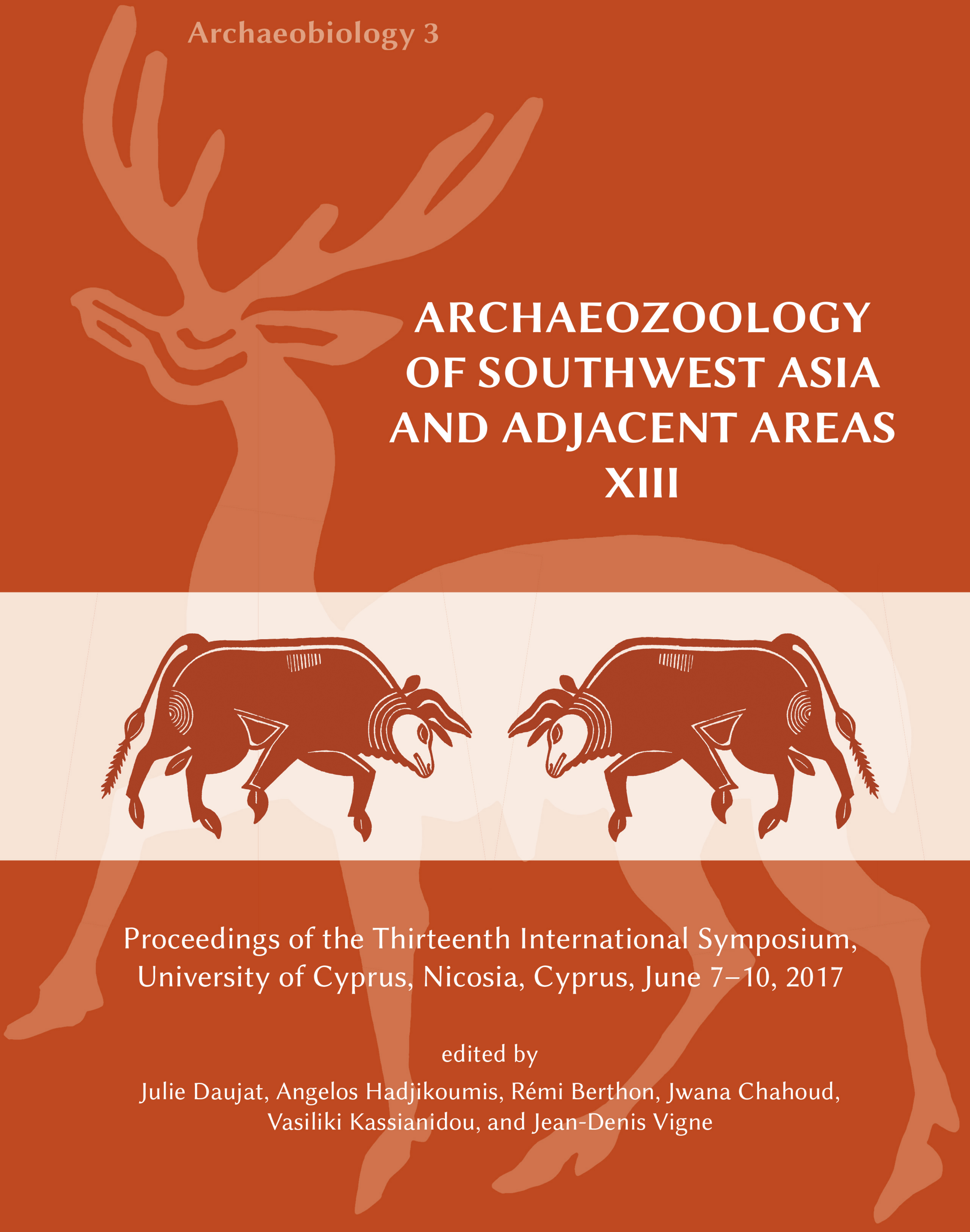

Archaeobiology 3

ARCHAEOZOOLOGY OF SOUTHWEST ASIA AND ADJACENT AREAS

XIII

Proceedings of the Thirteenth International Symposium,
University of Cyprus, Nicosia, Cyprus, June 7–10, 2017

edited by

Julie Daujat, Angelos Hadjikoumis, Rémi Berthon, Jwana Chahoud,
Vasiliki Kassianidou, and Jean-Denis Vigne

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Series Editors

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Group photo of the 13th ASWA[AA] meeting June 8th 2017
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FOREWORD

The 13th ASWA conference was hosted by the University of Cyprus, one of the youngest of Europe's universities. In 2019, it was only thirty years since its foundation. Nevertheless, this is a thriving academic institution, which currently consists of eight faculties, twenty-two departments, and eleven research units.

In 1991, and just two years after the university's foundation, the Archaeological Research Unit (ARU) was founded by decree from the Government of the Republic of Cyprus, following the issuance of the dependent legislation by the House of Representatives. The decision to establish the ARU was based on the recommendation of the Interim Steering Committee of the University of Cyprus, which stated the following:

1. Cyprus is offered for primary research in the field of archaeology thanks to its distinctive cultural signature and history, as well as due to the fact that Cypriot archaeology and archaeological research on the island already has a distinguished tradition and international reputation;

2. The subsequent international recognition of the importance of archaeological research in Cyprus should comprise one of the first incentives for choosing the University of Cyprus as a center for postgraduate studies, and will pave the way for the exchange of students and academics between the University of Cyprus and academic institutions overseas.

The faculty members of the ARU, who are also part of the Department of History and Archaeology academic staff, have contributed immensely over the past 28 years to the achievement of the aforementioned objectives for the study and promotion of Cypriot cultural heritage through their research, their teaching, and the practical training they have been providing to students at undergraduate and postgraduate levels. The active study of other regions of the Mediterranean world have not been overlooked either, as members of the ARU academic staff have been carrying out excavations and research projects in Greece, Turkey, and France.

The members of the ARU are actively carrying out research in Pre- and Protohistoric Archaeology, Classical and Byzantine Archaeology but also Archaeometry and Environmental Archaeology, Maritime Archaeology, and Western Art. In the course of the past 28 years, the ARU has laid very stable foundations in all aforementioned specialisations of the archaeological discipline, none of which existed at academic level in Cyprus before the unit's establishment. Through their teaching at undergraduate and postgraduate levels, all members of the ARU academic staff have been contributing to the formation of a new generation of Cypriot archaeologists, equipped with all the necessary knowledge and practical experience needed to excel in this scientific field.

Over the years, the ARU has been very active in organizing international conferences and workshops. The ARU has organized over 50 international conferences, while members of the academic staff have published the proceedings of over 20 scientific meetings held at the ARU.

Thus, when Jean-Denis Vigne came to my office several years ago with the suggestion to co-organize the 13th Archaeozoology of Southwest Asia and Adjacent Areas conference I gladly accepted. The meeting in Nicosia brought together colleagues from all over the world and offered a venue where new results from the field or the laboratory could be presented and discussed. The publication of the conference proceedings enables colleagues who were unable to attend the conference to read about the latest developments in the archaeozoology of this culturally important region.

I would like to close by thanking all the members of the 13th ASWA organizing committee for all the work they have put into bringing so many scholars to Cyprus, many of them for the first time. I would also like to thank the co-editors of this volume for all the work they have put into the publication of the proceedings.

Professor Vasiliki Kassianidou
Director of the Archaeological Research Unit,
University of Cyprus
Nicosia, August 2019

EDITORS' PREFACE

Due to their location at the meeting point of the three Old World's continents—Africa, Asia, and Europe—Southwest Asia and its adjacent areas played a pivotal role in the history of humanity. They received successive waves of our species—*Homo sapiens*—out of Africa. Different processes in several areas of this large region brought about the transition to the Neolithic, and later on the urban revolution, the emergence of empires bringing with them important subsequent religious, cultural, social, and political consequences. Southwest Asia also played a major role in the interactions between East (Asia) and West (Europe) during the last two millennia. The unique importance of Southwest Asia in the history of humanity is strengthened by the, also related to its location, fact that this area is a hotspot of biodiversity, especially in mammals, which were—as everywhere in the world—tightly associated to the history of civilizations in a diversity of roles: game, providers of meat and milk, traded raw material, symbol of prestige and wealth, pets, etc.

Everywhere in the world, the biological and cultural interactions between humans and animals often remain under-evaluated in their heuristic value for understanding complex social and biological interactions and trajectories. This is why, almost half a century ago, archaeologists who were carrying out research and reflecting on such themes founded a very active nonprofit world organization named the International Council for Archaeozoology (ICAZ). This is also why the ICAZ working group "Archaeozoology of Southwest Asia and Adjacent Areas" (ASWA[AA]) was one of the first ones created within ICAZ, constituting one of the largest and most active of ICAZ's working groups.

The ASWA[AA] was formed during the 1990 ICAZ International Conference in Washington, D.C. Its purpose is to promote communication between researchers working on archaeological faunal remains from sites in western Asia and adjacent areas (e.g., Northeast Africa, Eastern Europe, Central Asia, and South Asia). It carries out its mandate mainly through the sponsoring of biennial international conferences. Since 1998, these meetings have alternated in being hosted in Europe or in Southwest Asia: Paris (1998), Amman (2000), London (2002), Ankara (2004), Lyon (2006), Al Ain (2008), Brussels (2011), Haifa (2013), Groningen (2015).

Ongoing armed conflicts and political tensions in several countries of Southwest Asia made it difficult to locate a safe and convenient place that would enable the organizing the 13th ASWA[AA] meeting in within that region. Although Cyprus is currently a member of the European Union, in (pre-)history Cyprus was embedded in the eastern Mediterranean "world." Because of its location, Cyprus was indeed at the confluence of African, Levantine, Anatolian, and Greek cultural streams and, as is common for islands, recombined them in different but always original ways all along its history. Archaeozoology recently provided one of the most convincing illustrations of the tight connection between Cyprus and Southwest Asia, demonstrating that the earliest domesticated mammals, especially cats, pigs, cattle, sheep, and goats, were introduced to the island very shortly after their first incipient domestication on the near continent, that is, during the ninth millennium BC. For all these reasons, Cyprus represented an ideal place to host the 13th ASWA[AA] conference.

Despite the illegal military occupation of part of its territory by a foreign country, the option of hosting the meeting in Cyprus was enthusiastically embraced by all members of the working group, especially because it is open to all nationalities and maintains good diplomatic relationships with a large majority of countries in Southwest Asia. These facts contributed towards the 13th ASWA[AA] meeting in Cyprus (June 7–9, 2017) becoming one of the best-attended ASWA[AA] meetings. It brought together 80 scientists coming from 25 different countries: from Southwest Asia (6 countries), Europe (14 countries), North America (2 countries), and Japan.

They presented their results in 36 oral and 32 poster presentations. They debated the long-term interactions between humans and biodiversity, about the beginning of animal domestication and husbandry, the strategies of animal exploitation from the Paleolithic to modern times, and the symbolic and funeral use of animals through time. They also greatly enjoyed the numerous social events organized, including a fantastic Cypriot mezze dinner, enhanced by a local folk-music band, and a nice excursion to the archaeological sites of Amathous, Kourion, and Khirokitia, and to the museums of Nicosia and Larnaca, which provided ample opportunities for scientific exchanges in a friendly atmosphere.

The hosting of the conference at the new campus of the University of Cyprus was another major reason to the meeting's success. This campus was a convenient and pleasant venue for such a conference, and the strong support of the University of Cyprus, as well as its valuable experience for the organization of such meetings were deeply appreciated by both the scientific organizers and the delegates. Several other partners contributed to the organization: the French archaeological mission "Neolithisation—Klimonas," which is itself strongly supported by the French School at Athens, the Cyprus Department of Antiquities, the French Institute of Cyprus, the French National Center for Scientific Research (Centre National de la Recherche Scientifique [CNRS]), and the French National Museum of Natural History (Muséum national d'Histoire naturelle [MNHN]).

The present volume brings together the texts of 18 of the 68 presentations of the meeting in Nicosia. The editorial board collected the papers and organized their review and editing. We are very grateful to Sarah Kansa (and Open Context), Justin Lev Tov, and Lockwood Press for their constant support in bringing this volume to fruition.

Julie Daujat
Angelos Hadjikoumis
Rémi Berthon, Jwana Chahoud
Vasiliki Kassianidou
Jean-Denis Vigne

1.3 | Stable Isotope Evidence for Animal Husbandry Practices at Prehistoric Monjukli Depe, Southern Turkmenistan

Jana Eger,[*] Corina Knipper,[†] and Norbert Benecke[‡]

Abstract

Using stable carbon ($\delta^{13}C$) and oxygen ($\delta^{18}O$) isotope ratios of caprine tooth enamel from the Aeneolithic site of Monjukli Depe in southern Turkmenistan, this study investigates diet and seasonal movement of livestock. The carbon isotope profiles of some of the sequentially sampled third molars indicate a supply of C_3-plant-based forage year round, while the data from other teeth point to a seasonal contribution of C_4 plants. Considered in combination with archaeobotanical data, the first pattern likely relates to permanent use of pasture grounds in the closer vicinity of the site. In cases of varying carbon isotope ratios along the teeth, the highest $\delta^{13}C$ values co-occurred with the lowest $\delta^{18}O$ values. Contradicting expectations of enhanced availability of C_4 plants in summer, this finding indicates larger shares of this forage in winter and a prevalence of C_3 plants in summer. Among the possible explanations, stockpiling of winter forage containing C_4 plants and movement into the desert fringes during winter seem more likely than the use of upland pastures in summer. The study indicates diverse feeding practices and herding into a range of consciously selected habitats and illustrates intimate knowledge of the local ecology by those who tended the animal herds.

Keywords

Aeneolithic/Chalcolithic, oxygen and carbon isotopes, tooth enamel, sheep and goat, diet, mobility, seasonality, upland herding, steppe, desert, stockpiling

Introduction

Early forms of vertical seasonal mobility, where pastoralists and their herds moved between summer pastures in mountain regions and winter camps in the lowlands, are increasingly discussed in the archaeological literature of western Asia (e.g., Abdi 2003, 2015; Alizadeh 2010; Hole 2009; Potts 2014; Sumner 1994). Such kinds of pastoral nomadism are hypothesized for many places during the fifth millennium BC but most insistently for the area of the Aeneolithic Bakun tradition in southwestern Iran. In support of such scenarios of early pastoral lifeways, similarities with mobility patterns of today's pastoral nomadic societies in the same regions are assumed. Groups such as the Qashqai and Bakhtiari nomads serve as a basis for these reconstructions (Alizadeh 1988, 2003, 2010). This approach has also, however, been sharply criticized, particularly by Potts (2010, 2013), who insisted that there is no hard-and-fast empirical evidence for widespread mobile herding practices in prehistoric Iran.

We use data from a similar period and a region adjacent to the Iranian highlands (southeastern Turkmenistan) to test both the mobility scenario and its opposite, namely, the idea of sedentary village occupations. The point is not to refute one of these two scenarios and thus confirm the other but rather to investigate "degrees" and "variants" of mobility in fifth-millennium BC southern Turkmenistan. More specifically, this will be attempted based on data from the late Neolithic and early Aeneolithic levels (ca. 6000–4300 BC) of Monjukli Depe (Heit 2019). Archaeozoological and archaeobotanical studies have

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documented a subsistence economy based heavily on sheep- and secondarily goat-herding as well as crop cultivation on the fertile loess sediments that characterize the region. Hunting played only a minor role. Data on caprine age-at-death distribution and sex ratios suggest the exploitation of meat and milk products and do not indicate seasonal absence of animals (Benecke 2011, 2018; Eger 2018; Miller 2011; Ryan 2011). Nonetheless, seasonal mobility may have been important in buffering seasonal fodder shortages and water scarcity. Herders may have moved their herds to seek different types of grass from a variety of pastures and to access periodically fresh high-quality grazing areas in order to ensure herd survival and avoid overgrazing. It has also been proposed that agriculture and herding do not integrate harmoniously because goats in particular eat the growing crops. Herders might have solved this problem by moving the herds far from cultivations during the growing season (Bernbeck 1992:85; Köhler-Rollefson 1988:90). Better pastures might have prevailed seasonally in the Kopet Dag Mountains, so that vertical moves with herds could have been an attractive option. However, it has also been observed that the vegetation in the lowland Karakum Desert and on the piedmont strip can be used as high quality, permanent or seasonal pastures (Dolukhanov 1981:369–371). Therefore, horizontal shifts entailing movement out of a settlement's direct environment or possibly further away into the edges of the desert might have been practiced.

Analyses of stable oxygen ($\delta^{18}O$) and stable carbon ($\delta^{13}C$) isotopes were conducted on caprine—sheep (*Ovis aries*) and goat (*Capra hircus*)—teeth from the Monjukli Depe faunal assemblage. Stable oxygen isotope values of tooth enamel can provide information on seasonal temperature changes: higher values being correlated with warmer temperatures in summer and lower values being associated with colder temperatures in winter. Moreover, oxygen isotopes reflect hydrological and climatic conditions that can vary spatially with altitude, latitude, and distance from the sea (Delgado Huertas et al. 1995; Fricke and O'Neil 1996; Tütken 2010). Carbon isotope ratios reflect forage composition with regard to C_3 and C_4 plants (Cerling and Harris 1999; Tieszen 1991; Zazzo et al. 2000). In combination, they can offer important insights into animal husbandry strategies.

We applied stable carbon and oxygen isotope analyses in order to examine whether seasonal herd movements played any role in this prehistoric society and to characterize the feeding practices of domestic herbivores. More specifically, the analysis aimed at identifying whether the composition of the diet of domesticated animals varied seasonally. If so, which dietary components prevailed in warmer periods and which in colder ones? Do sampled teeth show similar patterns, or are there differences that imply variation in feeding? Moreover, do the observed patterns relate to vertical or other types of horizontal herd movements, or might they imply a complex combination of both? This study is part of an ongoing multi-isotope investigation that examines food resources, animal husbandry, and mobility patterns of the dominant animal taxa—sheep/goat—at the site. The aim is to gain a better understanding of the codevelopment of humans and caprines as well as their interactions over the time of the settlement's occupation.

Archaeological Context

The site of Monjukli Depe is a small settlement located in the piedmont zone of the Kopet Dag on the eastern edges of the gravel fan of the Wadi Meana, close to the present-day Turkmen–Iranian border and just south of the Karakum Desert (Figure 1.3.1).

The ancient village lies approximately 8 km to the east of the Kopet Dag's foothills and is situated between two streams, Meana and Chacha. They emerge from the mountains and flow south–north. Today, both streams carry water only seasonally. However, palaeoenvironmental investigations that examined landscape changes from the Pleistocene until modern times suggest a denser and more diverse flora and fauna than that observed today (Berking et al. 2017; Berking and Beckers 2018). Archaeological research was undertaken by a team from the Free University of Berlin under the direction of S. Pollock and R. Bernbeck from 2010 to 2014 (Bernbeck et al. 2012; Bernbeck and Pollock 2016; Pollock and Bernbeck 2011; Pollock et al. 2013, 2018, 2019). This work was preceded by a stratigraphic sounding excavated by A. Marushchenko in 1959 and an exposure of the site's uppermost levels by Marushchenko and O. Berdiev in the early 1960s (Berdiev 1972, 1974). The goals of the ongoing research project include an examination of the site's stratigraphy and chronology, of technological changes within the further mentioned prehistoric periods in the

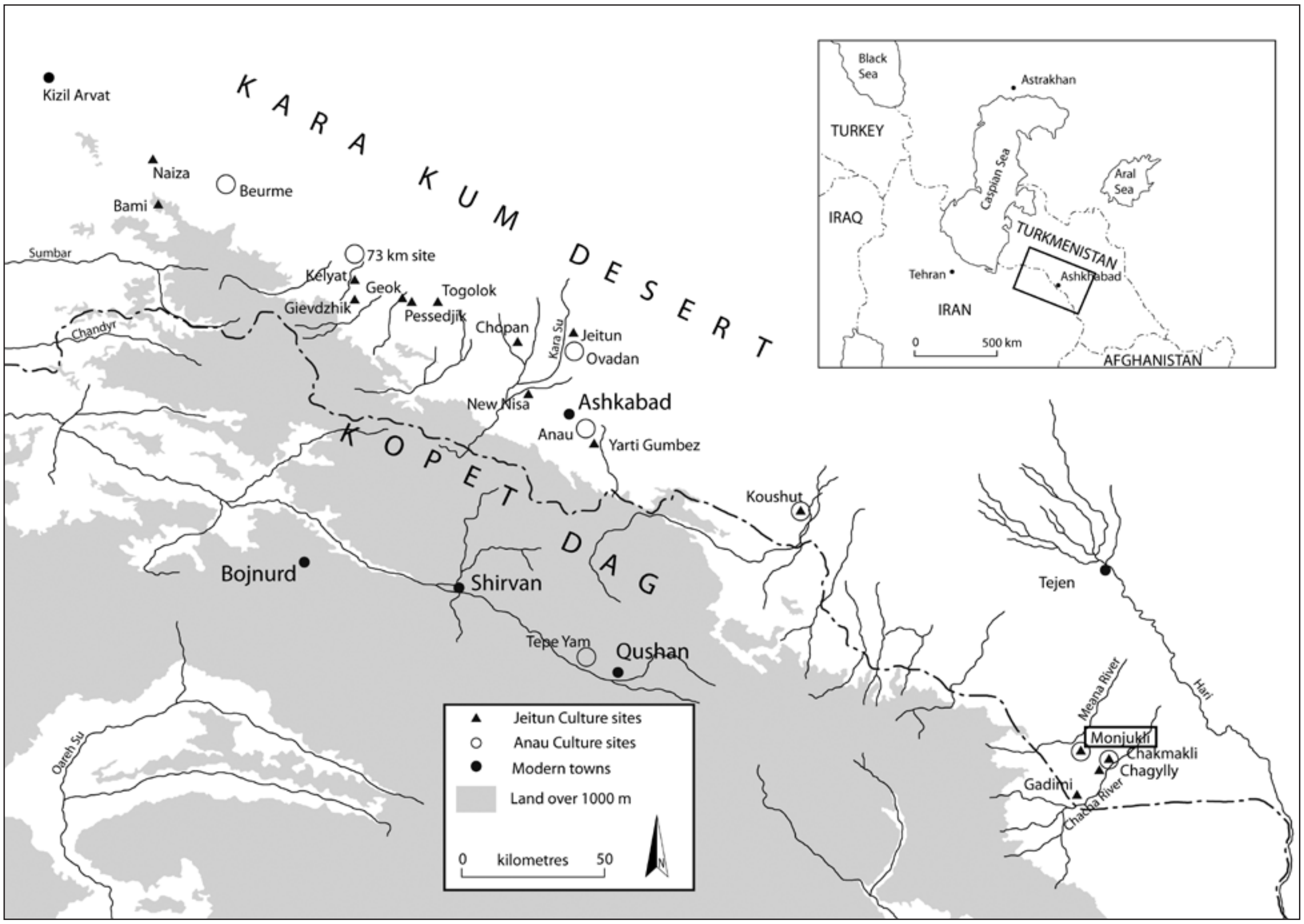

Figure 1.3.1. Monjukli Depe between the two rivers, Meana and Chacha, as well as other sites with Neolithic—Jeitun Culture—and Aeneolithic—Anau IA Culture—material. (Modified from Pollock and Bernbeck 2011:Figure 1.)

northeastern part of the Kopet Dag foothills, and of intrasettlement variability within the Aeneolithic village. Excavated levels date to the late Neolithic (ca. 6000–5650 BC) and early Aeneolithic period (ca. 4800–4350 BC). Contrary to the conclusions of the early research, the recent project has demonstrated that there was a lengthy hiatus of about 850 years between the Neolithic and earliest Aeneolithic levels at the site (Bernbeck and Pollock 2016; Heit 2019). The Aeneolithic levels are subdivided into four strata with Stratum I being the youngest and Stratum IV the oldest building level. The Aeneolithic occupation is characterized by well-preserved mud-brick architecture with walls still standing up to 1.5 m high (Bernbeck et al. 2012:15–16). The renewed excavations have produced a large sample of animal bones from undisturbed and well-stratified contexts. Most of the bones are in good condition. All primary and secondary contexts were dry-screened using 5 mm mesh. Samples from a large number of these contexts were also wet-screened, providing a reliable basis for quantitative evaluation (Pollock and Bernbeck 2011:175–176).

The study presented here is based on the zooarchaeological data recovered from the seasons 2010 to 2012 at Monjukli Depe; the bones were identified at the Department of Natural Sciences of the German Archaeological Institute in Berlin (Benecke 2011, 2018).

Domestic taxa are overwhelmingly predominant in the faunal remains collected at the site, pointing to animal husbandry as an important subsistence strategy in addition to the cultivation of plants (Miller 2011:219–221). This is the case both in Neolithic and Aeneolithic levels (Benecke 2011:209, Table 13). Nearly 96% of the identified Aeneolithic bones derive from domesticated animals (Table 1.3.1). Domestic caprines are the dominant taxa. Among the bones that could be attributed to genus, sheep outnumber goats based on criteria for postcranial skeletal elements (e.g., Zeder and Lapham 2010). Cattle is the second most common taxon with about 5.5% of the total bones. This is followed by dogs, which occur in very small proportions. Wild animals comprise only four percent of the bone collection, with onager and gazelle representing the most common hunted animals, closely followed by wild sheep. Fox is also attested, while other wild taxa occur only occasionally. The quantities of small animals are unexpectedly low, considering the extensive screening conducted.

The location of the site, the specific composition of the faunal assemblage, and an intensive discussion of the early importance of vertical seasonal movements by pastoral nomads in neighboring Iran contributed to the research questions formulated for this study.

Methods and Materials

Oxygen and Carbon Stable Isotopes

Oxygen and carbon are incorporated into the enamel during tooth development and can record seasonal fluctuations of the isotopic composition of these elements. Because enamel does not remodel after tooth formation and is rather resistant to diagenetic alteration, the isotopic information reflects the water and food consumption during the first years of an individual's life. This information differs in time, depending on which tooth is sampled and the range of its formation (Balasse et al. 2003; Cerling and Harris 1999; Makarewicz and Pederzani 2017; Zazzo et al. 2010). Sequential sampling—the extraction of enamel in multiple horizontal bands along the crown—is the standard method for obtaining the isotopic signals from high-crowned herbivore teeth (Balasse et al. 2002; Knipper 2011; Makarewicz 2017; Makarewicz and Pederzani 2017; Tornero et al. 2016). Plotting the resulting δ^{18}O and δ^{13}C values against the distance of each sample from the Enamel–Root Junction (ERJ) reveals relationships between the isotopic signals of both elements. The oxygen isotope composition in enamel bioapatite is linked to the water and food ingested throughout the time of tooth formation. During enamel mineralization, seasonal differences in rainwater/drinking water are transferred to the animal's tooth. They record temperature changes over the year, with the highest values occurring in the warmest and the lowest in the coldest season (Balasse et al. 2006; Fricke and O'Neil 1996; Henton et al. 2014; Knipper 2011; Sharp and Cerling 1998). Oxygen is incorporated into both the phosphate and the structural carbonate of teeth and bones' hydroxyapatite. Due to isotope fractionation in the body, δ^{18}O values in tooth enamel differ from those in water. However, since the fractionation of oxygen in body fluid takes place under constant temperature conditions in homeothermic animals, there is a direct correlation between isotopic ratios of drinking water and food and oxygen in the hydroxyapatite (Bryant et al. 1996; Knipper 2011:148–149).

Table 1.3.1. Faunal remains from Aeneolithic levels at Monjukli Depe as percentages of Number of Identified Specimens (NISP).

Taxa	**NISP**	**(%)**
Sheep/goat	11,009	87.7
Sheep (*Ovis aries*)	205	1.6
Goat (*Capra hircus*)	75	0.6
Cattle (*Bos taurus*)	688	5.5
Dog (*Canis familiaris*)	36	0.3
Total domestic animals	**12,013**	**95.6**
Onager (*Equus hemionus*)	109	0.9
Gazelle (*Gazella subgutturosa*)	72	0.6
Wild sheep (*Ovis orientalis*)	51	0.4
Fox (*Vulpes corsac*)	47	0.4
Other wild taxa	268	2.1
Total wild animals	**547**	**4.4**

Monthly average δ^{18}O values of precipitation in the region around Monjukli Depe can help to estimate expected oxygen isotope ratios in the animals' teeth; however, such data are generally scarce. Geographical work at Monjukli Depe and other prehistoric sites in southern Turkmenistan provides information on climatic conditions and annual rainfall (Berking et al. 2017; Berking and Becker 2018; Dolukhanov 1981). Accordingly, annual precipitation is around 230 mm and falls mostly in March and April. There is almost no rainfall in summer (Berking and Becker 2018:Table 1). The International Atomic Energy Agency (IAEA) holds a database of δ^{18}O values of precipitation at worldwide climate stations. However, none of them are located in Turk-

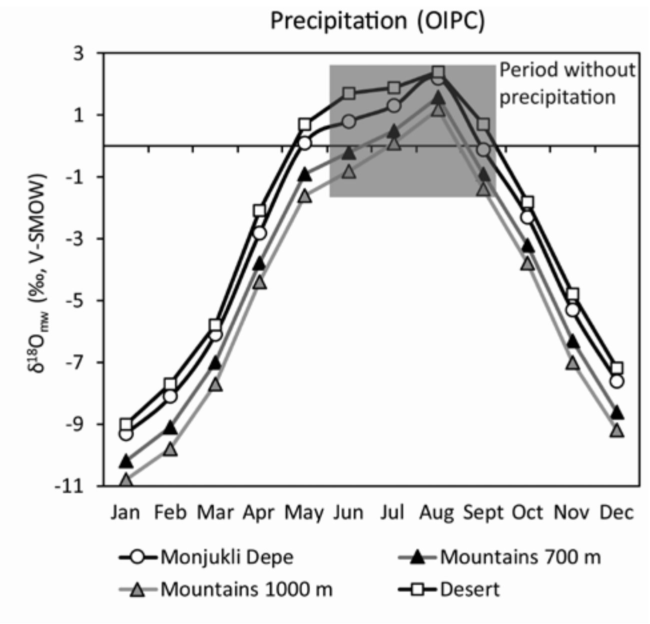

Figure 1.3.2. Modeled monthly average $\delta^{18}O$ values of precipitation at Monjukli Depe in comparison to the Kopet Dag (700 m and 1,000 m asl) and in the desert based on the Online Isotopes in Precipitation Calculator (OIPC).

menistan, and only few stations with available data, including those in Tehran (Iran), Astrakhan (Russia), Kabul (Afghanistan), and Tashkent (Uzbekistan), are found in the wider area (modern precipitation and hydrological data are accessible on the WISER portal of the IAEA homepage; see GNIP at https://www.iaea.org/services/networks/gnip and GNIR at https://www.iaea.org/services/networks/gnir). The Online Isotopes in Precipitation Calculator (OIPC) uses the IAEA data and general principles of spatial variation of oxygen isotope compositions to model yearly and monthly average $\delta^{18}O$ values at any place worldwide (Bowen and Revenaugh 2003; Bowen et al. 2005; Bowen 2018). Figure 1.3.2 illustrates the modeled seasonal variation of the oxygen isotope composition in precipitation at Monjukli Depe, in the Kopet Dag mountain range, and further into the Karakum Desert. These data provide an estimate of isotopic differences between winter and summer, and between Monjukli Depe, possible grazing areas in the uplands—arbitrary locations at 700 and 1,000 m asl, and others in the desert—Gulanly, a town in Oguzhan district in the Mary Region of Turkmenistan, was chosen as an example.

For all four locations, the model predicts seasonal variation of about 11–12‰ of $\delta^{18}O$ in meteoric water, with the lowest values in January and the highest in August. Practically, however, the area does not receive any precipitation between June and October. This suggests that the oxygen with highest $\delta^{18}O$ values returned by the model will most likely not have contributed to the oxygen isotope values recorded in the teeth. Instead, tooth data probably represent water present in food and in the drinking water that is attributable to precipitation that fell between autumn and spring, in addition to river and ground water.

Oxygen isotope ratios of precipitation are negatively correlated with elevation. Therefore, one would expect lower $\delta^{18}O$ values in the uplands compared to higher values around a lowland site such as Monjukli Depe. For our research area, we do not have any direct data to estimate whether $\delta^{18}O$ values in teeth could distinguish upland and lowland herding. The modeled seasonal curves of the isotopic composition of rainwater suggest that spatial variation is small in comparison to seasonal variation (see Figure 1.3.2). Moreover, rivers and shallow groundwater originating in the mountains are important water sources to supply animal herds in the lowlands (Berking et al. 2017:12). Taking into account the scarcity of data, inter-annual variation, and uncertainty about climate shifts between the Aeneolithic and today, we would expect relatively lower $\delta^{18}O$ values in the mountains than in the lowlands, but we do not have good enough background data to specify the expected differences reliably.

Carbon isotope ratios ($\delta^{13}C$) are determined in the same measurement as the $\delta^{18}O$ values. The isotopic composition of carbon in enamel carbonate depends on the plants consumed (Ambrose and Norr 1993; Balasse et al. 2002). Due to different fractionation rates in the photosynthetic pathway, C_3 and C_4 plants demonstrate differences in carbon isotope ratios. Modern C_3 plants have $\delta^{13}C$ values between about -35‰ and -22‰ (Cerling et al. 1997). Due to the fossil fuel effect in modern plants, $\delta^{13}C$ values of plants that grew during preindustrial times were about 1.4‰ higher and average around -25.6‰ (Balasse et al. 2006; Cerling and Harris 1999). In contrast, the mean carbon isotope ratio of C_4 plants is higher, with $\delta^{13}C$ values around -13.1 ± 1.2‰ (Bocherens et al. 2006). Originating from diet, carbon is incorporated into animals' teeth during enamel mineralization. Its isotopic composition provides information on the proportions of the consumed C_3 and C_4 plants. Due to isotope fractionation, $\delta^{13}C$ values in enamel apatite are 14.1‰ higher than those in the diet (Ambrose and Norr 1993; Cerling and Harris 1999). Thus, pure C_3 plant consumption should lead to average $\delta^{13}C$ values of -11.5‰ in enamel bioapatite of preindustrial large ruminants (Balasse et al. 2006:172), while $\delta^{13}C$ values of about 1 ± 1.2‰ can be expected for animals exclusively feeding on a C_4-based diet. Generally, enamel $\delta^{13}C$ values of above -8‰ indicate significant portions of C_4 plants in the consumed fodder. Both plant groups occur in southern Turkmenistan (Bocherens et al. 2006:254; Winter 1981). Archaeobotanical data from Monjukli Depe point to a predominance of C_3 plants, which also prevail in the mountains. In contrast, in the Karakum lowlands, proportions of C_4 plants were higher than at the settlement or in the mountains (Toderich et al. 2007). Therefore, variation of the $\delta^{13}C$ values in the sampled teeth can indicate grazing on different pastures. Animals permanently kept at the site or moved to the mountains likely received predominantly C_3 plant fodder. In contrast, constantly or periodically higher $\delta^{13}C$ values may point to animals that originated from the steppe or were seasonally pastured there. Combining carbon isotope and oxygen isotope data from the same samples links dietary and seasonal information. In other words, it indicates whether the same or different sources of food or grazing localities were used in different times of the year.

Sample Selection, Preparation, and Analysis

This study focuses on eleven mandibular cheek teeth—third molars—from adult sheep (N = 6) and goats (N = 5, Table 1.3.2). Distinction between sheep and goat third molars for this analysis was attempted based on criteria summarized by Zeder and Pilaar (2010), and the outcome is shown in Table 1.3.2. However, such identifications are fraught with uncertainty and, as the authors themselves point out, lack accuracy (Zeder and Pilaar 2010:241–242). Given the limitations of the method, we consider our sheep or goat identifications as tentative.

To avoid multiple sampling of the same individuals, only third molars from lower left jaws were selected for analysis. Third molars were chosen because they record a comparatively long time of enamel formation. Sheep third molars are formed between the end of the first year and the end of the second (Zazzo et al. 2010:3574). The sample selection also depended on the availability of suitable teeth in the exported faunal remains. The teeth represent all four Aeneolithic levels and different functional contexts inside and outside buildings, such as deposits above surfaces, room fill, and ashy layers.

Sample preparation took place at the Curt-Engelhorn–Center Archaeometry (Mannheim, Germany). The enamel surface of each tooth was mechanically cleaned by removing all cementum using a dental drill. Six to nine samples, placed parallel to each other between the occlusal surface and the root, were milled out from the buccal side of each tooth using a diamond drill bit. Midpoints of all sampling positions were recorded to a tenth of a millimeter using digital calipers. The isotopic composition of the enamel was determined without any chemical pretreatment. We decided for this procedure because comparisons of different pretreatment methods reported different degrees of alteration of the isotopic composition, also in modern enamel (Balasse et al. 2012; Pellegrini and Snoeck 2016). Balasse and colleagues (2012) found that modern enamel that was pretreated with sodium hypochlorite and acetic acid yielded around 1‰ higher $\delta^{18}O$ values than enamel that did not receive any pretreatment. Pelegrini and Snoeck (2016) confirmed a similar increase of $\delta^{18}O$ values of archaeological and modern enamel due to pretreatment with 0.1 M or 1 M acetic acid and reported unsystematic differences for different ways of organic removal or both. Differences of $\delta^{13}C$ values due to pretreatment with acetic acid were well below 1‰ for modern and archaeological enamel, while organic removal with sodium hypochlorite resulted in an increase of up to about 1.5‰. Since enamel is generally very resistant to post-burial alterations (Budd et al. 2000) and the teeth selected in this study were particularly well preserved, at least macroscopically, we favored the avoidance of any artificial alteration of the isotopic signals over a remaining risk of partial diagenetic overprint. From each sample, 800 to 850 µg of enamel powder were weighed into borosilicate Exetainer® vials, which were closed with silicone rubber septa. After flushing with helium, the samples were reacted with concentrated phosphoric acid for 2 h at 70°C. The isotope composition of the resulting CO_2 was measured using a GasBench II coupled to an isotope ratio mass spectrometer (Thermo Finnigan™ MAT 253) at the Department of Applied and Analytical Palaeontology, Institute of Geosciences of the University of Mainz, Germany. Carbonate contents of the enamel samples were extrapolated from signal

Table 1.3.2. Stable carbon ($\delta^{13}C$) and oxygen ($\delta^{18}O$) isotope ratios for sheep/goat teeth from Monjukli Depe. M3 = third mandibular molar. ERJ = enamel-root junction. Mean values are arithmetic averages of all values measured in a tooth with one standard deviation of all measured values of a tooth. Δ = difference between highest and lowest value in a tooth. V–PDB stands for Vienna–Pee Dee Belemnite standard.

ID	Stratum	Context	Tooth	ERJ (mm)	$\delta^{13}C$ (‰ V–PDB)	$\delta^{18}O$ (‰ V–PDB)	Mean $\delta^{13}C$	Δ $\delta^{13}C$	Mean $\delta^{18}O$	Δ $\delta^{18}O$
MD–1	I–II	Eastern Midden* (outside area)	M3 (Sheep)	6.1	-9.79	-5.28	-7.6 ± 1.2	3.28	-5.1 ± 2.1	6.56
				10.9	-6.56	-8.90				
				14.4	-6.82	-6.40				
				18.2	-6.51	-4.95				
				23.5	-7.53	-3.47				
				27.6	-8.56	-2.34				
				32.5	-8.38	-3.28				
				36.8	-6.75	-6.25				
MD–2	I–II	Eastern Midden (outside area)	M3 (Sheep)	5.1	-10.07	-5.28	-9.5 ± 0.3	0.97	-5.7 ± 1.7	4.30
				10.9	-9.60	-7.83				
				15.8	-9.19	-6.75				
				19.4	-9.10	-5.35				
				22.9	-9.27	-3.73				
				31.5	-9.48	-3.53				
				40.9	-9.52	-7.36				
MD–4	I–II	Eastern Midden (outside area)	M3 (Sheep)	2.6	-8.63	-7.24	-8.8 ± 0.2	0.39	-4.6 ± 1.9	5.38
				5.0	-9.02	-5.01				
				7.4	-8.83	-3.53				
				10.5	-8.71	-1.86				
				14.2	-8.68	-4.32				
				16.8	-8.63	-5.81				
MD–5	I	Ash layer (Building 1)	M3 (Goat)	4.4	-8.15	-4.60	-8.0 ± 0.8	2.30	-5.0 ± 1.8	5.06
				8.2	-8.15	-1.85				
				12.1	-9.27	-3.17				
				15.8	-8.02	-5.92				
				19.3	-6.97	-6.84				
				22.4	-7.05	-6.91				
				25.9	-7.37	-5.28				
				29.5	-8.67	-5.54				
MD–6	I	Room fill (Building 11)	M3 (Goat)	3.3	-7.78	-5.57	-7.3 ± 0.5	1.21	-4.6 ± 1.7	4.84
				5.8	-6.89	-7.08				
				10.1	-6.93	-5.27				
				12.5	-6.73	-3.67				
				15.0	-7.79	-2.24				
				17.7	-7.93	-3.82				

*The "Eastern Midden" is a large outside space that was filled with ash, animal bones, and other waste materials, and could be closed off from the center of the settlement by a gate. The settlement's residents most likely used it collectively, probably in order to deposit the remains of large-scale feasts (Eger 2019).

Table 1.3.2. (cont.) Stable carbon (δ^{13}C) and oxygen (δ^{18}O) isotope ratios for sheep/goat teeth from Monjukli Depe.

ID	Stratum	Context	Tooth	ERJ (mm)	δ^{13}C (‰ V–PDB)	δ^{18}O (‰ V–PDB)	Mean δ^{13}C	Δ δ^{13}C	Mean δ^{18}O	Δ δ^{18}O
MD–8	II	Room fill (Building 3)	M3 (Sheep)	4.5	-8.09	-6.03	-5.9 ± 1.3	3.33	-6.8 ± 1.6	4.01
				9.7	-5.32	-8.54				
MD–8	II			12.4	-5.08	-8.43				
				14.8	-4.76	-7.65				
				17.7	-5.58	-5.60				
				20.8	-6.83	-4.53				
MD–10	II	Room fill (Building 3)	M3 (Sheep)	5.6	-6.15	-7.72	-5.8 ± 0.7	1.86	-7.5 ± 1.4	4.43
				9.3	-6.38	-7.71				
				11.7	-5.26	-6.40				
				17.8	-7.01	-4.91				
				21.4	-5.98	-6.17				
				24.3	-5.16	-7.96				
				27.5	-5.61	-8.69				
				31.3	-6.05	-9.34				
				34.8	-4.74	-8.88				
MD–11	II	Room fill (Building 3)	M3 (Goat)	4.4	-7.41	-5.73	-6.1 ± 0.8	2.25	-6.3 ± 2.6	6.95
				6.7	-7.11	-7.63				
				9.8	-5.25	-8.77				
				13.4	-5.82	-9.31				
				17.7	-5.62	-8.77				
				20.9	-5.16	-6.98				
				24.3	-6.08	-3.24				
				27.7	-6.20	-3.66				
				32.1	-6.66	-2.36				
MD–12	IV	Deposit above surface (Building 3)	M3 (Goat)	5.7	-9.56	-8.48	-9.2 ± 0.4	1.35	-7.7 ± 1.5	3.98
				8.6	-9.16	-8.60				
				11.6	-9.23	-7.27				
				15.7	-9.36	-5.26				
				19.8	-10.11	-5.66				
				23.4	-8.76	-8.03				
				27.4	-8.90	-9.25				
				31.6	-8.86	-9.24				
MD–13	IV	Room fill (Building 14)	M3 (Goat)	3.5	-6.34	-0.67	-6.2 ± 1.3	3.24	-1.8 ± 4.5	10.96
				6.9	-7.01	2.43				
				9.3	-7.26	2.45				
				12.0	-7.30	-0.52				
				15.8	-5.12	-5.85				
				18.3	-4.06	-8.51				

Table 1.3.2. (cont.) Stable carbon (δ^{13}C) and oxygen (δ^{18}O) isotope ratios for sheep/goat teeth from Monjukli Depe.

ID	Stratum	Context	Tooth	ERJ (mm)	δ^{13}C (‰ V–PDB)	δ^{18}O (‰ V–PDB)	Mean δ^{13}C	Δ δ^{13}C	Mean δ^{18}O	Δ δ^{18}O
MD–25	III	Room fill (Building 9)	M3 (Sheep)	4.1	-7.99	-5.41	-8.5 ± 0.3	0.79	-5.7 ± 2.1	5.94
				6.0	-8.53	-2.77				
MD–25	III			8.7	-8.57	-4.25				
				11.4	-8.78	-6.16				
				14.2	-8.59	-7.13				
				16.7	-8.77	-8.71				

intensities of the internal IVA–Carrara marble standard (100% $CaCO_3$). The average values of the teeth varied between 5.6 ± 0.4% and 6.9 ± 0.4% (average: 6.1 ± 0.4%), falling into the upper range of values reported for modern enamel (Sydney-Zax et al. 1991; Zazzo et al. 2005), but they might be to some extent affected by the uncertainty of the extrapolation method. Signal heights of the enamel samples were in all cases within the range of those of the $CaCO_3$ standards included in each run. The isotopic raw data were corrected against the internal IVA–Carrara marble standard with δ^{18}O = -1.91‰ V–PDB and δ^{13}C = 2.01‰ V–PDB. Each run included twelve internal standards of three times each 45, 65, 90 and 120 ± 5 µg. The average internal precision (1 SD) was 0.03 for both isotope ratios (N = 36). Two to three samples of NBS–19 (NBS stands for the National Bureau of Standards), which is a calcium carbonate from a marble of unidentified origin with values of δ^{18}O = -2.20‰ and δ^{13}C = 1.95‰, were included in each run for quality check. They yielded average values of -2.19 ± 0.03‰ (N = 7) for δ^{18}O and 1.94 ± 0.02‰ (N = 7) for δ^{13}C. Results are expressed as per mill (‰) relative to the Vienna–Pee Dee belemnite standard (V–PDB).

Results

Oxygen and Carbon Isotope Ratios

The results of the stable carbon and oxygen isotope measurements are presented in Table 1.3.2. The δ^{13}C values varied between -10.11‰ and -4.06‰, while δ^{18}O values ranged from -9.34‰ to 2.45‰. Plotting the carbon and oxygen isotope values in relation to the distance of the samples from the Enamel–Root Junction (ERJ) illustrates changes of the isotope signals along the tooth crowns and differences or similarities between teeth (Figure 1.3.3). Patterns in the data are visually clearer when only the carbon isotope values of each tooth were plotted against the distance from the ERJ (Figure 1.3.4A–B), or in scatter plots of δ^{13}C against δ^{18}O values from the same samples (Figure 1.3.4C–D).

With regard to the carbon isotope ratios, two groups became apparent. In four teeth (MD–2, MD–4, MD–12, and MD–25; three sheep, one goat) the δ^{13}C values were consistently below -8.0‰, the threshold for considerable C_4 plant contribution. Their mean δ^{13}C values varied between -9.5 ± 0.3‰ (MD–2) and -8.5 ± 0.3‰ (MD–25) with δ^{13}C ranges (differences between highest and lowest values) of the intratooth variation between 0.39‰ (MD–4) and 1.35‰ (MD–12). The best example was individual MD–2, whose δ^{18}O profile confirms homogeneous δ^{13}C values throughout a whole year (Figure 1.3.3). The δ^{18}O values of the teeth from group 1 ranged from -9.24‰ to -1.86‰, with amplitudes of variation between 3.98‰ (MD–12) and 5.94‰ (MD–25) and mean δ^{18}O of values from -7.7 ± 1.5‰ to -4.6 ± 1.9‰.

The remaining seven teeth (MD–1, MD–5, MD–6, MD–8, MD–10, MD–11, and MD–13; three sheep, four goats) were assigned to a second group. This assignment is based on the δ^{13}C values being completely (MD–6, MD–10, MD–11, and MD–13) or partially (MD–1, MD–5, and MD–8) above -8.0‰. The δ^{13}C values of these teeth varied considerably along the crowns forming sinusoidal curves. Their δ^{13}C values ranged from -9.79‰ to -4.06‰, with amplitudes of intratooth variation from 1.21‰ to 3.32‰, and mean δ^{13}C values ranging from -8.0 ± 0.8‰ to

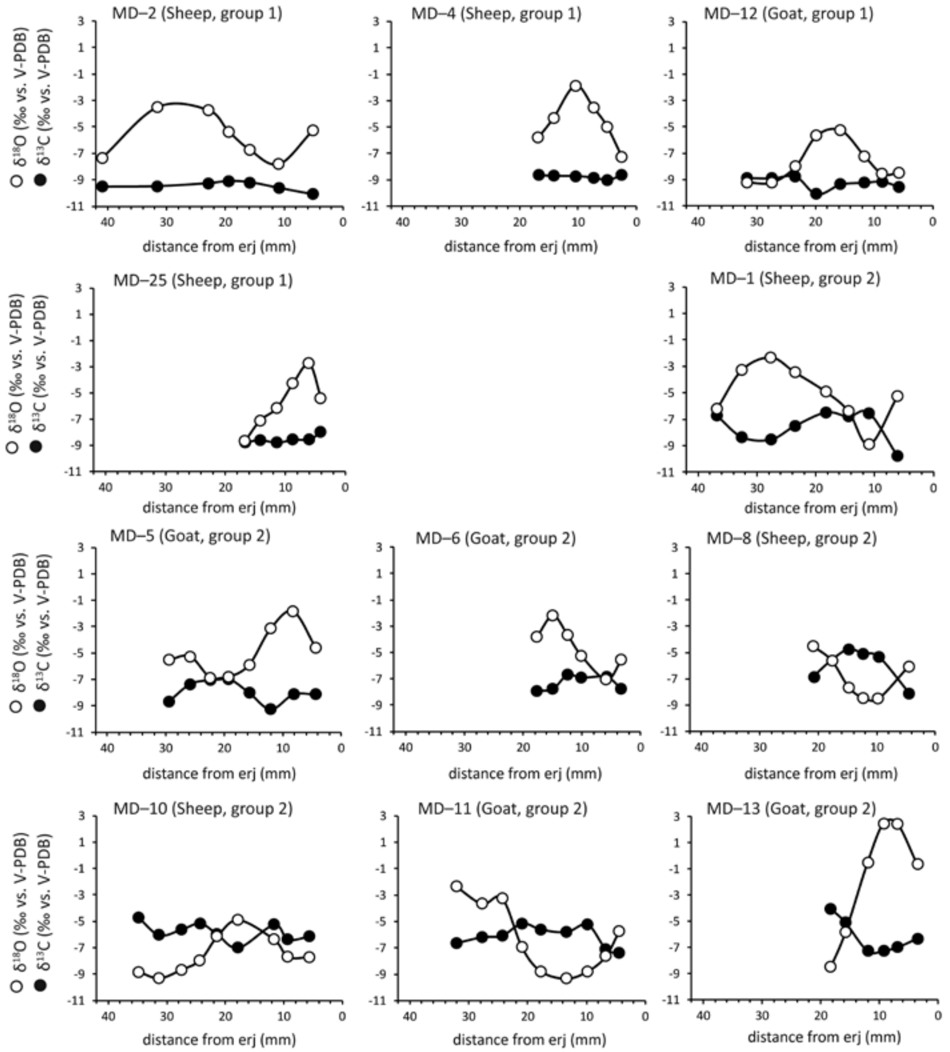

Figure 1.3.3. Intratooth variation of carbon (δ^{13}C, black circles) and oxygen (δ18O, white circles) isotope ratios of tooth enamel bioapatite from sequentially sampled third molars of sheep/goat from Monjukli Depe. ERJ = Enamel-Root Junction. The graphs for each sheep/goat individual are arranged according to similarity in patterns of carbon and/or oxygen values. Division into groups is based on the criterion of δ^{13}C values being below or above -8‰.

-5.8 ± 0.7‰. The δ^{18}O values of the teeth from group 2 ranged from -9.34‰ to 2.45‰, with amplitudes of intratooth variation between 4.01‰ and 10.96‰. The mean δ^{18}O values varied from -7.5 ± 1.4‰ to -1.8 ± 4.5‰. Within individual teeth, high δ^{13}C values coincided with low δ^{18}O values (Figure 1.3.4 D). Correlation coefficients (*r*) of δ^{13}C and δ^{18}O data ranged between -0.40‰ (MD–11) and -9.53‰ (MD–13). For individual MD–13 the negative correlation was statistically significant, and MD–5 revealed a tendency toward a negative relation (Pearson correlation MD–13: $p = 0.003$, N = 6; MD–5: $p = 0.083$, N = 8).

A scatter plot of the averages and standard deviations of the δ^{18}O and δ^{13}C values from each sequentially sampled tooth highlights the differences in carbon and the similarity in oxygen isotope data among individuals (Figure 1.3.5). A One-Way Analysis of Variance (ANOVA) identified statistically significant differences between the mean δ^{13}C values of the eleven molars (F [10, 69] = 17.80, $p = < 0.001$). Pairwise multiple comparisons (Holm-Sidak method) emphasized the differentiation of data groups suggested above. The δ^{13}C values of teeth from group 1 (low and homogeneous δ^{13}C values; MD–2, MD–4, MD–12, and MD–25; white symbols in Figures 1.3.4 and 1.3.5) did not reveal any statistically significant differences when tested against each other. Teeth from group 2 can be differentiated further, as indicated by black symbols (subgroup 2a: MD–8, MD–10, MD–11, and MD–13) and grey symbols (subgroup 2b: MD–1, MD–5, and MD–6) in Figures 1.3.4 and 1.3.5. Within these groups, differences are statistically insignificant, whereas the differences between each pair of teeth from group 1 and from subgroup 2a were highly significant, with $p < 0.001$ for each pair. Seven pairwise comparisons between

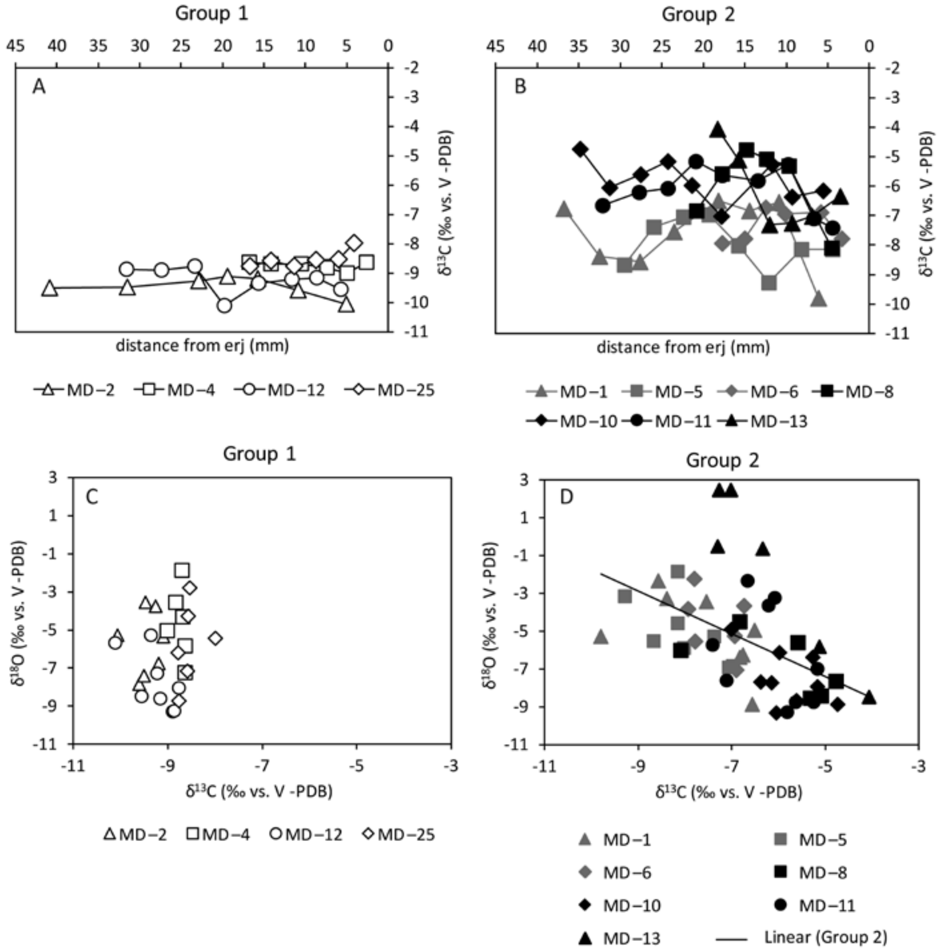

Figure 1.3.4. Plot of $\delta^{13}C$ values against the distance of Enamel-Root Junction (ERJ; top) as well as plot of $\delta^{13}C$ values against $\delta^{18}O$ values (bottom) of eleven third molars from sheep/goat. Left (A + C): Group 1 with homogenous $\delta^{13}C$ ratios of consistently < -8‰—white symbols; right (B + D): Group 2 with variable $\delta^{13}C$ values continuously > -8‰—black symbols—or partially > -8‰—grey symbols. For group 2, the $\delta^{13}C$ and $\delta^{18}O$ values are negatively correlated with each other.

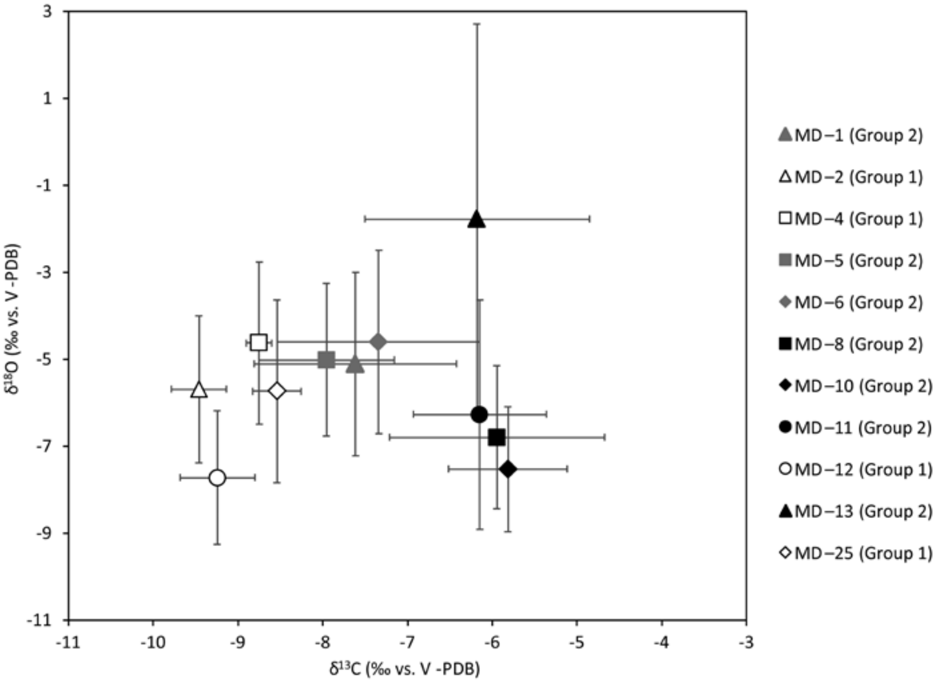

Figure 1.3.5. Mean isotopic composition of enamel structural carbonate from the sampled sheep/goat individuals. The mean $\delta^{13}C$ and $\delta^{18}O$ values were calculated for all samples of each mandibular molar, and bars indicate one standard deviation.

the $\delta^{13}C$ values of subgroup 2a and 2b were statistically significant (p between 0.05 and 0.001), while the difference between MD–10 and MD–5 was highly significant ($p < 0.001$). The differences between the teeth from subgroup 2b and group 1 were significant for four of the pairwise comparisons.

These differences in the carbon isotope ratios among individuals are not, however, reflected as clear differences in the oxygen isotope ratios. In fact, the $\delta^{18}O$ ranges overlap extensively with the representatives of both groups. Most noteworthy was, however, MD–13 with a difference between lowest and highest $\delta^{18}O$ values of 10.96‰, which is more than twice as large as the amplitudes for MD–6, MD–8, and MD–10. The ANOVA analysis identified, in general, significant differences between teeth (F [10, 69] = 3.93, p = < 0.001). However, the Holm-Sidak method revealed that MD–13 was responsible for this result as it was significantly different from MD–12 (p = < 0.001), MD–10 (p = < 0.001), MD–8 (p = 0.008), and MD–11 (p = 0.011). The mean $\delta^{18}O$ values between all other tooth pairs were not significantly different. Both patterns, homogeneous $\delta^{13}C$ values (group 1) and $\delta^{13}C$ values that are inversely related to the $\delta^{18}O$ values (group 2) are found in all four Aeneolithic strata of Monjukli Depe without any chronological shifts (Table 1.3.2). Taking our differentiation between sheep and goat, there are tentative differences between the two taxa. As with any samples subdivided by groups, strata, or context, limitations exist and, in this case, differences may be due to the low number of specimens in each group. Whereas group 1 includes three sheep and one goat, there are three sheep and four goats in group 2. Thus, the proportion of goats appears higher in the second group.

Discussion

The analytical results of the sheep and goat teeth from the Monjukli Depe samples demonstrate either similarity, group 1, or systematic variation of the carbon isotope ratios throughout the year, group 2 (Figures 1.3.3–1.3.5). Applying the enamel–diet enrichment factor (+14.1‰), the $\delta^{13}C$ values measured in the teeth from group 1 reflect a diet with $\delta^{13}C$ values ranging between about -22.0‰ and -24.0‰. Considering also the fossil fuel effect (Balasse et al. 2006; Cerling and Harris 1999), this converts into values between about -23.4‰ and -25.4‰ falling into the upper ranges of $\delta^{13}C$ values of modern C_3 plants in dry areas (Hartman and Danin 2010; Kohn 2010). The data therefore point to a predominance of grazing on C_3 plants with possibly minor contributions of C_4 plants and very little variation over the year. Archaeobotanical evidence attests to a prevalence of C_3 plants among the natural and cultivated vegetation at Monjukli Depe. We can therefore expect that animals that consumed fodder from habitats near the site or agricultural byproducts and waste would present $\delta^{13}C$ values typical of a C_3-plant-diet. In fact, a large volume of crops and crop processing debris deriving from dung was found among plant macroremains from Monjukli Depe, including six-row barley, glume, and bread wheat (Masoumeh Kimiaie, personal communication 2016). Thus, the presence of some parts of the herds at or near the village, where they could be grazing in the same habitat throughout the year, is a plausible explanation for group 1, which has constantly low carbon isotope ratios. These animals may represent a local component of the pastoral system, although movements between areas with similar environmental conditions—that is, a predominance of C_3 plants—cannot be excluded.

The results from group 2 indicate a different forage composition, for parts of the year at least. While the lowest carbon isotope values of group 2 are similar to those of group 1, and thus suggest mainly C_3 plants, the highest $\delta^{13}C$ values convert to $\delta^{13}C$ values of around -18.1‰ in the past and up to -19.5‰ in modern vegetation. This exceeds the isotopic ranges of C_3 plants, even in dry environments (Hartman and Danin 2010; Kohn 2010). With differences between the lowest and the highest values of up to 3.3‰, the internal variation of the $\delta^{13}C$ values of most teeth from group 2 is also more than twice as large as of those from group 1. Analyses of modern C_3 vegetation revealed seasonal variations of approximately 1–2‰ between samples from the wet and the dry season (Hartmann and Danin 2010; Smedley et al. 1991; Tornero et al. 2016). Since the amplitudes of most $\delta^{13}C$ curves of group 2 exceed this variation and either some or all values along the teeth are beyond the typical spectrum for C_3 plants, the seasonal variation seen in that group cannot be solely due to the natural variation of the $\delta^{13}C$ values of C_3 plants caused by water. Presuming similar carbon concentrations of C_3 and C_4 plant forage, we estimate maximal contributions of 45% to 60% of C_4

plants during enamel formation in the warmer periods.[1]

To evaluate these results regarding animal husbandry and seasonal mobility, archaeological and archaeobotanical evidence as well as current knowledge of the environmental conditions need to be taken into account. A possible explanation is that C_4 plants were indeed available in the vicinity of the site, even though direct evidence is scarce in the botanical record. Most cultivated and wild plant species identified in archaeobotanical samples from Monjukli Depe are C_3 plants, such as wheat and barley (Miller 2011; Ryan 2011). There are also some species with representatives in both systems, such as Poaceae, Brassicaceae, Chenopodiaceae, Boraginaceae, and Asteraceae (Masoumeh Kimiaie, personal communication 2017). However, their identification is at the family level and therefore does not convincingly indicate the presence of C_4 plants near the site. In phytolith samples wild Pooid and Panicoid grasses, including *Setaria* sp. and *Aegilops* sp., are documented, as are cones from sedges (Ryan 2010, 2011:225). C_4 plants are usually active during times of hot weather and several species of Chenopodiaceae flower at the end of the dry season (Batanouny 2001:97). Therefore, higher $\delta^{13}C$ values would be expected to coincide with high $\delta^{18}O$ values that represent the warmer periods (Tornero et al. 2016:31–33). However, $\delta^{13}C$ values of the teeth from group 2 vary in the opposite way: the lowest carbon isotope values are associated with the highest oxygen isotope ratios, suggesting a predominantly C_3-based diet during warmer seasons. Conversely, the highest carbon isotope ratios appear with the lowest oxygen isotope values, indicating significant inclusions of C_4 plant food in sheep and goat diet in colder periods of the year. A possible explanation of this pattern by feeding the animals on local resources is stockpiling growth rich in C_4 plants during the summer and providing it to the animals in winter (Makarewicz and Pederzani 2017; Makarewicz and Tuross 2006). These must have been wild and weedy species as there are neither indications for cultivated C_4 plants in Monjukli Depe nor did C_4 crops, such as millet, reach Central Asia before the third millennium BC (Herrscher et al. 2018; Miller et al. 2016). Therefore, stockpiling of agricultural byproducts and waste from C_4 crop plants is rather unlikely. Instead, fodder might have been collected during the peak of abundance of C_4 plants. As a result, the $\delta^{13}C$ values associated with enamel formation in winter became higher than those associated with enamel formation in summer when C_4 plants should have been naturally available. If the inhabitants of Monjukli Depe collected C_4 plants in the warm season as winter fodder, it raises the question as to why only some animals of the herd were provisioned with such food, whereas others (group 1) received forage of primarily C_3 plants year round. Possible explanations of the different feeding strategies include variation among different herders or households and dissimilarities between individual years.

An alternative set of explanations for the fluctuating $\delta^{13}C$ values of the teeth from group 2 involves mobility. One of these options is that parts of the herd were seasonally moved into the uplands. In such a case, the mixture of C_3 and C_4 plants would represent the forage from near the settlement and used in winter, while the lower summer values would represent mountain pastures with only a minor contribution of C_4 plants. Since the volume of C_4 plants reduces with altitude, lower $\delta^{13}C$ values should correlate with higher $\delta^{18}O$ values, if the animals were herded in the uplands during summer (Bocherens et al. 2001:72–73). Based on their expected variation with altitude, we explored the oxygen isotope data for information supporting or rejecting the possible use of upland pastures. The averages, amplitudes, and also minima and maxima of the $\delta^{18}O$ curves of the potentially mobile animals from group 2 were very similar to those of group 1, being likely animals kept relatively stationary, and were unrelated to the differences in the carbon isotope compositions (Figures 1.3.2 and 1.3.4). Especially the similarity of the maximum $\delta^{18}O$ values of both groups does not support the use of upland pastures in summer because this practice should have caused lower $\delta^{18}O$ values in the animals from group 2. The only exception from the overall similarity is individual MD–13. However, the very high $\delta^{18}O$ summer maximum of its tooth contradicts the expectations for the use of mountain pastures in summer.

Converting the $\delta^{18}O$ data of enamel carbonate into oxygen isotope compositions of the drinking

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[1] This estimation uses the following parameters: average $\delta^{13}C$ values of C_3 plants: -25.6‰, average $\delta^{13}C$ values of C_4 plants: -13.1‰, $\delta^{13}C$ increase between plants and enamel: 14.1‰, maximal $\delta^{13}C$ values in enamel of group 2: -6.0‰ to -4.0‰. Linear regression: y = 8x + 92 (x = $\delta^{13}C$ enamel; y = C_4 contribution in %).

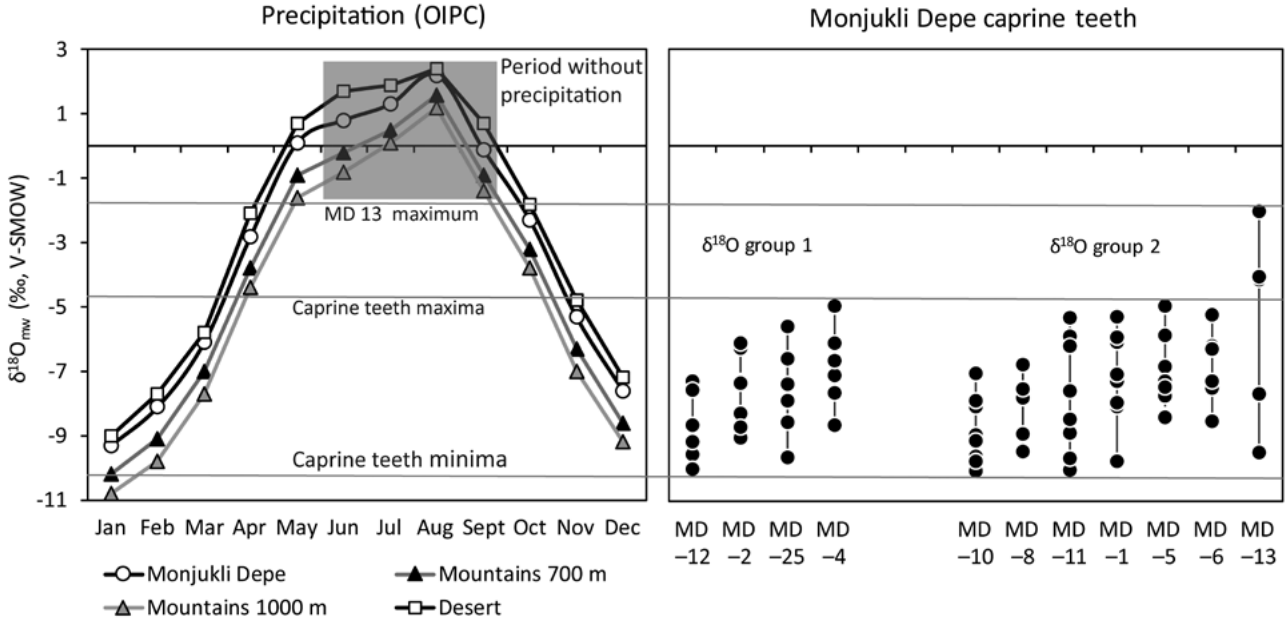

Figure 1.3.6. Left: Modeled monthly average $\delta^{18}O$ values of precipitation at Monjukli Depe in comparison to the Kopet Dag (700 m and 1,000 m asl) and in the desert based on the Online Isotopes in Precipitation Calculator (OIPC). Right: Oxygen isotope ratios of the sheep/goat teeth from Monjukli Depe converted into $\delta^{18}O$ values of the ingested water. MD = Monjukli Depe, sample identification no.: e.g., MD–1, MD–2, etc.

water fits well with the modeled oxygen isotope composition of precipitation falling in winter and spring as modeled using OIPC (Figure 1.3.6).[2] A differentiation between upland and lowland pastures is, however, not straightforward in this case. All teeth have considerably lower maximal $\delta^{18}O$ values than the modeled summer precipitation in both the mountains and the lowlands. This agrees with the expectations, since although the models produce $\delta^{18}O$ values for precipitation in the area, there is no significant rainfall in summer that could contribute substantially to the drinking water of the animals. Instead, the maximum values fit generally to the modeled $\delta^{18}O$ values of modern precipitation in spring, while the minimum values are in accordance with winter precipitation. However, neither the modeled precipitation data nor the converted enamel data are precise enough to differentiate reliably among upland and lowland pastures. Besides the lack of direct data from near the site, the fluctuation of precipitation values from one month to the next in the same landscape often exceeds the variation between landscapes and blurs spatial diversity. Moreover, the conversion from enamel carbonate to water values involves high uncertainty, and water that originates from the mountains feeds rivers and groundwater reservoirs in the lowlands. Therefore, the $\delta^{18}O$ data do not clearly support upland pasturing of the animals from group 2 during the summer, but low data resolution does not exclude it either.

The assumption that a predominance of C_3 plants indicates upland pastures and a mix of C_3 and C_4 forage was typically fed in the lowlands also has consequences for the interpretation of the animals from group 1. Their constant and low $\delta^{13}C$ values would then imply feeding on mountain pastures year round. This seems, however, unlikely because it would have required permanent settlements in the mountains for which there is so far no archaeological evidence. In winter, the mountains are even colder and more uninviting than the plains with subzero temperatures and snow cover on the plateaus. Moreover, such a scenario would imply movement of the animals into the lowlands at Monjukli Depe only for culling or even just transporting the carcasses to the site.

Another explanation for the higher $\delta^{13}C$ values in winter than in summer is moving out into the

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[2] Conversion steps: V–PDB standard to V–SMOW standard (Standard Mean Ocean Water); $\delta^{18}O$carbonate (V–SMOW) to $\delta^{18}O$phosphate ($\delta^{18}O$phosphate = 0.98 * $\delta^{18}O$carbonate - 8.5); $\delta^{18}O$phosphate to $\delta^{18}O$drinking water ($\delta^{18}O$drinking water = ($\delta^{18}O$phosphate - 27.21) / 1.48) equation for sheep/goat (Henton et al. 2010).

steppe or desert portions of the landscape in the colder months. While vegetation is overall sparse during the dry summers in this landscape, enhanced plant growth can be expected with winter and spring precipitation. At such times, seasonal mobility would be possible, and forage consumed from there may have included more C_4 plants than potentially available near the site. A possible reason to move herds further away from the village would be to keep crops from being eaten by the animals. The danger to crops is not so much to be expected in the colder months, as the cold season is unlikely to have been the growing season for barley and wheat. However, barley may have been a winter crop, which was sown in fall and harvested between May and July, thus requiring protection of fields in winter. This could have been achieved by moving the herds out of the vicinity in winter. The scenario of movement to the edge of the Karakum Desert rather than into the Kopet Dag also fits the wild animal contributions to Monjukli bone collection, with onager and gazelle as the most frequent wild taxa. Overall, more bones from animals inhabiting semidesert habitats and steppes are present than bones of animals from mountain habitats. Furthermore, the desert vegetation in Turkmenistan is known to be used as a valuable food resource for sheep grazing throughout the year (Rustamov 1994). Chenopodiaceae and other C_4 plants occur in steppe-like environments and in the vegetation of the Karakum Desert (Toderich et al. 2007), but further information on plant composition in the Karakum Desert is required to evaluate this proposal. The modeled $\delta^{18}O$ values of precipitation at Monjukli Depe and at locations further out in the steppe or desert are too similar to expect any significant differentiation in the teeth.

The isotopic patterns of group 1 and 2 occurred over the complete span of the Aeneolithic occupation of the site were noted. Also no spatial patterns within the site. Moreover, both groups included sheep and goat, which implies that both species were raised and kept together in the same herds. At present, deciding in favor of one of the scenarios formulated is difficult, and more data is needed to confirm or refute these possibilities. However, the similarity of the $\delta^{18}O$ values in both groups indicates habitats with similar climatic conditions. This would support that all animals grazed on local pastures, with some animals receiving supplementary winter fodder that was rich in C_4 plants, or on winter pastures further out in the steppe or desert rather than summer pastures in the mountains. The possibility that a considerable portion of the herd stayed year round at pastures near the village is supported by the results from an examination of wear stages on sheep/goat teeth (Eger 2018). In this analysis various stages of dental attrition of the deciduous lower fourth premolars were estimated providing a precise determination of age-at-death up to roughly a few months (Blaise and Balasse 2011:3091; Grant 1982). From the presence of all wear stages in the faunal assemblage it is suggested that animals stayed close to the village during all four seasons and, combining this evidence with the anatomical representation, were culled at the site. Thus, at least a portion of the animal population was not moved away from the settlement.

Conclusion

Carbon and oxygen isotope ratios of sequentially sampled caprine teeth have implications for animal husbandry strategies at Aeneolithic Monjukli Depe but also for the role of herd movement more generally in this early village society. The analysis of sheep and goat molars aimed at testing the occurrence of seasonal movements of livestock. The initial hypothesis was driven by scenarios of vertical pastoral nomadism postulated for the Iranian highlands during the same chronological period. Oxygen and carbon isotope ratios were used to estimate the season in which these movements could have occurred, as well as to detect seasonal changes in diet through the period of enamel mineralization. The carbon isotope ratios suggest that a minority of the sampled sheep and goats grazed on C_3 plants all year round. Archaeobotanical evidence points to a predominance of C_3 plants in the habitats around Monjukli Depe, implying that these animals were kept near the site. A larger portion of the herds revealed higher and more variable carbon isotope ratios along the tooth crowns, indicating contribution of C_4 plants to their diet. Opposite trends observed in the $\delta^{13}C$ and $\delta^{18}O$ curves of some of the teeth indicate that C_4 plant consumption was more important in winter than in summer. However, overall similar averages and amplitudes of the $\delta^{18}O$ data point to similar environmental conditions in the habitats where C_3 and C_4 plants grew. The result contradicts general expectations of favorable growth and availability of C_4 plants in summer and generally under warmer conditions. Among the possible explanations for our findings, stockpiling of C_4-plant-containing forage in summer for winter feeding and moving the herds toward the southern fringes of the Karakum Desert in winter are more likely than the use of upland pastures in summer. However, none of these explanations exclude other options. More comparative data from the mountains, the near vicinity of the site, and the Karakum Desert are required. Data evaluation of the striking pattern of enhanced C_4 plant contribution in winter would also benefit from further analyses of animal teeth and the inclusion of other isotope systems, such as radiogenic strontium isotopes and carbon and nitrogen isotope ratios of bone collagen. If the observed pattern was associated with moving out from the site during the cold season, a possible motive might have been the cultivation of winter barley, which would have required keeping the animals away from the cultivated fields. In conclusion, animal husbandry and provision at Monjukli Depe involved different feeding and mobility strategies. So far, however, the results do not clearly indicate vertical seasonal nomadism but rather local livestock breeding with variable winter-feeding strategies and/or movement within the lowlands, including the fringes of the Karakum Desert.

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