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Close management of sheep in ancient Central Asia: evidence for foddering, transhumance, and extended lambing seasons during the Bronze and Iron Ages

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ABSTRACT

Pastoralism in Central Asia directed the utilization of natural resources, yet information on livestock management strategies remain scarce. Carbon ($\delta^{13}\text{C}$) and oxygen ($\delta^{18}\text{O}$) isotope analyses of domesticated sheep teeth are used to identify animal management strategies. Sheep from Kent exhibit an inverserelationship where low $\delta^{18}\text{O}$ values coincide with high $\delta^{13}\text{C}$ values, consistent with the foddering of caprines in the winter for this location which occurs alongside evidence for an extended lambing season. At the high altitude encampment of Turgen, Bronze Age sheep exhibit low $\delta^{18}\text{O}$ values that coincide with high $\delta^{13}\text{C}$ values, suggesting that livestock were moved to low altitude pastures in the winter months. Iron Age sheep sequences also have an inverserelationship, where low $\delta^{18}\text{O}$ values coincide with high $\delta^{13}\text{C}$ values, yet high $\delta^{13}\text{C}$ values in the winter suggest that livestock were foddered. Our findings indicate variation in livestock management strategies with distinct adaptations to local ecologies.

KEYWORDS

Kazakhstan; pastoralism; livestock; fodder; transhumance; millet

Introduction

The subsistence economies of Late Bronze and Iron Age groups inhabiting central and southeastern Kazakhstan were based on pastoralism or agro-pastoralism and drew from a suite of domesticated animals that included cattle, horses, sheep, goats and dogs. Our current understanding of animal management strategies during this period largely relies on zooarchaeological relative abundance measures which define herd composition (Outram et al. 2012; Bendrey 2011; Frachetti and Benecke 2009; Benecke and von den Driesch 2003). On a continental scale, species proportion is correlated with environmental variables such as precipitation, as areas with higher rainfall generally supporting higher proportions of cattle (Bendrey 2011). But, both local ecologies as well as cultural factors play a part in defining herd composition, moderating and overriding precipitation levels as a limiting factor (Haruda 2018; Outram et al. 2012).

There is, however, a significant dearth of information regarding animal age at death from this region due to recovery and archival issues as well as earlier zooarchaeological assessment standards and practices in the regions across Central Asia (Morales Muñiz

and Antipina 2003). These issues have impeded more detailed analysis of pastoral management strategies. Furthermore, heavy fragmentation and small sample sizes for assemblages recovered from settlement sites often preclude further detailed zooarchaeological analysis (Doumani et al. 2015). This deficiency limits widespread comparison of herd management strategies, such as culling and seasonality of births. Recent zooarchaeological analyses of fauna recovered from Bronze and Iron Age settlement sites across Kazakhstan suggest that there may be consistent exploitation strategies in which larger bovids and equids were managed for secondary products, while ovicaprids were managed instead for meat and possibly wool production (Haruda 2018; Outram et al. 2012).

Current models of pastoral management systems suggest that Bronze Age subsistence economies were underpinned by settled and mobile pastoralism and included diverse herding strategies that varied by location and period (Koryakova 2002). Domesticated bovids in the eastern Urals were in use by the mid-third millennium cal BCE evidenced by a shift from horse herding to mixed sheep and cattle management

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at Sergeevka and Balandino (Kislenko and Tatarintseva 1999). By 2300 cal BCE, Middle Bronze Age sites associated with the Sintashta and Petrovka cultural groups in northern Kazakhstan heavily exploited domesticated cattle, sheep, and goats alongside horses with occasional hunting of wild fauna (Koryakova and Epimakhov 2007). By the mid-second millennium during the Late and Final Bronze Age, domesticated cattle, sheep and goats were almost exclusively exploited at varying intensities throughout northern Kazakhstan (Haruda 2018; Outram et al. 2012). The Final Bronze Age in central and southeastern Kazakhstan is characterized by shared material culture, evidenced by ceramic technology and style, from the Begazy-Dandybaev and Dongal cultures (Margulan et al. 1966; Lohman 1987; Kuz'mina 1994; Koryakova and Epimakhov 2007; Varfolomeev 2011a; Beisenov, Taimagambetov, and Kassenalin 2014). The spread of shared material culture across central and southeastern Kazakhstan, as well as similar proportions of livestock taxa exploited across this region, suggests pastoralist groups regularly engaged in tight interaction networks that extended across different ecological zones.

Recent research has highlighted the role of mobile pastoralism or nomadism as a key catalyst for the construction of durable networks of interaction across the steppe throughout antiquity (Frachetti et al. 2017), while overlooking high density settlements and the development of agriculture. Pastoral nomadic mobility supported by livestock herding is thought to have intensified human interaction in steppe environments, eventually resulting in the emergence of the Silk Road (Kuz'mina 2008; Frachetti et al. 2017) and globalization processes (Frachetti 2006). However, many of these models utilize the mobility patterns of contemporary and historic pastoralists as proxies for the past while suffering from a limited corpus of archaeological evidence (Frachetti 2012). Historically, pastoralists participated in seasonal herding strategies that included long-distance movements across Kazakhstan (Abramzon 1971), which were often mapped onto ancient herding practices and treated as direct analogs for prehistoric pastoral lifeways. This approach has overestimated the temporal and geographical continuity of mobility pathways and livestock management strategies, despite research suggesting that more nomadic forms of pastoralism only emerged in the Late Bronze Age (Tkacheva 1999; Grigor'yev 2000; Kuz'mina 2007; Anthony 2007, 2009). Much research has documented pastoralism as a highly variable strategy that is resilient and responsive to changes in resource availability and human social variation (Cribb 1991; Chang and Koster 1994; Leonard and Crawford 2002; Frachetti 2008; Outram et al. 2012).

Here, we explore Bronze and Iron Age livestock management strategies through carbon and oxygen stable isotope analyses of sequentially sampled sheep

tooth enamel. These data will not only serve to add to the limited corpus of information available to support and construct prehistoric mobility models, but also to demonstrate the potential of isotopes to support and inform zooarchaeological analyses, particularly in regions which lack high recovery rates for animal bone and broader regional comparative material. In particular, we investigate seasonal husbandry practices involving the manipulation of sheep dietary intake, birth season, and movement (e.g. Balasse et al. 2003; Britton, Müldner, and Bell 2008; Balasse et al. 2012; Tornero et al. 2013; Tornero et al. 2016b; Knockaert et al. 2017; Makarewicz, Arbuckle, and Öztan 2017). Carbon isotope sequences were used to investigate dietary intake and infer mobility by taking advantage of variation in floral biomes to track movement in the landscape (e.g. Balasse et al. 2003) and intra-tooth oxygen isotope variation was used to examine livestock mobility and vertical transhumance (Tornero et al. 2016b; Makarewicz 2017). In so doing, we not only create detailed pictures of livestock practices at two different archaeological settlements in prehistoric Kazakhstan, but we also provide an integrated approach for regions where zooarchaeological remains are understudied to create robust data for model building.

Kent, Central Kazakhstan

The site of Kent is located in the Kent mountain range within the semi-arid steppe of central Kazakhstan (Figure 1). Covering over 45 hectares, the settlement contains 130 pithouses and is surrounded by smaller settlement clusters dating to the same period forming a proto-urban or urbanized locality (Beisenov, Taimagambetov, and Kassenalin 2014; Evdokimov and Varfolomeev 2002; Varfolomeev 2011b). Aggregated populations found in the steppe are not always dependent on agriculture, often engaging in small scale cultivation, and their urban configurations vary greatly from agricultural societies (Evdokimov and Varfolomeev 2002). Urbanized localities of pastoral groups are composed of multiple settlements surrounding a larger regional center such as Kent (Varfolomeev, Lohman, and Evdokimov 2017). A landscape of smaller sites that are economically interconnected may be due to the need for more pasture for larger herds that were necessary to provision aggregated populations.

Kent was previously dated to 1300–1100 BCE on relative terms based on the Begazy-Dandybaev ceramic typology (Evdokimov and Varfolomeev 2002). Our current radiocarbon dating of two sheep mandibles (5571/5578) from the site have uncalibrated radiocarbon ages of 3160 ± 35 BP (Poz-93206) and 3125 ± 35 BP (Poz-93207), with calibrated dates of 1506–1383 cal BCE and 1457–1289 cal BCE, respectively (Intcal13; OxCal ver 4.2.3; Bronk Ramsey 2017; Reimer et al.

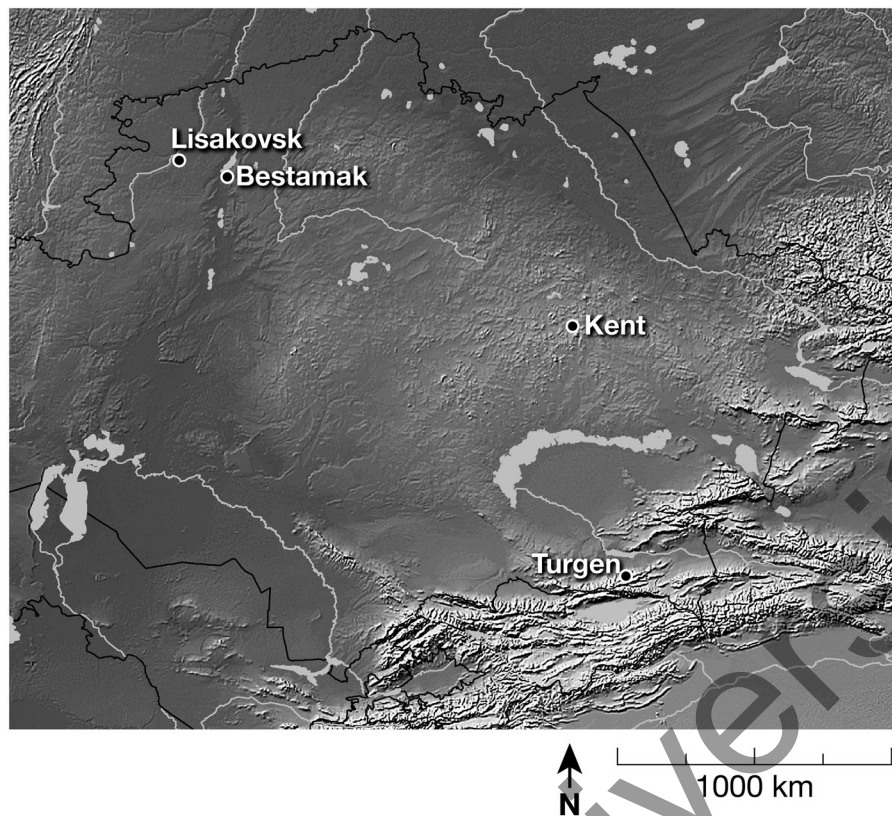


Figure 1. Location of the sites of Kent and Turgen within the broader region and in reference to the sites of Lisakovsk and Bestamak (where water was sampled in 2014).

2013). This earlier radiocarbon date is not unexpected, as other dating programs have similarly pushed relative dates back several hundred years (Beisenov et al. 2016; Svyatko et al. 2009; Hanks, Epimakhov, and Renfrew 2007).

Kent sits on the Kizylkinesh River and is situated within a well-watered valley (c. 925 masl) surrounded by a granite escarpment, which at their highest extent reach 1470 masl. The granite outcrops provide shelter from harsh winds for those living in the river valley which opens onto the flat to slightly hilly semi-arid steppe (Figure 2). Temperatures average -15°C in the winter and 18°C in the summer months (Ilyakova et al. 2015). Annual precipitation in the Kizylkinesh River valley averages c. 250 mm per annum with the majority falling during the summer months and c. 30 mm falling as snow during the winter (Ilyakova et al. 2015). Contemporary land cover classifications for Central Asia indicate that the Sary Arka region, where Kent is situated, supports mixed C_3/C_4 grassland vegetation (Klein, Gessner, and Kuenzer 2012; Eisfelder et al. 2014). Today, the region is classified as part of the East-Central Kazakhstan low mountain sub-province (IId) with four subzones of steppe: droughty, moderately dry, dry, and desert (Rachkovskaya and Bragina 2012); Kent is located in the droughty zone. The zonation varies considerably and is influenced by low mountains and hills. One characteristic feature is a great diversity of shrubs in the steppe including species of *Spiraea* and *Caragana*, some of which grow on the

granite outcrops (Rachkovskaya and Bragina 2012). Today, the region is dotted with areas of rain-fed agriculture alongside sparse vegetation at low elevations (~ 900 masl) and coniferous trees at higher elevations (Klein, Gessner, and Kuenzer 2012; Eisfelder et al. 2014).

Access to fresh water is important in the semi-arid steppe, and Kent is located in the broader Nura-Sarysu Basin, an area of low water supply (UNDP 2004) (Figure 2). Rivers in this basin receive their main annual water discharge (90% or more) during the short spring flood with low water availability the rest of the year. Approximately 2000 lakes are found in this region, yet the majority are located in the vicinity of the Nura and Karagalinka rivers far to the north of the site (UNDP 2004). Kent is located on the Kizylkinesh River, a tributary of the Taldy River. The Taldy river is east of the site and originates in the Shubai low-mountain massif. It then flows southwest and west through the Kent mountains into Karasor lake.

Turgen, Southeastern Kazakhstan

The site of Turgen is located in Balkash-Alakol River Basin (Almaty Oblast') within the Tian Shan mountain range at an altitude of 1900 masl (UNDP 2004). It is located in a lightly wooded conifer valley on the bank of the Kyzylbulak River (Figure 2). The Turgen settlement consists of rectangular pithouses featuring central hearth features and storage pits located between houses

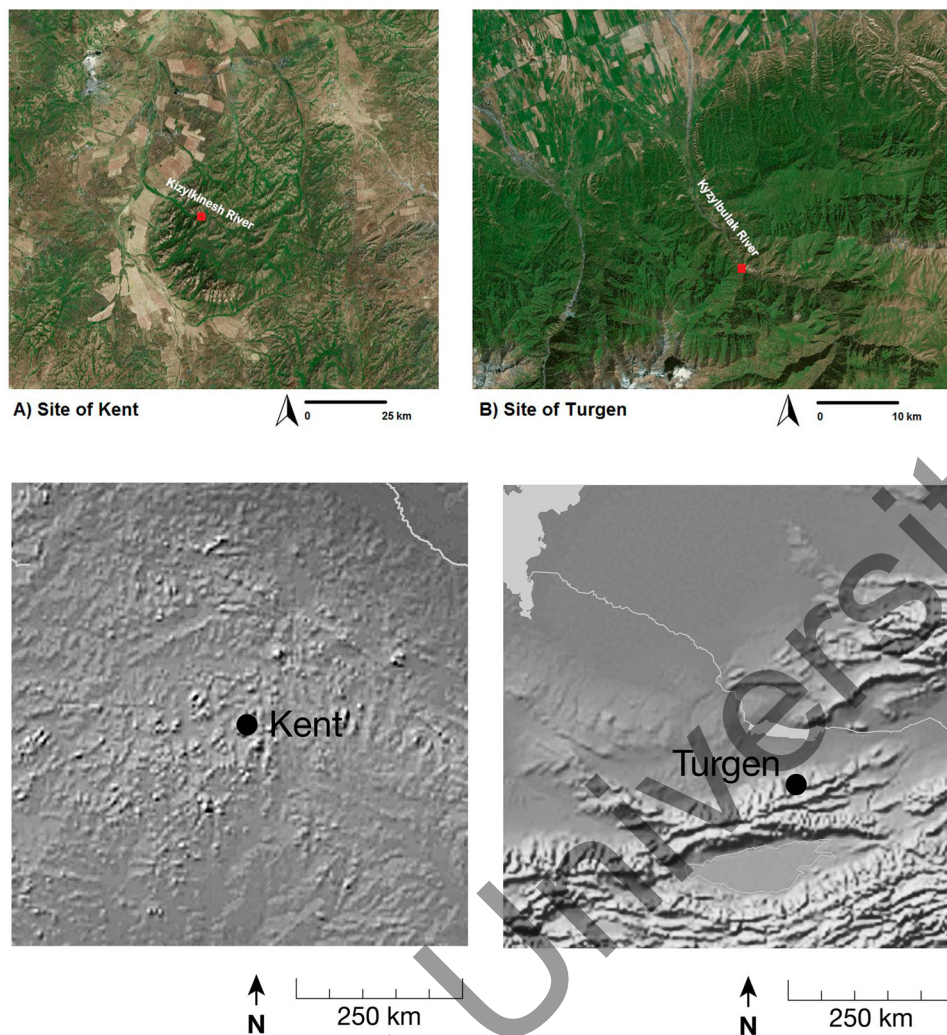


Figure 2. (a) Detailed overviews of the sites of Kent and Turgen. (b) Detailed topography of Kent and Turgen.

(Goryachev 2004). Turgen has been dated to the Final Bronze Age based on a relative chronology of ceramic and bronze forms, including Sary Arka (1300–900 BCE) and Dongal (1000–900 BCE) pottery (Lohman 1987; Kuz'mina 1994) and Kulsai tradition bronze forms (1200–800 BCE). However, while relative dating of material culture suggests that Turgen was occupied from 1300 to 800 BCE (Goryachev 2004), recent radiocarbon dating of two sheep mandibles (5589/5588) from the site have conventional radiocarbon ages of 3395 ± 35 BP (Poz-93209) and 2460 ± 35 BP (Poz-93210). These findings indicate that the site had at least two occupations from 1862–1614 cal BCE and 759–416 cal BCE (OxCal ver 4.2.3; Bronk Ramsey 2017; Reimer et al. 2013).

The Tian Shan range varies in elevation, with the highest point at Pik Talgar at 4,980 masl. On average snow covers the site for at least six months of the year, with snow at higher elevations year round (Tang et al. 2017). Glacial meltwater from the summits of the Tian Shan supplies the Kyzylbulak River and smaller streams with a steady supply of water. The phytographic region is the Northern Tian-Shan province

contains vertical mountain zones and meadows (Sokolov 1968). The area surrounding Turgen consists of a mosaic of ecotones that vary by altitude (Rosen, Chang, and Grigoriev 2000; Shahgedanova 2003), from reliable and rich pasturage present in alpine meadows (3500–3000 masl), to juniper forest (3000–2055 masl), conifer forest (2600–1500 masl) and finally the grassland steppe zone where patches of shrubland are found (1500–500 masl) (Klein, Gessner, and Kuenzer 2012; Eisfelder et al. 2014). At the lowest elevation is the arid steppe (500–300 masl), with mixed C_3/C_4 vegetation. At this elevation, the Kyzylbulak River quickly fans out across the alluvial plain forming a well-watered zone in the spring, draining into the modern Kapchagay reservoir and eventually into Lake Balkash. Today, temperatures at Turgen average 8°C , with winter temperatures falling to -6°C while summer temperatures reach on average 22°C (Ilyakova et al. 2015, 2015). Precipitation averages 400 mm per annum with approximately one third of all precipitation falling in the spring (Ilyakova et al. 2015). Altitudinal transhumance is currently practiced in the Tian Shan, with herders moving livestock from high-

altitude summer pastures to lower altitude winter pastures in the sheltered valleys of the foothills (Kerven et al. 2011). Grassland steppes of valleys in the foothills (500-1500 masl) offer protected areas with high pasture productivity (Kerven et al. 2011).

Bronze Age animal use at Turgen and Kent

Proto-urban localities such as Kent had large aggregated populations, and archaeological remains demonstrate that regional centers sustained populations in the hundreds or thousands in the semi-arid steppe in contrast to smaller settlements in southeastern Kazakhstan (Margulan et al. 1966; Margulan 1979; Varfolomeev 2003, 2011a, 2011b). While there are similarities in material culture assemblages from the proto-urban site of Kent and pastoral encampment of Turgen (Figure 1), there is little direct evidence for interactions between groups that lived at these sites. Geometric morphometric analyses of sheep from these two settlements in central and southeastern Kazakhstan suggest that herds remained local to their respective environments with no admixture between flocks at the two sites (Haruda 2017).

Despite the difference in sheep flocks, zooarchaeological analysis demonstrates both sites engaged similar exploitation of domesticated taxa. Specifically, larger domesticated herbivores, including horses and cattle, exploited at moderate intensities (ca 20% NISP), were culled after four years of age. Sheep and goat dominate zooarchaeological assemblages at both sites (over 50% NISP) and were slaughtered after 18 months of age, although less than 30% of flocks survived beyond four years of age (Haruda 2018; Outram et al. 2012). These survivorship curves indicate that sheep and goats were likely the main source of meat, and slaughtered once they reached full size, while cattle and horses were exploited for secondary products such as milk and riding. Animals were butchered on site, and there was no evidence for preferential transport of specific elements. Of the 25% of bones identifiable to taxon, a large proportion of specimens from Kent (70%) and nearly a quarter of bones from Turgen exhibit evidence of fresh fractures indicative of marrow extraction which suggests limited access to other sources of dietary fats (Haruda 2018, Outram 2001).

Isotopic approaches to delineate herding strategies

Combined oxygen and carbon isotope measurements from sequentially sampled teeth have been increasingly used to investigate livestock management strategies across a range of environments (Britton, Müldner, and Bell 2008; Makarewicz 2017; Makarewicz, Arbuckle, and Öztan 2017; Tornero et al. 2016b; Knockaert et al. 2017; Makarewicz and Pederzani 2017). Sequences of $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ values along the tooth crown have clarified seasonal vertical mobility

of wild sheep feeding in Alpine environments (Tornero et al. 2016a) and, when compared to the isotopic composition of other herbivorous species, in early domesticated sheep and goat in mountainous terrains east of the Jordan Valley (Makarewicz 2017). Notably, recent work on domesticated caprines showing higher maxima $\delta^{18}\text{O}$ values within an intra-tooth time series relative to co-localized wild caprines indicates that relying solely on oxygen isotope values to establish herbivore mobility is problematic due to differences in the contribution of leaf water and open water sources to body water (Makarewicz and Pederzani 2017).

Carbon isotopes in floral biomes

The carbon isotope composition of herbivore tooth bioapatite is determined by the carbon isotopic composition of ingested plants (Ambrose and Norr 1993; Lee-Thorp, Sealy, and Van Der Merwe 1989; Tieszen and Fagre 1993). Shifts in the $\delta^{13}\text{C}$ values of sequentially sampled herbivore teeth are useful for establishing dietary change on seasonal scales (Balasse et al. 2002; Britton et al. 2009; Makarewicz, Arbuckle, and Öztan 2017; Makarewicz and Pederzani 2017; Knockaert et al. 2017). The carbon isotope compositions of plants are influenced by aridity, salinity, water availability and altitude. Among C_3 plants, there is a negative relationship between water availability and plant $\delta^{13}\text{C}$ values (Farquhar, Ehleringer, and Hubick 1989; Farquhar 1991; Stewart et al. 1995), while there is little to no correlation between water availability and the $\delta^{13}\text{C}$ values of C_4 plants (Farquhar, Ehleringer, and Hubick 1989; Swap et al. 2004; for slight positive correlation see Murphy and Bowman 2009). As water availability decreases, the water-use efficiency (WUE) of C_3 plants increases, leading to carbon isotope discrimination (Δ) and ^{13}C enrichment in leaf carbon (Farquhar, O'Leary, and Berry 1982b; Farquhar, Ehleringer, and Hubick 1989; Lajtha and Getz 1993). Floral water uptake capacity is reduced in conditions of high soil salinity, contributing up to 3‰ enrichment in ^{13}C of plant tissues (leaves, stems, roots) of halophytic and non-halophytic species (Farquhar et al. 1982a; Bowman et al. 1989; Hokmabadi, Arzani, and Grierson 2005; Wei et al. 2008). In mountainous zones, plant $\delta^{13}\text{C}$ values increase along altitudinal gradients, which is related to leaf mass, carboxylation efficiency, or stomatal conductance (Körner, Farquhar, and Roksandic 1988, 1991; Friend, Woodward, and Switsur 1989; Morecroft and Woodward 1990; Hultine and Marshall 2000). The observed correlation is modest, with a 1.5‰ increase in the Alps from 400 to 2500 m (Zhu et al. 2010). In concert, the relative abundance of C_4 taxa decreases along elevation gradients (Teeri and Stowe 1976; Cavagnaro 1988; Mo et al. 2004; Li et al. 2009), which may have a greater effect on the isotopic composition of

herbivore tissues as they move from higher to lower elevations (Tornero et al. 2016a).

Floral biomes in central and southeastern Kazakhstan are composed of a mix of grasses and flowering non-woody plants, the majority of which follow a C_3 photosynthetic pathway. A comparatively smaller number of C_4 plants have been identified in these biomes, often represented by grasses and Chenopodiaceae (Toderich et al. 2007; Ventresca Miller et al. 2018a). Terrestrial plants have carbon isotope values that vary depending on the way that plants fix carbon, whether following a C_3 pathway with lower $\delta^{13}C$ values (-31‰ to -20‰) or following a C_4 pathway with higher $\delta^{13}C$ values (-16‰ to -12‰) (O'Leary 1981; Farquhar, Ehleringer, and Hubick 1989). Contemporary C_3 plants in southern central Asia exhibit values ranging from -26.3‰ to -23.6‰ while C_4 yield values that range from -16.4‰ to -11.3‰ (Toderich et al. 2007). In the northern steppe, contemporary C_3 plants exhibit slightly lower $\delta^{13}C$ values ranging from -29.2‰ to -22.1‰ reflecting higher precipitation levels, while C_4 plants have values ranging from -13.7‰ to -12.3‰ (adjusted to correct for the Suess effect) (Ventresca Miller et al. 2018a).

In arid and semi-arid regions of the steppe, the isotope values of vegetation have higher average $\delta^{13}C$ values during the summer and lower values during the winter. This is attributed to seasonal changes in humidity levels, available precipitation, and nocturnal temperatures which impact the abundance of C_3 and C_4 plants. In mixed C_3/C_4 grasslands, there are a higher relative proportion of C_4 plants in the summer months, with greater abundances of C_4 plants in warmer and more arid environments (Toderich et al. 2007). C_4 plants germinate later than C_3 plants, during the late spring or early summer months when temperatures are higher (Yamori et al. 2014). The growth of C_4 plants ceases during the fall when lower temperatures interfere with growth. Seasonal variation in plant growth has been modeled on a broad scale through mean monthly NPP (net primary productivity) in Kazakhstan and demonstrates increased productivity of landscapes in the late spring and summer (May through August) compared to the winter months (Eisfelder et al. 2014).

Variation of oxygen isotopes in diverse systems

The oxygen isotope ratios in herbivore bioapatite directly reflect the $\delta^{18}O$ of body water, which is influenced by atmospheric oxygen, food, and imbibed water (Kohn 1996; Luz and Kolodny 1985). While the relative contributions of each source to body water is influenced by dietary intake and energy expenditure, enamel bioapatite $\delta^{18}O$ values appear to be largely controlled by the composition of imbibed water (Fricke and O'Neil 1996; Kohn, Schoeninger, and

Valley 1998). Among domesticated livestock, imbibed water sources include surface water from rivers, lakes and standing pools, leaf water, and groundwater from springs or wells. Tooth enamel from herbivores that obtain a high proportion of water from leaf water are enriched in ^{18}O relative to precipitation (Kohn 1996; Longinelli 1984; Makarewicz and Pederzani 2017). Obligate drinkers that ingest surface waters exhibit comparatively lower oxygen isotope values than non-obligate drinkers from similar environments as the latter obtain a larger proportion of water from vegetation (Levin et al. 2006; Wang et al. 2008).

The oxygen composition of water sources is influenced by meteoric water $\delta^{18}O$ values and relative humidity, which are determined by continental positioning, rainfall amount, altitude, and temperature (Dansgaard 1964; Gat 1996). Seasonal variation in meteoric water $\delta^{18}O$ values is relative to changes in temperature and precipitation amounts, which produce precipitation enriched in ^{18}O during the summer (Dansgaard 1964; Gat 1996). As air masses move, whether traveling inland or to higher elevations, they lose water as precipitation which is enriched in ^{18}O relative to the vapor mass (Gat 1996). Subsequent rains are depleted in ^{18}O compared to earlier rains from the same air mass (Clark and Fritz 1997). As air masses move over continental areas they lose water by rainout and become depleted in ^{18}O (Gat 1996). As the air mass moves to higher altitudes it loses precipitation, which is continuously depleted in ^{18}O (Dansgaard 1964; Rozanski, Araguás-Araguás, and Gonfiantini 1993). Spring and summer melt water at high elevations is often ^{18}O -depleted, as it comes from snow that accumulated over the winter (when precipitation $\delta^{18}O$ values are the lowest) and from glaciers (with low $\delta^{18}O$ values) (Bhatia et al. 2011; Tornero et al. 2016a).

Riverine systems exhibit oxygen isotopic change throughout the year relative to seasonal shifts in the isotopic composition of precipitation that coincides with the evaporation of river water (Gibson et al. 2002). Water in rivers is largely derived from precipitation falling in upstream catchments as well as from glacial meltwater, tributaries, groundwater, surface runoff, and localized precipitation (Gibson et al. 2002; Halder et al. 2015). As rivers integrate discharge and water from sub-catchments they may exhibit geospatial variation in oxygen isotopes (Halder et al. 2015). Comparatively, waters in evaporative systems (e.g. lakes) are generally enriched in ^{18}O relative to precipitation (Gat 1995, 1996; Gibson et al. 2002, 2008). In general, $\delta^{18}O$ values of surface and meteoric waters are generally lacking for Kazakhstan. To overcome a gap in the data, we summarize regional variation in water isotope data from multiple sources. Modern precipitation for this region, based on predictive modeling (Bowen et al. 2017), demonstrates $\delta^{18}O$ values with yearly averages ranging from -7.5‰ to -8.1‰ .

In the northern steppe (Kostanay Oblast') river water $\delta^{18}\text{O}$ values were measured in the summer of 2014 within a 15 km radius of the archaeological sites of Lisakovsk and Bestamak (Ventresca Miller 2018; Ventresca Miller et al. 2018b). Six samples were taken along a 20 km stretch of the Tobol River which ranged from -10.8 to -11.1‰ , two samples along a 10 km portion of the Ubagan River ranged from -9.01 to -11.0‰ , and one sample of the Buruktal stream which measured -3.5‰ (Ventresca Miller 2018; Ventresca Miller et al. 2018b) (Figure 1). Comparative values measured that same summer indicate that lakes from the region varied in $\delta^{18}\text{O}$ values ranging from -2.0‰ to -8.7‰ (Ventresca Miller 2018; Ventresca Miller unpublished data). On a broader scale, recently published data sets from the Tian Shan Mountains (from locations in Kyrgyzstan and China) indicate seasonal variation in $\delta^{18}\text{O}$ of precipitation. At high elevations in the Tian Shan Mountains (~ 2000 masl), just east of the site of Turgen, winter $\delta^{18}\text{O}$ values range from -13.4‰ to -28.4‰ , while average summer $\delta^{18}\text{O}$ values range from -5.4‰ to -10.5‰ (Wang et al. 2016). Variation in $\delta^{18}\text{O}$ values in the mountains is due to diversity in terrain and precipitation distribution, with event based $\delta^{18}\text{O}$ in precipitation ranging from 0‰ to -30‰ (Feng et al. 2013). On the lower northern slopes of the same mountains (320–935 masl), precipitation exhibits lower values in winter ranging from -16.3‰ to -24.5‰ , with average summer $\delta^{18}\text{O}$ values that range from -4.9‰ to -10.5‰ (Wang et al. 2016). Due to the diversity of elevations, site latitude, and precipitation distribution, altitudinal trends in $\delta^{18}\text{O}$ values are not readily apparent. Further, few locations had collection points at the peak, north, and south side of the Tian Shan range in location suitable to study effects of altitude. In general, $\delta^{18}\text{O}$ values were enriched in summer months (April to October) relative to winter months (November to March) (Wang et al. 2016). Mountain lake water to the southeast of Turgen has a reported value of 10.8‰ (collected in June 2014).

Prehistoric climate

Reconstructions of climate conditions in Kazakhstan during the Bronze Age suffer from a lack of data sets. Pollen analyses of lake cores from northern and central Kazakhstan indicate cyclical changes in climate (Kremenetski, Tarasov, and Cherkinsky 1997a, 1997b). The period between 2550 and 1650 cal BCE was characterized by a drier and continental climate, when forest cover decreased. In the following period (1350–750 cal BCE), when Kent and Turgen were established, pollen records indicate there was a less continental climate which coincided with the expansion of pine forests (Kremenetski, Tarasov, and Cherkinsky 1997a, 1997b). These findings are slightly

different than those of Khotinsky (1984), who analyzed pollen sequences suggesting that the early phase (3357–2600 cal BCE) was cool and dry, followed by a warmer moister climate (2600–1440 cal BCE), then a cool phase that coincides with the Kent occupation (1440–600 cal BCE) (for discussion Rosen, Chang, and Grigoriev 2000). Rosen, Chang, and Grigoriev (2000) compiled available data, showing that there is a lack of consensus among paleoenvironmental reconstructions for the Bronze and Iron Ages.

Materials and methods

Faunal remains

Eighteen caprine mandibles with erupted third molars were selected from Kent ($n=10$) and Turgen ($n=8$). At Kent, mandibles were recovered from settlement contexts, while at Turgen samples were recovered from occupation deposits associated with two domestic structures and surrounding storage pits. Left mandibles were chosen from Kent (Excavation 11) while at Turgen, the most frequent side from secure contexts were used in order to maximize sample size. Eighteen caprine mandibles were collected from the Bronze Age sites of sites of Kent ($n=10$) and Turgen ($n=8$) (Table 1) (Haruda 2018; Outram and Kasparov 2007). Taxonomic assignments were accomplished using qualitative morphological criteria outlined in Payne (1985) and Zeder and Pilaar (2010). Ageing was recording using the state of occlusal wear using Grant (1982) and an age range ("Real Age") as well as a more precise age by month ("Absolute average age") which were calculated using Greenfield and Arnold (2008). For completeness, occlusal wear was also recorded with Payne (1973) and Jones (2006) (Table 1).

Isotopic analyses were conducted on the second mandibular molar, which begins to form in *Ovis aries* during the second month of life with the initiation of mineralization at six months and completion by ca. 10 months (Zazzo et al. 2010); the tooth crown is exposed and comes into wear after twelve months (Noddle 1974; Zazzo et al. 2010). In general, lambs suckle for approximately two months before weaning, and, consequently, the carbon and oxygen isotopic composition of second molar tooth enamel should not be impacted by milk intake (Silver 1969). Overall, individuals from Kent were younger at age of death compared to those from Turgen (Haruda 2018) (Table 1).

Stable isotope methods

Second molars were extracted from mandibles, cleaned with a scalpel, and sonicated in distilled water to remove adhering sediments. The surface of the lobe

Table 1. Age of sheep mandibles based on wear stages.

Site	Sample number	Side	Payne wear stage	Jones wear stage	Grant MWS value	Real age	Absolute average age
Kent	5571	Right	G	Gb	39	4–6 years	60 months
Kent	5572	Right	F		34	3–4 years	42 months
Kent	5573	Right	G	Gb	36	4–6 years	42 months
Kent	5574	Right	G	Gb	34	4–6 years	42 months
Kent	5575	Right	G	Ga	34	4–6 years	42 months
Kent	5576	Right	G	Gb	36	4–6 years	42 months
Kent	5577	Right	H	H	46	8–10 years	108+ months
Kent	5578	Right	E	E3+	28	2–3 years	24 months
Kent	5579	Right	F+		35	3+ years	42 months
Kent	5580	Right	G	Gb	40	4–6 years	60 months
Turgen	5581	Left	H	H	45	8–10 years	108+ months
Turgen	5582	Right	G	G?	40	4–6 years	60 months
Turgen	5583	Right	H	H	45	8–10 years	108+ months
Turgen	5584	Right	F	F9/10	34	3–4 years	42 months
Turgen	5586	Left	G	G?	39	4–6 years	60 months
Turgen	5587	Left	G	Ga	34	4–6 years	42 months
Turgen	5588	Left	D	D5	24	16–22 months	18 months
Turgen	5589	Left	H	Gb	45	8–10 years	108+ months

was then cleaned by abrasion with a diamond bit to remove any remaining contaminants. Enamel sampling was performed on the buccal side of the tooth, on the anterior lobe. Enamel was drilled incrementally, perpendicular to the tooth growth axis from the apex to the enamel-root junction (ERJ). Enamel samples were removed by drilling with a diamond bit along a horizontal band measuring less than one millimeter in width. This sampling strategy provides a high-resolution profile of environmental and dietary inputs (Balasse et al. 2002; Zazzo et al. 2010; Zazzo et al. 2012). However, the geometry and rate of tooth growth are not constant, as the growth rate decreases exponentially as the tooth approaches its maximal length (Zazzo et al. 2012). Enamel samples were chemically treated in 0.1 M acetic acid and left to soak for 4 h in order to remove diagenetic carbonates (Balasse et al. 2002). Samples were then rinsed 5 times with distilled water, and freeze-dried. Samples were analyzed for carbon and oxygen isotopes at the Leibniz Labor, Kiel University using a Finnigan MAT 253 mass spectrometer coupled to a Kiel IV device with an analytical precision of 0.05‰ for carbon and 0.08‰ for oxygen. Analytical precision of the enamel standard was 0.07‰ for carbon and 0.1‰ for oxygen.

Modeling of incremental $\delta^{18}\text{O}$ series to investigate birth seasonality

Series of $\delta^{18}\text{O}$ values on the second molar were modeled following a cosine-function (Balasse et al. 2012) for sheep that had long enough sequences. The timing of tooth development is fixed within a species, therefore seasonality of birth can be investigated through the study of inter-individual variability in incremental $\delta^{18}\text{O}$ values along with the tooth crown (Balasse et al. 2003; Balasse and Tresset 2007; Britton et al. 2009; Henton, Meier-Augenstein, and Kemp. 2010). Season and seasonality of birth were assessed by the identification of the position in the tooth crown where the

highest and lowest $\delta^{18}\text{O}$ values were measured. All sequences were normalized against the ERJ as a comparative measure. Individuals that were rejected from the modeling procedure exhibited advanced tooth wear and subsequent short sequences. The majority of the sheep from Kent (5571, 5572, 5573, 5574, 5576, 5577, 5580) and all sheep from Turgen were rejected from the model due to sequences that had short sequences.

In an effort to eliminate inter-individual variability in tooth size, the data were normalized to the periodic cycle identified from $\delta^{18}\text{O}$ values using the following model (Balasse et al. 2012):

$$\delta^{18}O_m = A * e \left(\frac{x - x_B}{x_A} \right) * \cos \left(2\pi \frac{x - x_0}{X + bx} \right) + M + px$$

The model was applied with p, b and x_B fixed to 0, x_A fixed to 10^6 with only X, A, x_0 and M allowed to vary. Several parameters were used to model individual $\delta^{18}\text{O}$ series: X (is the period in mm, corresponding to the length of the tooth crown), A (=max–min/2; amplitude of the isotope signal in ‰), x_0 (delay in mm, depending on the time of year when tooth growth started), M (mean expressed in ‰) (Balasse et al. 2012).

Results

Carbon and oxygen isotope values for each incremental sample are available in supplemental materials (Tables S1 and S2).

Oxygen isotope ratios

Results of $\delta^{18}\text{O}$ analyses of enamel bioapatite for incrementally sampled domesticated sheep (*O. aries*) second molars from Kent and Turgen are shown in Table 1. Overall, sheep from both Kent and Turgen exhibit a similar range of $\delta^{18}\text{O}$ values, from –2.9 to –14.9 for Kent and from –1.7‰ to –13.7‰ for Turgen (Table 2). The amplitude of sinusoidal intra-

Table 2. Stable oxygen and carbon isotope data for each sheep tooth sampled.

Site	Sample number	Oxygen						Carbon					
		Min	Max	Mean	SD	Midpoint	Amplitude	Min	Max	Mean	SD	Midpoint	Amplitude
Kent	5571	-11.7	-7.1	-9.2	1.6	-9.4	-4.6	-10.2	-8.8	-9.5	0.7	-9.5	-1.4
Kent	5572	-14.9	-4.9	-9.3	3.6	-9.9	-9.9	-10.3	-8.5	-9.4	0.6	-9.4	-1.8
Kent	5573	-12.5	-3.6	-7.3	3.2	-8.0	-9.0	-9.5	-7.7	-8.7	0.7	-8.6	-1.8
Kent	5574	-12.7	-4.9	-8.5	3.1	-8.8	-7.9	-10.7	-9.3	-10.1	0.6	-10.0	-1.4
Kent	5575	-12.9	-5.5	-9.4	2.7	-9.2	-7.4	-9.1	-7.8	-8.3	0.5	-8.5	-1.3
Kent	5576	-10.6	-3.8	-7.3	2.9	-7.2	-6.8	-10.3	-8.6	-9.6	0.6	-9.5	-1.7
Kent	5577	-8.8	-2.9	-5.6	2.2	-5.9	-6.0	-9.7	-8.4	-9.2	0.4	-9.1	-1.2
Kent	5578	-11.8	-5.0	-8.5	2.5	-8.4	-6.8	-10.2	-8.9	-9.7	0.6	-9.6	-1.3
Kent	5579	-13.1	-5.2	-9.3	3.0	-9.2	-7.9	-10.5	-9.2	-9.9	0.5	-9.9	-1.4
Kent	5580	-12.0	-3.5	-6.9	3.3	-7.7	-8.5	-10.1	-8.6	-9.3	0.7	-9.4	-1.5
Turgen	5581	-7.2	-2.1	-4.7	3.6	-4.7	-5.1	-9.6	-6.4	-8.0	2.2	-8.0	-3.2
Turgen	5582	-9.5	-5.1	-7.1	2.0	-7.3	-4.5	-11.5	-10.4	-11.0	0.5	-11.0	-1.1
Turgen	5583	-11.1	-1.7	-6.0	4.2	-6.4	-9.4	-10.7	-9.4	-10.3	0.6	-10.1	-1.3
Turgen	5584	-11.1	-2.5	-6.2	3.2	-6.8	-8.6	-10.7	-10.2	-10.5	0.2	-10.5	-0.5
Turgen	5586	-13.7	-4.8	-7.7	3.4	-9.2	-8.9	-7.3	-4.5	-5.9	0.9	-5.9	-2.7
Turgen	5587	-10.9	-3.1	-8.1	2.8	-7.0	-7.8	-11.6	-10.0	-10.7	0.6	-10.8	-1.6
Turgen	5588	-11.3	-2.3	-5.8	3.1	-6.8	-9.0	-8.4	-3.8	-6.4	1.6	-6.1	-4.6
Turgen	5589	-6.3	-2.3	-3.9	1.5	-4.3	-4.0	-10.5	-9.1	-9.6	0.5	-9.8	-1.4
Turgen	5581	-7.2	-2.1	-4.7	3.6	-4.7	-5.1	-9.6	-6.4	-8.0	2.2	-8.0	-3.2

tooth isotopic change observed for animals from Kent ranges from 4.6‰ to 9.9‰. At Turgen, the amplitude of oxygen isotope variation within each tooth ranges from 4.0‰ to 9.4‰.

Incremental $\delta^{18}\text{O}$ series

At the site of Kent, sequences of incremental $\delta^{18}\text{O}$ values follow a sinusoidal curve, reflecting the seasonal cycle in the oxygen isotope composition of available water. These data suggest that the duration of the sequence recorded and preserved in the highest M2 crowns within the Kent assemblage is just under a year (5572, 5575, 5576, 5578, 5579) while the remaining M2 crowns have much smaller sequences (5571, 5573, 5574, 5577, 5580) and are generally from older individuals with similar wear stages. Incremental $\delta^{18}\text{O}$ series of sheep from Turgen also follow an undulating pattern similar to a sinusoidal curve, with the lowest values in the cold season and highest values in the warm season. These data suggest that the duration of the sequence recorded and preserved in M2 crowns in the Turgen assemblage covers less than 6 months, with the most complete sequence evident in sample 5587 (Table 1).

Inter-individual variation is observed by the position of the maximum and minimum $\delta^{18}\text{O}$ values along the tooth crown in the M2 (Figure 3(a)). At the site of Kent, the maximum $\delta^{18}\text{O}$ values which represent the warm season are evident at a distance varying from 7.4 to 28.4 mm from the ERJ (not observable in 5571, 5576 and 5577) while the minimum $\delta^{18}\text{O}$ values were recorded from 9.7 to 37.9 mm from the ERJ (not observable in 5571, 5573-4, 5577, and 5580). Series have been classified based on their shape and the position of the highest $\delta^{18}\text{O}$ values, with three sequences identified (Figure 4). The first series type has the highest $\delta^{18}\text{O}$ values at 13–16 mm along the ERJ, series type 2

has the highest $\delta^{18}\text{O}$ values at 22 mm (5578) or greater than 29 mm (5576) along the ERJ. The final type 3 has its highest $\delta^{18}\text{O}$ value at 8 mm along the ERJ. The offset between $\delta^{18}\text{O}_{\text{max}}$ values of sheep at Kent is 2.3‰ while the offset between $\delta^{18}\text{O}_{\text{min}}$ values is 4.3‰. Only sheep with clear maximum or minimum values were used to calculate offsets.

At the site of Turgen maximum $\delta^{18}\text{O}$ values, which represent the warm season, are found at a distance ranging from 4.1 to 13.9 mm from the ERJ (not observable

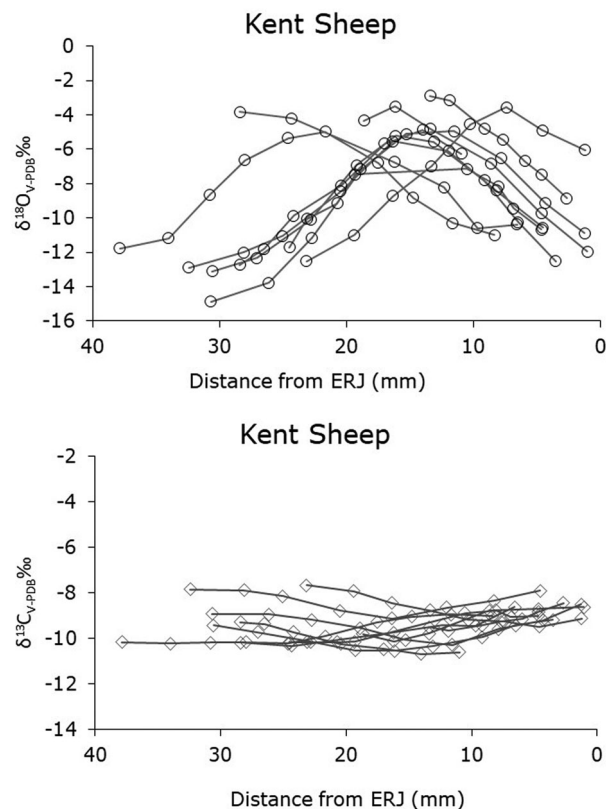


Figure 3. (a) Oxygen isotope series for sheep (second molars) from Kent. (b) Carbon isotope series for sheep (second molars) from Kent.

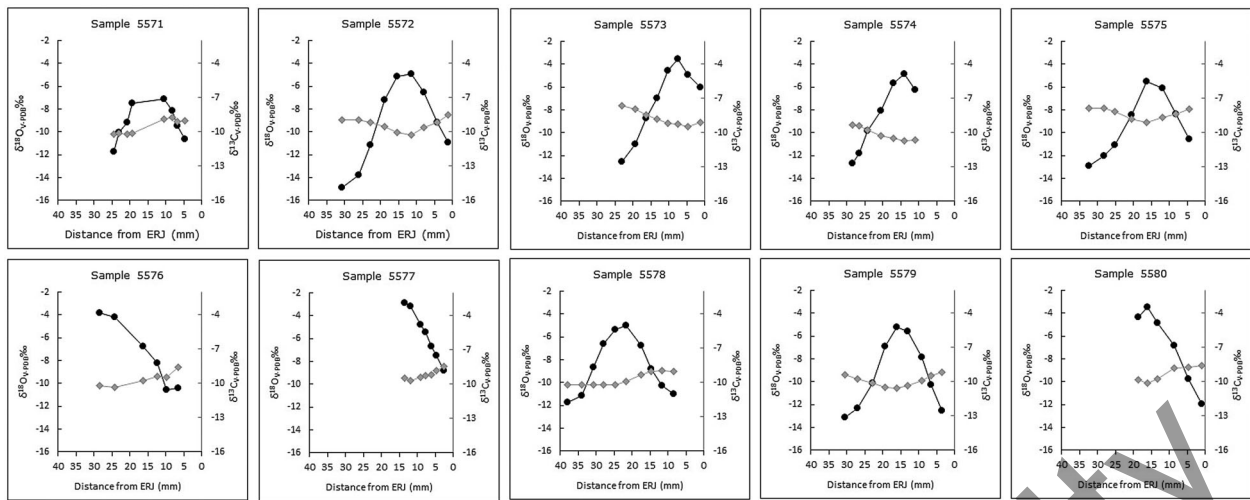


Figure 4. Oxygen and carbon isotope series for sheep from Kent.

in samples 5582, 5583). Minimum $\delta^{18}\text{O}$ values were only recorded for a single sheep (sample 5587) at 20 mm from the ERJ. Series were then classified based on shape and position of highest $\delta^{18}\text{O}$ values and three sequences have been identified (Figures 5(a) and 6). The highest $\delta^{18}\text{O}$ values in the first series are at approximately 13 mm from ERJ. The second series has the highest $\delta^{18}\text{O}$ values at 5.7 mm from the ERJ, while series three has the highest values at 4 mm from the ERJ. Variation may be related to differences in the season of birth, but could also be related to the

timing of tooth formation or variation in tooth size (Balasse et al. 2012). The offset between $\delta^{18}\text{O}_{\text{max}}$ values of sheep at Turgen is 3.4‰ while the offset between $\delta^{18}\text{O}_{\text{min}}$ values is 7.4‰. However, winter values are unclear as many of the sheep teeth are too worn and are lacking minimum $\delta^{18}\text{O}$ values.

Modeling results of $\delta^{18}\text{O}$ series

The measured and modeled $\delta^{18}\text{O}$ values are presented for each sheep, fitting of the model to the dataset is estimated using the Pearson's correlation coefficient. In all cases there is a very good fit between the model and the dataset ($R \geq 0.99$ for all series). Among four specimens from Kent (5572, 5575, 5578, 5579), the period X varies from 28.7 to 36.6 (mean = 31.7). The distance from the enamel-root junction (ERJ) where the highest $\delta^{18}\text{O}$ value is recorded ($x_{\text{max}}=x_0$) varies between 12.4 and 22.7 mm. Values for x_0/X vary from 0.45 to 0.79, with an average of 0.52 (Figure 7). This pattern suggests that sheep were born over a wide range of time from the late spring through early fall.

Carbon isotope ratios

Kent sheep have carbon isotope ratios that range from -7.7‰ to -10.7‰ (Figures 3(b) and 4). Incremental samples of sheep teeth yielded carbon isotope ratios that varied throughout the year, with amplitudes ranging from 1.2‰ to 1.8‰ and a mean amplitude of 1.5‰. The carbon isotope curves are consistent between individuals and exhibit values within 3‰ of each other. While oxygen isotopes of Kent sheep follow sinusoidal curves reflecting seasonal cycles, the carbon isotope curves do not correspond to seasonal trends. Carbon isotope ratios measured for sheep from Turgen have a much wider range from -3.8‰ to -11.6‰ (Figures 5(b) and 6). The carbon isotope ratios from incrementally sampled sheep teeth varied substantially

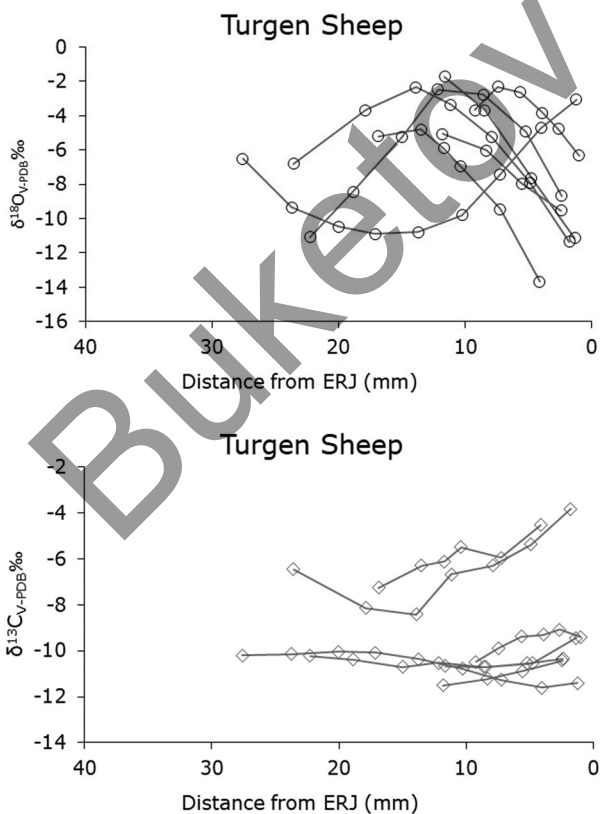


Figure 5. (a) Oxygen isotope series for sheep (second molars) from Turgen. (b) Carbon isotope series for sheep (second molars) from Turgen.

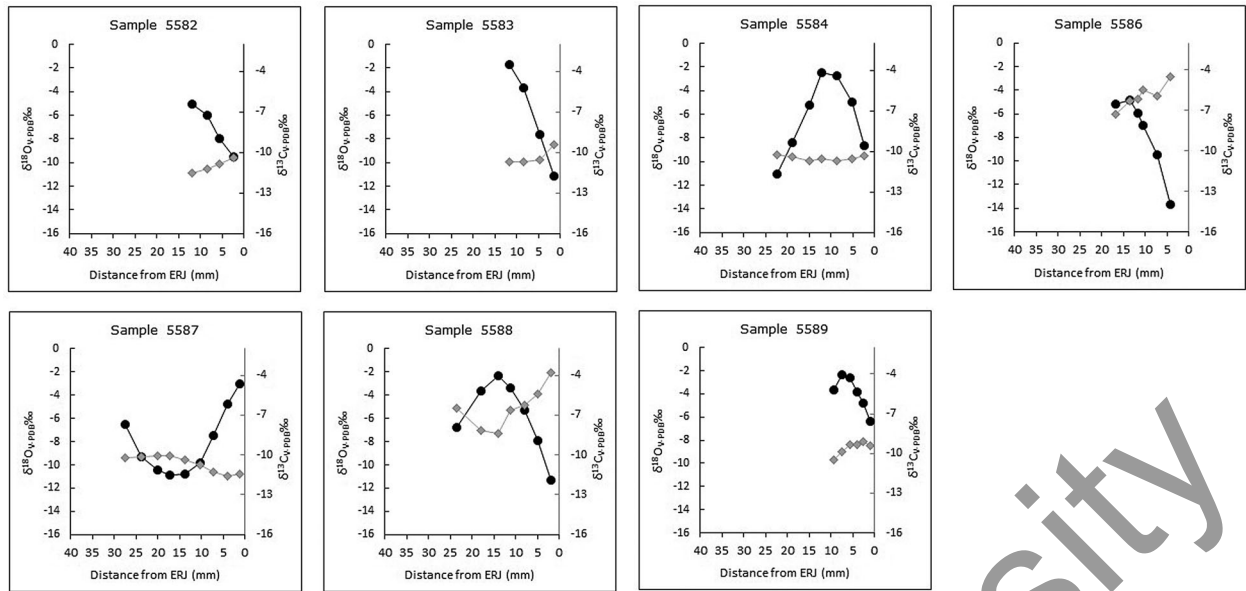


Figure 6. Oxygen and carbon isotope series for sheep from Turgen.

through the year, with amplitudes ranging from 0.5‰ to 4.6‰ and a mean amplitude of 1.9‰. Carbon isotope curves for sheep at Turgen are not consistent between individuals, with two sheep exhibiting much higher $\delta^{13}\text{C}$ values than the other five individuals. For most sampled individuals, low $\delta^{13}\text{C}$ values in an intra-tooth sequence correspond to high summer season $\delta^{18}\text{O}$ values, contrary to the expectations of a seasonal increase in carbon isotope ratios during the summer months.

Discussion

Birth seasonality

Today, the birthing season for lambs in central Kazakhstan spans from April to May (Robinson 2000). At the ancient site of Kent, sheep $\delta^{18}\text{O}$ sequences and modeled $\delta^{18}\text{O}$ sequences indicate distinct patterns of cyclical variation with the lambing season ranging from the late spring through early fall (Figures 3 and 7). Fertility in modern European breeds of domestic sheep is controlled by photoperiod and animals enter estrus in the autumn, triggered by decreasing sunlight hours. The length and onset of the fertile period are modulated by environmental

factors, nutrition, breed, and date of previous lambing and ranges from three to six months. The higher the latitude the greater the impact of photo dependence upon the onset of estrus (Rosa and Bryant 2003) and Kent is affected as the site is located at 49° N. Although ancient sheep at these two sites were likely very different from modern breed types, it is possible that sheep in northern Central Asia had a limited period of photoperiod sensitive estrus during the autumn period which ceased at some point during the winter or spring.

Pregnancy in sheep lasts approximately five months, thus lambs born in August or September indicate a March or April mating, which falls at the tail end of the estrus period. There are two explanations for this second lambing period in the early autumn. The weather phenomenon known as the *jut*, a late spring freeze, is notorious for killing off a large amount of livestock and significantly weakening the condition of the survivors. It is possible that this phenomenon, or a very extreme winter with extremely low temperatures and lack of food, could have caused spontaneous lamb abortion. Depending upon the timing of the abortion, the sheep may have re-entered estrus and mated again, resulting in an autumn birth. This may also be explained by a frequent lambing husbandry pattern,

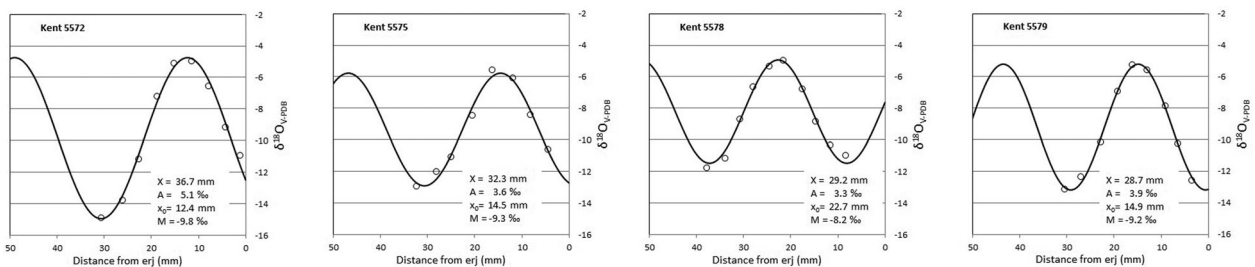


Figure 7. Modeled oxygen isotope ratios for sheep from Kent.

where separate lambings in April/May and August/September are achieved by separating the flock and limiting mating to two periods in November/December and March/April (Hogue 1987). In addition to the presence of a prolific breed with extended fertility, this system necessitates close management of the flock that would involve penning and constant physical separation of flock members by sex and cohort. Exposure of the ewes to fertile rams, even by smell alone, can bring ewes into estrus (Rosa and Bryant 2003), so groups would need to be enclosed or moved in separate mobility patterns in order to limit contact. Despite this investment in human labor this system would not only increase flock productivity of meat, as lambs born in the autumn would on the whole be less likely to survive the winter, but would also extend dairy production into the autumn and into winter. These late lambings suggest that pastoral husbandry involved a sophisticated and intimate knowledge of sheep reproductive capacity that maximized productivity.

Additional data will be needed to explore if this pattern of bimodal lambings is consistent throughout the duration of occupation at Kent. This unexpected variability in birth timing necessitates a re-evaluation of the seasonality of slaughter and will need to be adjusted in light of these extra cohorts. It is rare to find sheep remains from individuals younger than 6 months of age due to taphonomic destruction and thus are unlikely to be reflected in harvesting profile (Lyman 2008). At Kent, survivorship plots based on fusion and dental ageing indicate that only 30% of caprines survived past 4 years of age and the majority of the flock was killed between 18 and 36 months of age (Haruda 2018). The period of slaughter could be considered to have occurred in the second autumn after a spring birth or could also have taken place in the second spring after an autumn birth. Unfortunately, because of the older ages of sheep at Turgen, tooth profiles were too short due to wear and we were unable to model the isotopic variation in sequentially sampled teeth.

Seasonal foddering and patterns of transhumance

Sequential $\delta^{13}\text{C}$ values measured in sheep tooth enamel permits the investigation of seasonal variation in sheep diets, from those relying exclusively on mostly C_3 plants and those foddered with C_4 or ^{13}C -enriched C_3 plants. The seasonal range of the sheep diet is estimated from the values measured in enamel bioapatite using a bioapatite-diet spacing of 14.1‰ for large ruminant mammals (Cerling and Harris 1999). The highest average $\delta^{13}\text{C}$ values measured in Kent sheep reflect dietary $\delta^{13}\text{C}$ values for terrestrial vegetation of -24.8‰ to -21.8‰ , with higher values falling during

the winter months. These fall close to the normal range of values for C_3 vegetation in southern Central Asia (-26.3‰ to -23.6‰) (Toderich et al. 2007) and measured values for plants in the northern steppe (-29.2‰ to -22.1‰) (Ventresca Miller et al. 2018a) that were adjusted for the Suess Effect ($+1.5\text{‰}$, Keeling 1979; Yakir 2011). Low summer dietary $\delta^{13}\text{C}$ values (-23.2‰ to -24.8‰) indicate that sheep grazed in C_3 pastures during spring and summer months. Comparatively, winter season dietary $\delta^{13}\text{C}$ values were enriched in ^{13}C on average by 1.5‰, with values ranging from -23.4‰ to -21.8‰ . Vertical transhumance was not possible at Kent, as the surrounding mountains consist of vertical granite outcrops supporting little vegetation. Furthermore, the highest peaks are only 800 masl, and the nearest high-altitude mountains are over 500 km away. Further, geometric morphometric data suggest that sheep were constrained to their respective environments (Haruda et al. 2019). Variation in the morphology of sheep astragali reflects that they inhabited localized topographies and were discontinuous populations (Haruda et al. 2019). These findings support our conclusion that sheep were not moved long distances but were foddered at low levels during the winter with C_4 or ^{13}C -enriched C_3 fodder (Table 2).

Modern herders fodder their livestock over the winter months on harvested hay, especially when the number of animals is low, as moving herds long distances in search of graze may have a negative effect on health and survivorship of livestock (Robinson 2000). In the Soviet era, migrations were supported by physical and social infrastructure in the Betpak-Dala desert, including deep wells (Robinson et al. 2016). Water-stressed C_3 , or mixed C_3/C_4 , vegetation could have been collected during the late summer season in the open steppe, as occurs in contemporary central Kazakhstan (Robinson and Milner-Gulland 2003). The relatively small variation in amplitude in carbon isotope values of Kent sheep (average 1.5‰) is not unexpected, as steppe biomes have a low abundance of C_4 plants. At Kent, sheep spent their winters in sheltered valleys protected from freezing winds and were foddered with plants collected during the late summer, which accounts for winter $\delta^{13}\text{C}$ values that are slightly enriched in ^{13}C relative to summer values. The proto-urban landscape surrounding Kent included smaller sites that were economically interconnected, suggesting a need for larger herds managed intensively to provision aggregated human populations. As the semi-arid steppe lacks pasturage outside of the period of high precipitation in early summer, an increase in herd numbers and extended lambing periods could only be sustained through the incorporation of fodder.

The diets of sheep from the site of Turgen were managed using a variety of strategies indicated by three distinct carbon isotope sequences. The first

group of sheep (5582, 5583, 5584, 5587) date to 1860–1610 cal BCE and have the lowest $\delta^{13}\text{C}$ values, reflecting $\delta^{13}\text{C}$ values for terrestrial vegetation of -25.7‰ to -23.5‰ . Low dietary $\delta^{13}\text{C}$ values (-25.7‰ to -24.8‰) during the summer months indicate that sheep grazed in C_3 pastures. In the winter, $\delta^{13}\text{C}$ values were enriched in ^{13}C on average by 1.6‰ (-24.8‰ to -23.5‰) indicating that sheep ingested small amounts of ^{13}C -enriched C_3 or C_4 plants. A greater abundance of ^{13}C -enriched C_3 or C_4 plants, including graze and fodder, are available throughout the year at lower elevations in the semi-arid steppe. Turgen is positioned at high altitude (1900 masl), and, snow likely covered the site during the winter making it impractical for grazing. Therefore, these sheep were likely moved from these higher elevation summer pastures to lower elevations in the winter months when (and where) and provided with a ^{13}C -enriched C_3 or mixed C_3/C_4 fodder source.

The second group of sheep (5586, 5588) date to the Iron Age occupation of the site (759–416 cal BCE) and ingested higher amounts of ^{13}C -enriched C_3 or C_4 vegetation, reflected in $\delta^{13}\text{C}$ diet values from -22.5‰ to -17.9‰ . Again, the highest $\delta^{13}\text{C}$ values occurred in the winter (-18.6‰ to -17.9‰) and lower values in the summer (-22.5‰ to -21.4‰). Average $\delta^{13}\text{C}$ values of modern vegetation near the site of Turgen do not explain the high winter values of sheep, as the site is located at a high altitude. At lower elevations during the summer months, there are a greater frequency of C_4 grasses and water-stressed C_3 plants. However, it is unlikely that this mixed C_3/C_4 zone in southeastern Kazakhstan had a high enough density of C_4 grasses and water-stressed C_3 plants to result in sheep $\delta^{13}\text{C}$ diet values reaching -17.9‰ , especially during the winter months. Comparatively, summer vegetation from the much drier desert-steppe in modern Mongolia had a weighted (based on stem density) $\delta^{13}\text{C}$ value of -17.8‰ (after adjustment by $+1.5\text{‰}$ for the Suess effect) (Makarewicz and Tuross 2006). This suggests that either Turgen sheep were foddered with C_4 plants throughout the year, potentially with the stalks of a domesticated plant such as millet, or that during the winter months they were moved to low elevations and foddered with a combination of C_4 and ^{13}C enriched plants. This is further supported by evidence of cultivation of foxtail millet at the site as early as the Late Bronze Age, identified through phytoliths (Roberts 2016). In addition, at nearby Iron Age sites there is evidence for a system of seasonal transhumance of livestock alongside crop production (Chang 2017; Schmaus, Chang, and Tourtellotte 2018; Ullah, Chang, and Tourtellotte 2019).

The last sheep (5589) analyzed is undated but found in a layer with materials from the Iron Age. This sheep has corresponding carbon and oxygen sequences, with high $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ values in the summer and low

values in the winter. The average carbon isotope value for this sheep is 9.6‰ which reflects a $\delta^{13}\text{C}$ diet value of -23.6‰ suggesting it lived in a C_3 biome at a higher elevation for example in alpine meadows or in juniper and conifer forests. These findings suggest that this sheep may have lived near Turgen during the period of mineralization of its M2.

There is a difference in management strategies for Bronze and Iron Age sheep at Turgen, demonstrated by high $\delta^{13}\text{C}$ values coinciding with low $\delta^{18}\text{O}$ values, that could be driven by two different husbandry methods. Sheep had diets with contributions of ^{13}C -enriched C_3 or C_4 plants, which suggests that either (a) they lived near Turgen and were foddered, with moderate amounts of ^{13}C -enriched or C_4 plants, or (b) that they were moved seasonally to lower elevations and grazed in areas with ^{13}C -enriched or C_4 plants which potentially included naturally growing pastures and fields with crop residues after harvest. Bronze Age sheep with only slightly higher $\delta^{13}\text{C}$ values in the winter reflect a small contribution of ^{13}C -enriched C_3 or C_4 plants to the diet. It is unlikely that sheep lived in the mountains surrounding Turgen year-round as deep snow occurs throughout the winter and sheep would have difficulty grazing and accessing pasture. The occurrence of ^{13}C -enriched C_3 plants in high-altitude pastures of the Tian Shan is extremely unlikely, as plant $\delta^{13}\text{C}$ values decrease along altitudinal gradients in mountain zones (Körner, Farquhar, and Roksandic 1988, 1991), while the relative abundance of C_4 taxa decrease along elevation gradients (Teeri and Stowe 1976; Cavagnaro 1988; Mo et al. 2004; Li et al. 2009). Therefore, the most likely explanation is that sheep were moved to semi-arid steppe pastures during the winter months. A higher $\delta^{13}\text{C}$ value for some Iron Age sheep during the winter months, compared with sheep from earlier Bronze Age periods, suggests that they were much more likely to have been foddered with a ^{13}C enriched food source, which may have included C_4 plants such as millet, during this time of the year.

A comparison of the oxygen isotope values for sheep from Turgen with those from Kent demonstrate that oxygen sequences had the same average amplitude (7.5‰). However, sheep at Turgen had higher average oxygen isotope values by 1.5‰ (relative to Kent) indicating variation in water sources available to sheep at these locales. This finding demonstrates that sheep at Turgen likely accessed ^{18}O -enriched leaf water and/or open water that was present at lower elevations in the semi-arid steppe. However, characterizing the contribution of isotopically diverse water sources (including graze, wells, or open water) in the body water of sheep is challenging, as humans direct the feeding and drinking practices of domestic livestock. Furthermore, oxygen isotopic measurements of water sources, including well water, lakes, rivers, and leaf water are

not available for southeastern Kazakhstan, limiting our attribution of these water sources.

The oxygen isotope values of sheep from Turgen have a wide range of amplitude (4.0–9.4‰) indicating pronounced seasonal changes in the oxygen isotope values of meteoric water. Winter $\delta^{18}\text{O}_{\text{min}}$ values coincide with higher $\delta^{13}\text{C}_{\text{max}}$ values, indicating that sheep from Turgen were foddered with plants collected at the end of the summer. If sheep were living at high elevations during the winter, ingesting dry fodder with low moisture content and water from open sources or wells, they would have low oxygen values and low carbon values, rather than the pattern that we see here. This supports a model of pastoral husbandry at Turgen which involved a component of vertical movement to access low elevation mixed C_3/C_4 pastures during the winter months. However, as we have no locally available wild or modern sheep populations with which to compare, it is difficult to determine unequivocally if this was the case.

Conclusion

The outcomes of this study add to the limited amount of data available to support models of ancient pastoral land use and demonstrate the potential of stable isotopic studies to inform traditional zooarchaeological analyses in regions which lack high recovery rates for animal bone. Despite the small datasets presented here, this study has resulted in novel findings for the region which have implications for other key questions about the Bronze to Iron Age transition among steppe societies, such as the effect of the adoption of agricultural products on pastoral systems, and the degree of mobility as part of economic production patterns. These two locales did not take part in the long-distance exchange of livestock but focused on pastoral husbandry strategies that were specific for the local ecologies around each site. At Kent, and nearby sites, during the Final Bronze Age there was an increase in human population density and wealth, which coincided with the close management of livestock and the first isotopic evidence for low levels of millet consumption by local populations (Lightfoot et al. 2015). Sheep grazed in the open steppe during the warmer months and were foddered during the winter season to support an intensive and extended frequent lambing model to sustain aggregated human populations. The management and foddering of livestock allowed for the extension of the season of lambing and the prolongation of dairy products across the year. The diversification of subsistence regimes at this locale, alongside settlement evidence, suggests that populations were living at Kent year-round.

At the mountain encampment of Turgen there were multiple livestock management strategies utilized by

pastoralists during the Bronze and Iron Ages. This suggests that smaller groups living in high-altitude ecotones had less pressure to closely manage livestock productivity and more flexibility in terms of pasture availability and foddering strategies. The early adoption of cultigens in the Dzhungar mountains of southeastern Kazakhstan is evident in the foddering of livestock (c. 2600 BCE) (Hermes et al. 2019) and paleobotanical remains (by 2200 cal BCE) (Frachetti et al. 2010; Spengler, Doumani, and Frachetti 2014). However, the use of millet as fodder for livestock at high-altitude encampments in the Tian Shan may have occurred much later (600 cal BCE). Additional data is needed to confirm these patterns across other regions and periods in the steppe, and should also include wild and domestic modern taxa in order to provide a finer grained and more conclusive assessment of pastoral strategies. However, these data indicate that economies in this period were localized, and do not support models of long-distance uniform pastoral mobility across this region.

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