I., Rubino M., Terrasi F., Sadori L., 2018. $\delta^{13}C$ values in archaeological ^{14}C-AMS dated charcoal: assessing mid-Holocene climate fluctuations and human response from a high-resolution record (Arslantepe, Turkey). *Rapid Comm Mass Spectr* 32: 1149-1162

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