Food Fit for a Khan: Stable Isotope Analysis of the Elite Mongol Empire Cemetery at Tavan Tolgoi, Mongolia

Jack N. FENNER[a], TUMEN Dashtseveg[b] and KHATANBAATAR Dorjpurev[c]

[a] Department of Archaeology and Natural History, College of Asia and the Pacific, The Australian National University, Canberra, ACT 0200 Australia

[b] Department of Anthropology and Archaeology, National University of Mongolia, Ulaanbaatar-46, Mongolia

[c] Department of History and Culture, The Mongolian University of Science and Technology, Ulaanbaatar-210646, Mongolia

Corresponding Author: Dr Jack Fenner

+61 2 61252121   jack.fenner@anu.edu.au

ANH, HC Coombs Bldg 9, Australian National University,

Acton ACT 0200 Australia

This is the final manuscript for the following published article:

Fenner, Jack N., Tumen Dashtseveg, and Khatanbaatar Dorjpurev (2014)

Food Fit for a Khan: Stable Isotope Analysis of the Elite Mongol Empire Period Cemetery at Tavan Tolgoi, Mongolia. *Journal of Archaeological Science* 46:231-244.

DOI: 10.1016/j.jas.2014.03.017

The supplementary information published online with the article has been attached to the end of this manuscript.

Highlights

- Analysed collagen $\delta^{13}C$ and $\delta^{15}N$ from three cemeteries in eastern Mongolia
- Sites date to the Mongol Empire period and the Early Bronze Age
- Ruling elite ratios are higher than those of commoners and Bronze Age people
- Found modern isotopic correlation with growing season temperature
- Isotopic differences may be due to environmental rather than dietary changes

Abstract

The creation and expansion of the Mongol Empire during the thirteenth century A.D. brought with it many changes, both for the conquered peoples and for the conquerors themselves. Ruling elite Mongols in foreign lands imposed new customs onto their new subjects, but also adopted some of the characteristics of the cultures they ruled; these are topics of sustained and continuing research interest. Equally interesting but less well researched is what impact the Empire had on Mongols remaining in the Mongolian homeland. Historical sources suggest that the fruits of Empire would have flowed not only to remote Mongol capitals of the Empire but also back to Mongolia proper. Here we use dietary stable isotope analysis to assess whether the Empire brought large changes to the diet of either ruling elites or more common people in the Mongolian homeland. Carbon and nitrogen stable isotope ratios are measured in bone collagen from human and faunal remains from Tavan Tolgoi, a ruling elite cemetery in eastern Mongolia, and compared with ratios from lesser ranked people at the cemetery of Tsagaan chuluut. These are also compared with ratios from the Bronze Age cemetery of Ulaanzuukh, a post-Empire set of human remains, and modern and archaeological human and faunal remains from the wider region. The Tavan Tolgoi isotope ratios do differ from those of Tsagaan chuluut and Ulannzuukh. Comparison with isotope data from the wider region, however, suggests that the differences may be due to differing environmental conditions rather than dietary differences.

Keywords: carbon isotope ratio, nitrogen isotope ratio, Tavan Tolgoi, Tsagaan chuluut, Ulaanzuukh, diet, temperature

1. Introduction

During the thirteenth century AD, Mongol peoples from the steppes of Central Asia conquered a huge swath of Asia and eastern Europe. The impact of the Mongol Empire on conquered or translocated peoples was dramatic and long lasting, and has been the subject of considerable scholarly interest. Perhaps due to a relative lack of historical sources, the impact of the Empire on Mongols in traditional Mongolian lands is less understood. Mongolian military victories would have led to a flood of exotic goods, artisans, slaves, and ideas arriving in a homeland dominated by transhumant pastoralists owning relatively few possessions. It is currently unclear how this affected either the local elites or commoners. Diet is one cultural component that might have changed as Mongol people became both wealthier and more knowledgeable of foreign customs. As discussed below, historical sources generally suggest that elite Mongolians maintained a strong preference for meat and other animal products while incorporating into their diet a host of other foods, flavourings, and cooking styles of Chinese, Turkic, Persian and other origins. These sources, however, primarily date from the later Empire Period and frequently refer to Mongols living in northern China or other parts of the Empire outside the Mongol homeland. It is currently unclear how much impact the new foods had on elite diets, and whether less-elite Mongolians were affected to a similar degree.

Here, we use carbon and nitrogen stable isotope analysis of human remains from eastern Mongolia to see whether certain aspects of diet differed between a group of elites likely belonging to a powerful Chinggisid clan and a group likely composed of lesser elites or commoners. We also compare the Chinggisid data to isotopic data from Mongolian pastoralists from the Bronze Age (ca. 1500 – 1100 B.C.) and from the immediate post-Empire period (A.D. 1434 – 1651). Given the wealth which the ruling elite obtained—and which is displayed in funeral offerings—it is expected that they would have had nearly unlimited access to meat as well as the highly regarded fermented milk beverage *koumiss*. A higher consumption of these products by the ruling elite would be indicated by elevated nitrogen isotope ratios and, to a lesser degree, elevated carbon isotope ratios in bone collagen relative to pre- and post-Empire Mongolians and, perhaps, to Empire-period lesser elites and commoners. Carbon isotope ratios in the elite may also have been affected by differential consumption of C4-based food, especially millet imported from northern China or west-central Asia. Millet seems to have considered a poor food, and thus would be expected—if present at all—to be more strongly emphasised in commoner diets. On the other hand, millet was at least to some degree included in the diet of Mongols of the Yuan Dynasty during the later Empire (Buell and Anderson, 2000) and thus may in fact have been more frequently included in Empire ruling elite diets than otherwise expected. Thus stable isotope ratios indicating a lower consumption of C4 plants in ruling elite diets would be consistent with a traditional Mongolian attitude towards millet while ratios indicating higher consumption would suggest greater adoption of foreign dietary practices. Unfortunately, as discussed below, protein routing within the body may mask such effects in isotope ratios derived from collagen so it is likely that only a large change in C4 consumption would be discerned by the present study. Nitrogen and carbon isotopes used in combination can nevertheless provide insight into dietary change in the Mongol homeland during the Mongol Empire period.

1.1 The Mongol Empire

The rise of the Mongol Empire was a pivotal event in world history. Discussions of its formation, impact, and eventual collapse are available in many publications (e.g., Beckwith, 2009; Golden, 2011; Lane, 2009a, 2009b; Man, 2004; Weatherford, 2010) from which the following very brief synopsis is extracted. The future Chinggis (or Genghis) Khan was born ca. A.D. 1167, probably near the Onon River in north-central Mongolia. Named Temüjin, he was born into a local elite family but suffered hardship following the murder of his father. His early adulthood involved a series of battles, alliances and betrayals, but in 1206 Temüjin was named ruler of all the Mongols and took the title Chinggis Khan. After consolidating his power, in 1209 Chinggis Khan began a series of military conquests that would bring much of Central Asia, including northern China, under his control. Following Chinggis Khan's death in 1227 control of the Empire passed to four of his sons and their descendants, who would expand Mongol control west as far as Poland and Hungary, south throughout China, Iran, Iraq and to the gates of Egypt, and east to the Pacific Ocean. The evolution and breakup of this vast empire is a complex story, with geographically and temporally varying amounts of disruption to and integration with local customs, politics, religions, and ethnicities. Of particular interest in the context of southeastern Mongolia is the establishment by Qubilai Khan of the Yuan Dynasty; as ruler of China he established a new Mongol capital at what is now Beijing. The previous Mongol capital of Qaraqorum in north-central Mongolia continued to be used as well; the archaeological site of Tavan Tolgoi discussed below is roughly midway between Beijing and Qaraqorum. Mongol rule in China continued under Qubilai's successors until the Mongols were finally driven from China by Ming Dynasty forces in 1368.

1.1.1 The Mongolian Diet

Stable isotope ratio analyses provide information about certain aspects of diet, so we will very briefly review historical sources on Mongol diet. As the Mongols at the start of the Empire had no written language, much of what we know about the early Mongol Empire period is derived from texts by foreign visitors and conquered peoples, and tends to date to the later half of the Empire period. Besides the obvious biases inherent in such writings, they also tend to be most informative about Mongol behaviour outside of Mongolia proper. A notable exception is *The Secret History of the Mongols*, probably written ca. 1228 (though subsequently enhanced) for the Khan's court (de Rachewiltz, 2004). *The Secret History* describes Chinggis Khan's background, rise to power, military conquests, death, and succession by his son Ögödei.

Of particular interest for this project is assessment of the amount of animal products consumed by Mongolian elites and commoners. As pastoralists, Mongols can be expected to emphasise meat, and *The Secret History* has abundant references to eating, cooking, raising, hunting, and sharing meat (e.g., de Rachewiltz, 2004:3, 26, 28, 88, 150, 218). John of Carpini, who travelled through Mongol lands in A.D. 1245-47, describes a Mongol diet of all sorts of meat but without bread, herbs or vegetables (Dawson, 1955:16). Kirakos of Ganjak, writing ca. 1241, indicates the Mongols "ate all living creatures, clean and unclean, and they most esteemed the flesh of the horse" (Boyle, 1968). William of Rubruck, travelling about a decade later, also emphasises meat in the Mongol diet (Jackson, 1990). Beyond meat, Mongols also drank milk products. John of Carpini notes "They drink mare's milk in very great quantities if they have it; they also drink the milk of ewes, cows, goats and even camels" (Dawson, 1955:17). William of Rubruck frequently mentions consumption of *koumiss* prepared from the milk of various livestock (Jackson, 1990), as do *The Secret History* (e.g., de Rachewiltz, 2004:6, 25, 55, 172) and Kirakos of Ganyak (Boyle, 1968).

Dating to the fourteenth century but very detailed, the *Yin-shan Cheng-yao* is a manual and cookbook for the Yuan court. It has abundant recipes for meat (especially mutton) and organ foods, but also shows Chinese and Turkic influences with the inclusion of recipes featuring noodles or bread, as well as incorporation of a variety of spices and flavourings (Buell, 1990; Buell and Anderson, 2000). It is unclear how much impact this dietary assimilation had on the overall Yuan court diet, and its influence on the diets of local elites and commoners is even more uncertain.

Millet is of special interest because a substantial inclusion of millet in the diet would increase carbon isotope ratios. Consumption of millet is known from archaeological stable isotope analyses to be common at Bronze and Iron Age sites in northern China (Hou et al., 2013; Liu et al., 2012) and southern Siberia (Murphy et al. 2013; Svyatko et al. 2013) but has not previously been investigated within Mongolia. Millet is never specifically mentioned in *The Secret History*, but two mentions of grains owned by or plundered from the Merkit tribe are likely to refer to millet (de Rachewiltz, 2004:74, 99). After establishment of the Empire, grain keepers were apparently maintained (de Rachewiltz, 2004:214, 216) but the grain may have been rice, wheat or millet. John of Carpini describes a thin millet soup drunk for breakfast (Dawson, 1955:17), as does William of

Rubruck (Jackson, 1990:141). The *Yin-shan Cheng-yao* lists three recipes with millet among the 95 "exotic delicacies" recipes and also includes it in four soups (Buell and Anderson, 2000). Thus millet may have been a part of the Mongol elite diet, and may have had a smaller role in commoner diets as well.

Freshwater and marine fish are also of special interest because of their potential impact on isotope ratios. *The Secret History* mentions fish consumption only in the context of poverty foods that Temüjin's family were reduced to eating following the death of his father (de Rachewiltz, 2004:20). Neither John of Carpini nor William of Rubruck mentions fish consumption. This attitude may have changed by the Yuan Empire period. The *Yin-shan Cheng-yao* lists four fish recipes (all carp) and also includes general discussions of the taste and medical properties of a wide variety of fish and other seafood (Buell and Anderson, 2000). We would not expect to find evidence of fish consumption in common Mongolian diets, but it may have played a role in elite diets of the Yuan Dynasty.

1.2 Stable Isotope Ratio Analysis

Stable isotope ratio analysis is becoming a common archaeological technique and good overviews are available (Hedges et al., 2005; Lee-Thorp, 2008; Tykot 2002, 2004) so we will only highlight aspects of the technique which are particularly relevant to this study. Nitrogen isotope ratios ($\delta^{15}N$) are correlated with trophic level, with plants having lower ratios than herbivores which in turn have lower ratios than carnivores. Each step up the food chain is usually associated with a 3 to 5‰ increase in $\delta^{15}N$, although recent work suggests that in humans a 6‰ increment may be more accurate (O'Connell et al., 2012). $\delta^{15}N$ ratios in plants at the base of the food chain are ultimately derived from physiological processes in nitrogen-fixing plants and microbes. These ratios can be altered by environmental conditions such as aridity (e.g., Pate and Anson, 2008) and salinity (e.g., Ugan and Coltrain, 2011). It is thus important to assess $\delta^{15}N$ in local plants or—more likely in archaeological situations—herbivore tissues to determine the nitrogen isotope ratio basis of the local food chain.

These physiological and environmental influences lead to $\delta^{15}N$ variation among plant foods. A recent survey of modern foods shows that legumes typically have lower $\delta^{15}N$ than cereals, which in turn have lower $\delta^{15}N$ than fruits (Huelsemann et al. 2013). Human and faunal physiological processes can also affect $\delta^{15}N$ values. Disease, starvation, rapid growth, and pregnancy have been shown to increase $\delta^{15}N$ in human tissues, but their impact on slowly remodelling bone is uncertain (Reitsma 2013). Human actions such as fertilizing fields or penning livestock can also have large impacts on localised plant nitrogen isotope ratios (Fraser et al., 2011; Millard et al., in press).

Such influences may lead to $\delta^{15}N$ variation within sites, and if there are large sustained differences among groups could contribute along with trophic level differences to inter-site variation.

Carbon isotope ratios in animals are driven by the ratios in plants consumed, which in turn are determined by the plants' photosynthetic pathways. Most plants use the C3 pathway, while some hot or arid-adapted grasses and forbs use the C4 pathway and succulents such as cacti use the CAM pathway. C3 plants have $\delta^{13}C$ values of around -25‰ while C4 plants average about -15‰ and do not overlap the C3 plant isotope ratios (Deines, 1980). CAM plants can have values that overlap either the C3 or C4 ranges, but are generally assumed to be insignificant in most mammal diets including humans. Environmental influences including aridity (Arens et al., 2000; Fenner and Frost, 2009) and light intensity (Bonafini et al., 2013) can affect C3 plant isotope ratios, but are not usually of sufficient magnitude or direction to bridge the gap between C3 and C4 plants. Due to fractionation effects during tissue creation, there is a +5‰ offset between diet and bone collagen carbon isotope ratios (Fernandes et al., 2012), and about a 1‰ increase in carbon ratios per trophic level (Kelly, 2000; Mannino et al., 2011). Modern samples are offset from pre-20th Century samples by about -1.5‰ (Tieszen and Fagre, 1993) due to recent fossil fuel-driven changes in atmospheric carbon isotope ratios.

Importantly, collagen is a protein and the body preferentially incorporates dietary protein into collagen during collagen production. Collagen isotope ratios therefore primarily reflect the ratios of dietary protein rather than the whole diet (Ambrose and Norr, 2003; Fernandes et al., 2012). Controlled feeding studies indicate that, when protein is reasonably abundant in the diet, about 75 percent of bone collagen carbon is routed from dietary protein with the remaining 25 percent being derived from carbohydrates and lipids (Fernandes et al., 2012; Jim et al. 2006). When these macronutrients are obtained from sources with differing ratios—perhaps carbohydrates from C4 plants and protein from animals consuming C3 plants—collagen $\delta^{13}C$ will be shifted in proportion to differing $\delta^{13}C$ values and relative dietary contributions (Froehle et al. 2010). Bone apatite does not display this macronutrient routing and therefore its $\delta^{13}C$ is more representative of overall diet than collagen $\delta^{13}C$ but less informative of the protein portion of diet (Fernandes et al., 2012). Diet estimation is best done using a combination of both collagen and apatite ratios, but unfortunately apatite ratios are not available for the current project. This restricts the identification of specific components of the diet but collagen $\delta^{13}C$ differences among the various sites can be investigated regarding broad dietary differences, with emphasis on potential protein sources.

Differential koumiss consumption may have affected sites' relative collagen carbon ratios. Milk has higher lipid content than meat and most other animal tissues, and fermentation increases the relative difference by removing lactose carbohydrates. Milk lipids are more depleted in heavy carbon isotopes, averaging a little more than 4‰ less than milk casein protein (Braun et al. 2013). Heavy koumiss consumption could therefore depress carbon isotope ratios, although the effect will be somewhat mitigated by collagen protein routing. Milk is essentially one trophic level above its producer's diet so is expected to increase $\delta^{15}N$ values. The fermentation process does not significantly alter milk $\delta^{15}N$ (Privat 2004 cited in Ventresca Miller et al. 2014) so heavy koumiss consumption should elevate collagen $\delta^{15}N$ values.

2. Sites and Sources

To investigate dietary differences, we sampled human skeletal remains from two Empire Period cemeteries in eastern Mongolia: Tavan Tolgoi (interpreted as associated with the ruling elite) and Tsagaan chuluut (interpreted as incorporating lesser elites and perhaps commoners) (Figure 1). It may be that even Mongolian commoners had access to abundant resources during the Mongol Empire period, so we have also included data from Bronze Age burials at Ulaanzuukh for comparison. We furthermore utilize data from a previously published study of post-Empire human remains from Hets Mountain Cave (Turner et al. 2012). To help assess the significance of the human isotope ratios, we also measured carbon and nitrogen ratios from animal remains incorporated into human graves at Tavan Tolgoi and utilise modern and archaeological isotope data from the wider region.

2.1 Tavan Tolgoi

Tavan Tolgoi is a cemetery located on a hill slope within the open steppe in far southeastern Mongolia (Figure 1). It is marked by a post at the top of the hill and unique stone carvings of two human figures interpreted as male and female medieval Mongol aristocrats. Surface stone markers indicate the presence of at least 14 graves. Portions of the site were excavated in 2004 and 2005 by a team from the National University of Mongolia (Baatar, 2006; Tumen et al., 2006; Youn et al., 2007). Eight graves at Tavan Tolgoi were excavated and, along with human and animal skeletal remains, yielded a large collection of exotic luxury burial goods including gold, silver, jade and silk objects (Table 1; Figure 2). These goods appear stylistically to date to the Mongol Empire period. A series of seven radiocarbon dates on human remains and grave goods from Tavan Tolgoi were performed by Youn et al. (2007); six of these produced dates consistent with the Mongol Empire period. The seventh dates to 230 to 540 cal AD; this sample was taken from a coffin made of slow growing cinnamon wood (not native to the area) and is likely to predate the burial due to old wood within the timber or heirloom preservation of a precious wood. Bayesian analysis of the six accepted dates clearly shows that the cemetery was initiated during or just prior to the Empire period, with a likely end date in the late 13th or early 14th centuries AD (Supplemental Appendix 1).

Of special significance are two gold rings found in Grave 1 which have images of a falcon carved on their inner surfaces (Figure 3). The gerfalcon was the *sülder* (or totem) of the Kiyat tribe to which Temüjin's father Yisügei belonged (de Rachewiltz, 2004:328-331), and according to the *Secret History* (§63) it was a white gerfalcon who in a dream announced the arrival of a young Temüjin to the father of Börte, a member of the Onggirat tribe who became Temüjin's first and primary wife. Thus the image of a falcon on the inner surface of a gold ring indicates close ties to the Chinggsids, and in combination with the other valuable and exotic items found in the graves indicates that these were members of the ruling elite during the Mongol Empire period (Baatar, 2006). Tavan Tolgoi is located within Ongon *sum* or province, which was the home of the Onggirat tribe during the Empire Period, and may in fact be an Onggirat burial ground and therefore very closely connected with the Chinggsids (Tumen et al., 2006).

2.2 Tsagaan chuluut

Tsagaan chuluut is a large cemetery located on a mountain in eastern Mongolia (Figure 1). It was first visited by Mongolian archaeologists in 1967, and then revisited and partially excavated in 2008-2010 by teams from the National University of Mongolia as part of the *Eastern Mongolia: Anthropological and Archaeological Approach* project (Navaan et al. 2009; Tumen, 2009, 2010, 2011). At least 163 graves are marked by surface stones, and 14 graves have been excavated. The graves held a variety of goods, some of which may have been considered fairly precious or exotic but most of which appear to be ordinary items likely available to most individuals. Based on the grave shapes, stylistic assessment of recovered artefacts, and a single radiocarbon date of A.D. 1166 to 1259 (830 ± 24 RCYBP, IAAA-1420), the cemetery appears to date to the Mongol Empire period.

The assemblage from Tsagaan chuluut clearly has less prestigious goods than does Tavan Tolgoi. The status of the persons in the excavated graves is thus likely to have been less than at Tavan Tolgoi, but it is not clear whether Tsagaan chuluut should be regarded as a cemetery for commoners, local elite, or both. During the Empire period it is likely that most Mongols enjoyed the fruits of military victory and taxation of conquered territories so that even commoners may have had access to some exotic goods. Of importance to our analysis is that this situation may also have extended to exotic foods or to increased abundance of preferred foods.

2.3 Ulaanzuukh

Ulaanzuukh is a large cemetery on the open steppe in eastern Mongolia (Figure 1). In addition to at least 65 grave markers, Ulaanzuukh contains a number of rectangular stone line formations that resemble building foundations. As at Tsagaan chuluut, excavations were carried out from 2008-2010 as part of the *Eastern Mongolia: Anthropological and Archaeological Approach* project (Navaan et al. 2009; Tumen, 2009, 2010, 2011). Fourteen graves have been excavated. Artefacts were scarce within the graves (Table 1). Bodies were laid face down, an unusual practice within Mongolia. The internal construction of the graves likewise differed substantially from other graves within Mongolia (Tumen, 2011). However, the artefacts recovered and "slab grave" morphology are typical of Bronze Age graves within eastern Mongolia. Radiocarbon dates from four graves confirm an Early Bronze Age date for the Ulaanzuukh cemetery (Table 2).

Ulaanzuukh grave 63 (sample id 6D) is about 250 m from the main cemetery area and includes birch bark grave goods indicative of the Mongol Empire period. It therefore must be intrusive to the Early Bronze Age burials, and will be treated as a separate case when comparing individuals within and among sites.

The paucity and unremarkable character of Early Bronze Age artefacts at Ulaanzuukh may indicate that the people interred there were commoners. We should keep in mind however that the stone tombs and related markers themselves represent a significant investment. Johannesson (2011:255) calculates that 158 Xiongnu period stone grave monuments could be produced by a population of only 13 to 31 people over 300 years, and similar calculations apply to Ulaanzuukh. Thus even a large cemetery likely represents only a small portion of the local population, and some basis must have been used for selecting those persons to be interred in elaborate stone graves. As Johannesson argues for Bronze Age and Xiongnu graves located in a valley west of Ulaanzuukh, we should therefore consider the persons interred at Ulaanzuukh to be "elite" in some manner. The status of persons at Ulaanzuukh is, however, of secondary interest within the current project. We will use stable isotope information derived from Ulaanzuukh as a kind of baseline of stable isotope ratios for a Mongolian pastoralist population unlikely to have consistent access to exotic foods. This can then be compared to Tavan Tolgoi and Tsagaan chuluut data to assess the importance of exotic or particularly abundant food for the Mongol Empire individuals.

2.4 Hets Mountain Cave

Turner et al. (2012) report carbon, nitrogen and other element isotope ratio data from six individuals whose naturally mummified remains were found in a cave at Hets Mountain, which is to the southwest of Tavan Tolgoi (Figure 1). All the remains show evidence of violent death, and were dated to the fifteenth to sixteenth centuries AD. This was during the Ming Dynasty, which followed the Mongol-led Yuan Dynasty and may have been a time of scarcity, conflict and economic turmoil within Mongolia. We will use this isotope data as a post-Empire reference set for comparison with Mongol Empire period data.

Hets Mountain individual 3-C was a six month old infant (Turner et al. 2012:3131). The nitrogen and oxygen isotope ratios reported by Turner et al. for this individual are both substantially higher than those of other Hets Mountain individuals. This is likely due to trophic effects related to breast feeding during infant growth. Individual 3-C's diet is therefore not representative of the general Hets Mountain group diet and these isotopes are excluded from statistical comparisons.

3. Materials and Methods

We selected bones in visibly good condition from each site. Samples were obtained from seven individuals from Tavan Tolgoi, eleven individuals from Tsagaan chuluut, and thirteen individuals from Ulaanzuukh (Table 1). In addition, we sampled four *Equus* sp. (horse) bones and two ovicaprid bones which were included in Tavan Tolgoi graves (Table 3). In all cases samples were taken from long bone diaphyses. After obtaining the appropriate Mongolian government permission, the bones were temporarily exported to laboratories at Australian National University for analysis, and have since been returned to the National University of Mongolia for curation.

Collagen was extracted using a modified Longin (1971) method. Briefly, for each sample, approximately 1 g of cortical bone was obtained using a Dremel drill saw. The bone was ultrasonically cleaned and then demineralised in 0.5M HCl, with the HCl changed every two days. The sample was then rinsed to neutral pH using deionized water, gelatinised in pH 3 water at 75 ºC, and then filtered using an Ezee filter. The supernatant liquid was frozen at -40 ºC and then freeze-dried. Collagen extract isotope ratios, percent carbon and percent nitrogen were measured using an isotope ratio mass spectrometer at the Stable Isotope Laboratory at the Research School of Biology, The Australian National University. Samples were run at least in duplicate, with the reported value the average of multiple runs. Cysteine and alanine laboratory standards indicate a 1-σ measurement error of 0.2‰ for carbon isotope ratios and 0.1‰ for nitrogen isotope ratios. Percent carbon and nitrogen measurement errors are 0.3% and 0.1%, respectively. Isotope ratios are reported in the usual per-mil format using the VPDB and AIR standards for carbon and nitrogen, respectively. Collagen extract is considered to be adequately preserved if its collagen:bone weight percentage is at least 1%, its carbon weight percent is at least 3%, its nitrogen weight percent is at least 1%, and its C:N atomic ratio is between 2.9 and 3.6 (Ambrose, 1990). The C:N atomic ratio is computed as (%C/12.0) / (%N/14.0).

Statistical analyses were performed using SPSS v20. The human carbon isotope ratio sample set is consistent with a normal distribution per Shapiro-Wilk and Kolmogorov-Smirnov normality tests. The human nitrogen isotope ratio set is only marginally consistent with a normal distribution due to skew, and therefore was $\log_{10}$ transformed prior to statistical tests. The $\log_{10}$-transformed data easily passes both Shapiro-Wilk and Kolmogorov-Smirnov normality tests. Parametric tests were therefore used for statistical analyses of human data. Samples are considered outliers for a particular isotope ratio if they are more than twice the interquartile range from the mean. Equality of means was evaluated using *t* tests without assuming equality of variance (Ruxton, 2006).

When comparing archaeological $\delta^{13}C$ data to modern $\delta^{13}C$ values, the modern values are increased by 1.5‰ to account for the fossil fuel effect (Tieszen and Fagre, 1993). Hair keratin $\delta^{13}C$ values are likewise increased by 1.5‰ due to differing fractionation offsets between keratin and collagen (Turner et al., 2013; Webb et al., 2013). No keratin-to-collagen $\delta^{15}N$ correction is required (Ambrose, 2000). Importantly, keratin is a protein and therefore likely to be derived using the same protein routing within the body as is collagen.

4. Results

All bones sampled appear to be in excellent condition. Results of the stable isotope ratio and related elemental analyses for diagenesis evaluation are presented in Table 3. The mean collagen percentage is 15.2 ± 3.4%, with a minimum value of 5.9%. The mean %C is 42.0 ± 1.8% with a minimum of 12.7%, while the mean %N is 15.4 ± 0.6% with a minimum of 12.7%. The mean C:N atomic ratio is remarkably consistent at 3.2 ± 0.0 with a range only 3.1 to 3.2. All samples thus easily meet the criteria for good collagen preservation (Ambrose, 1990) and are included in subsequent statistical analyses. Such good preservation is likely due to the generally cold, dry conditions in eastern Mongolia.

4.1 Faunal Results

There appear to be two groups of horse isotope ratio data (Table 3; Figure 4), with the two horses from graves 10 and 85 having lower $\delta^{13}C$ and $\delta^{15}N$ than the other two horses. With such small sample sizes, it is unclear whether these groups represent different dietary populations or simply reflect variation within a single population. Nevertheless it may be that these two horses had a somewhat different protein diet than the rest, and perhaps came from a different location (see discussion relating to humans below). Treating them as a single group, the overall horse mean $\delta^{13}C$ is -18.6 ± 1.1‰ and the mean $\delta^{15}N$ is 6.5 ± 1.4‰.

There are only two ovicaprid samples, and their isotope ratios seem rather different from each other (Table 3; Figure 4). The ovicaprid from grave 4 is near the human Tsagaan chuluut and Ulaanzuukh cluster while the other is near one of the horses. With only two samples, it is difficult to assess the meaning, if any, of this variation. It may be due to substantially different diets between the ovicaprids, potentially related to different husbandry practices or locations, or to natural variation of plant isotope ratios within the landscape. Because of the well-known difficulty in distinguishing sheep and goat bones from archaeological sites, we also cannot rule out the possibility that one of these bones was from a sheep with the other from a goat. Since sheep are primarily grazers while goats have a broader diet, this could account for the isotopic difference. Treated as a single group, the overall ovicaprid mean $\delta^{13}C$ is -17.3 ± 2.1‰ and the mean $\delta^{15}N$ is 9.0 ± 1.7‰.

Given a diet-to-collagen offset of about 5‰ (Fernandes et al., 2012), both the horses and the ovicaprids $\delta^{13}C$ values fall in the higher part of the C3 range. There is no evidence of substantial millet fodder in their diet, nor do they indicate a large intake of wild C4 plants which do grow in the region (Pyankov et al., 2000). The wool of modern sheep raised in southeastern Mongolia produce very similar carbon isotope ratios (Auerswald et al., 2012), after adjustment for the keratin-to-collagen offset.

4.2 Human Results

The human isotope data is listed in Table 3. There are two potential outliers among the data measured. Tavan Tolgoi sample 3A has a nitrogen isotope ratio of 11.5‰, which is only slightly less than twice the interquartile range from the mean. This sample will be included in statistical tests but also discussed separately. Tsagaan chuluut sample 7F's $\delta^{13}C$ ratio is more than 2.6 times the interquartile range from the mean and thus is clearly an outlier. It is not, however, clear whether that indicates a varied diet among Tsagaan chuluut people, an intrusive burial (although its grave structure and goods are consistent with other Tsagaan chuluut graves), or a late immigrant to the Tsagaan chuluut area. Statistical comparisons will therefore be done both including and excluding 7F, and the results discussed separately.

Tavan Tolgoi is in general higher in both carbon and nitrogen ratios than either Tsagaan chuluut or Ulaanzuukh, but lower than the Hets Mountain Cave ratios (Table 4). Statistical significance tests (Table 5) indicate that for carbon Tavan Tolgoi is significantly different than Tsagaan chuluut only when clear outlier sample 7F is excluded from the Tsagaan chuluut sample, but for nitrogen ratios they are different regardless of whether 7F is included. Tavan Tolgoi is also significantly different from Bronze Age Ulaanzuukh in both carbon and nitrogen ratios. On the other hand, there are no significant differences between Tavan Tolgoi and Hets Mountain Cave or between Tsagaan chuluut and Ulaanzuukh.

As with the faunal samples, C4 plants do not appear to have made a substantial contribution to collagen formation. Most human collagen samples fall comfortably in the higher end of the C3 range. Only a few samples, most notably sample 7F (the outlier from Tsagaan chuluut), have sufficiently elevated samples to suspect a millet or other C4 contribution to diet. Even those few elevated samples are only slightly influenced by C4 foods; strong millet consumption cultures of northern China, for instance, commonly produce human collagen δ^{13}C values above -10‰ (Hou et al., 2013; Liu et al., 2012).

Sample 6D, the Mongol Empire period burial intrusive in the Ulaanzuukh cemetery, has δ^{13}C of -15.7‰ which is greater than any of the Bronze Age Ulaanzuukh samples but close to the mean value of the Mongol Empire burials at Tavan Tolgoi. Sample 6D's δ^{15}N of 11.9‰ is well within the range of other Ulaanzuukh samples but lower than all Tavan Tolgoi samples except sample 3A. Sample 3A is itself interesting. With a δ^{15}N value slightly less than 1.5 times the interquartile range from the Tavan Tolgoi mean δ^{15}N, Sample 3A is not formally considered an outlier for this analysis. But it clearly is somewhat different than the others. Perhaps not coincidentally, Sample 3A is from grave 10 at Tavan Tolgoi which also contained one of the two horses with very low δ^{15}N. It may be that both man and horse came from an area with lower local δ^{15}N ratios.

As shown by the generally upward slope of Figure 4, δ^{13}C and δ^{15}N are moderately positively correlated (Pearson R=0.45, df=34, $p<0.01$; human values only, $\log_{10}\delta^{15}$N used). A positive collagen δ^{13}C and δ^{15}N correlation is sometimes interpreted as indicating marine or freshwater aquatic contributions to diet (e.g., Jones and Quinn, 2009; Valentin et al. 2006; Weber et al. 2011). That seems unlikely to be the case here. As previously noted, historical sources indicate that fish was not a preferred food for Mongolians during the greater Mongol Empire period. Furthermore, Tavan Tolgoi is more than 1400 km from the Pacific Ocean and while there are scattered lakes and streams in eastern Mongolia it is a dry steppe and desert region that is unlikely to produce sufficient aquatic resources to have a substantial impact on human population bone collagen. An environmental driver for the correlation is feasible as both δ^{13}C and δ^{15}N are known to be influenced by a variety of environmental conditions; this will be explored further below.

5. Discussion

The mean Tavan Tolgoi human δ^{15}N value is 7.5‰ higher than the mean Tavan Tolgoi horse δ^{15}N. This is much larger than the commonly accepted trophic level shift of 3 to 5‰, and also well above the recently reported range of 5.9 to 6.3‰ for a group of living humans (O'Connell et al.

2012). Likewise, their $\delta^{13}C$ is 3.0‰ higher than the mean horse $\delta^{13}C$. It is thus clear that the persons buried at Tavan Tologi were not consuming a large amount of horse meat, or at least not meat from the same horse population that was buried with them. For ovicaprids, the mean human $\delta^{15}N$ value is 5.0‰ higher while the mean human $\delta^{13}C$ is 1.3‰ higher. These ovicaprids may have constituted a significant portion of the humans' protein diet.

Given that the Tavan Tolgoi human $\delta^{15}N$ values are significantly and substantially higher than those from Tsagaan chuluut and Ulaanzuukh (Table 4), it is tempting to conclude that the ruling elite at Tavan Tolgoi consumed more meat or milk protein than did the lower class people at Tsagaan chuluut or the Bronze Age people at Ulaanzuukh. This would be consistent with historic and modern Mongolian preferences for animal-based foods. However, the Hets Mountain Cave human remains have $\delta^{15}N$ and $\delta^{13}C$ values not significantly different than the Tavan Tolgoi people. It is difficult to assess the status of the Hets Mountain Cave persons, but their traumatic deaths, deposition in a cave, and post-Empire dates suggest less than elite status. Their values nevertheless tend to be slightly higher than those from Tavan Tolgoi. If very high meat consumption were linked to elite status, why would the Hets Mountain Cave people have equal or higher isotope ratios as the Tavan Tolgoi people? As noted previously, there may be environmental conditions affecting the isotope ratios; these could confound the usual diet-to-isotope ratio links and cause misleading interpretations of the relative diets of groups from differing environmental conditions. To investigate this, we need more faunal and human samples from differing environmental regimes within the region. As there are no more isotopic data available from the four sites of direct concern here, we will expand the analysis to include modern and archaeological data from the wider region.

5.1 Environmental Correlations

Carbon and nitrogen isotope ratios are available from a number of modern human, horse, sheep and goat populations in Mongolia, northern China, and southern Siberia (Figure 5; see Supplemental Table S2-1 for full data and references). These data have been adjusted as necessary for the modern $\delta^{13}C$ fossil fuel offset and the fractionation difference in hair keratin as compared to bone collagen. In addition to modern data, the set includes data from the Iron Age in southern Siberia (Murphy et al. 2013). There is also a large isotopic data set available from Neolithic and Bronze Age cemeteries near Lake Baikal in southern Siberia but that data is thought to be heavily influenced by fish and aquatic mammal consumption (Katzenberg et al., 2012) and therefore is not included here.

The expanded data set maintains a correlation between $\delta^{13}C$ and $\delta^{15}N$ (Figure 5) though it is not quite as strong as is found with only the four sites of primary interest ($R=0.38$, $df=122$, $p<0.01$;

humans only). (As discussed in the Materials and Methods section, all $\delta^{15}N$ correlations were based on log_{10}-transformed data to improve normality of the distribution.) The fact that the correlation exists across such a wide spatial and temporal data set suggests that the relative isotope ratios may be influenced by more than dietary differences. As noted previously, carbon and nitrogen isotope ratios in plants are known to be affected by environmental conditions, especially aridity. Iacumin et al. (2004) found a similar positive correlation in faunal samples from archaeological sites spanning a long time period in central Russia; their oxygen isotope analysis indicates that the correlation is related to precipitation differences among the sites. Liu et al. (2012) likewise found a positive correlation in Neolithic samples from northern China, which they attribute at least in part to aridity differences among sites.

To investigate this further, we reduced the data set to only Mongolian human samples and then checked for cross-correlations of isotope ratios, temperature and precipitation. Temperature and precipitation data are based on 2-km PRISM-modelled data from 1961 to 1990 obtained from Climate Source, Inc. (Climate Source, 2013; see Supplemental Table S2-1). The Climate Source data was provided in the form of georeferenced raster maps of Mongolian annual and monthly temperature and precipitation data. The corresponding data for each site's location was then determined using a GIS. Growing season data was computed by averaging the monthly data for the months between May and September, inclusive. Note that this represents the environmental conditions for the burial sites rather than the unknown but presumably nearby living areas.

The Mongolian human data set has a fairly strong correlation between $\delta^{13}C$ and $\delta^{15}N$ ($R=0.62$, $df=75$, $p<0.01$). However, when controlled for growing season (May to September) temperature, the correlation drops dramatically ($R=0.26$, $df=72$, $p=0.03$). Carbon and nitrogen isotopes are incorporated into plant tissue during the growing season, so growing season environmental conditions are commonly more strongly correlated with isotope ratios than are annual conditions, especially in highly seasonal environments (e.g., Fenner and Frost, 2009). Somewhat surprisingly for such an arid region, controlling for growing season precipitation has less effect ($R=0.44$, $df=72$, $p<0.01$). Growing season temperature and precipitation are themselves strongly correlated ($R=-0.73$, $df=75$, $p<0.01$), so controlling for both has no more impact than controlling just for growing season temperature ($R=0.26$, $df=71$, $p=0.03$). Thus it appears that, while there is individual variation, growing season temperature affects both $\delta^{13}C$ and $\delta^{15}N$ in this region, with increasing temperatures linked to increased $\delta^{13}C$ and $\delta^{15}N$. Of course, the effect may be indirect such as through increased evapotranspiration in high temperature areas.

So how should these correlations affect our interpretations of the relative diets of ruling elites and non-elites in Mongol Empire period Mongolia? While temperature clearly affects the ratios, there is a lot of uncertainty in the relationship. We used interpolated modern temperature and precipitation data to assess modern and archaeological $\delta^{13}C$ and $\delta^{15}N$ correlations; data specific to the precise sample locations and time periods would likely improve the correlation but is not available. Likewise there may be a range of other environmental conditions such as light intensity which contribute to the correlation but are unknown for our samples. It would therefore be unwise to attempt a rigorous quantitative evaluation of the impact of environmental conditions on our isotope ratios. A provisional, qualitative assessment may however provide insight into the situation. We therefore computed regression equations for growing season temperature versus $\delta^{13}C$ and $\delta^{15}N$ (Figure 6). The slopes of these equations were then used to compute $\delta^{13}C$ and $\delta^{15}N$ values for each of the four sites of primary interest if temperature was adjusted to give an equal contribution to each site. That is, archaeological isotope ratios from the Mongol Empire and Bronze Age were adjusted to compensate for modern growing season temperature differences among sites. This does not assume that temperature is unchanged between the time periods; rather it assumes that the *relative* impact of temperature on isotope ratios at the three sites has not changed. As temperature has a strong geographical component, this is a reasonable (but unproven) assumption. We want to emphasise that this assessment has not accounted for many uncertainties and is not a rigorous analysis but simply a qualitative or at most semi-quantitative approach to see how much impact temperature had on the differences among sites. The result (Figure 7) indicates that when temperature is accounted for, the sites' $\delta^{13}C$ and $\delta^{15}N$ values all overlap to a large degree. Temperature-driven isotopic impacts are thus of the right direction and magnitude to account for the differences among the sites. This suggests that the isotopic differences among sites described above may not be caused by dietary differences per se, but rather by environmental differences that affect isotope ratios in the diet.

6. Conclusions

We analysed human collagen carbon and nitrogen ratios from three cemeteries in eastern Mongolia, and compared the result to ratios from faunal samples in one of the cemeteries, previously published data from post-Mongol Empire human remains, and a variety of human and faunal isotope data from the wider region. The data show substantial and significant clustering by site, with the ruling elite burials in Tavan Tolgoi having significantly higher isotope ratios than two other sites. By itself, this would suggest that the ruling elite had significantly different sources or proportions of protein in their diets. The high $\delta^{15}N$ values in particular suggest more animal products were included in the diet. That is consistent with historical sources which indicate a strong Mongolian preference for meat and, especially, the fermented milk beverage *koumiss*. The elite buried at Tavan Tolgoi with gold, silver and jade clearly had access to wealth, and could be expected to indulge in their dietary preferences. However, when considered in the context of samples from the wider region and in comparison with environmental data, it appears likely that the isotopic differences relate primarily to environmental differences among the sites rather than to substantial dietary differences. It is therefore not clear, despite very high $\delta^{15}N$ values, whether the ruling elite at Tavan Tolgoi ate substantially more meat or drank more *koumiss* than did the other populations.

If the true prehistoric environmental impact on $\delta^{13}C$ and $\delta^{15}N$ is similar to the modelled impact, then there are few or no isotopically-visible dietary differences among these ruling elite, local elite or commoners, and Bronze Age pastoralist populations. That would be surprising, given the differences in available resources and access to foods from throughout the Empire. Compact bone remodels slowly, so perhaps the elite died before an enriched diet affected their bone collagen isotope ratios. Or perhaps the isotopic effects of increased meat and milk are offset by other dietary changes in the elite, such as consumption of carp, millet or other assimilated foods.

There are a number of additional investigations which would help to understand Mongolian elite and commoner diet and movements during the Mongol Empire. Assessment of dietary composition and differences would be greatly aided by analysis of carbon isotopes from bone apatite. Apatite isotope data relate to the entire diet, rather than primarily to the protein portion of the diet as is the case for collagen (Ambrose and Norr, 1993). Of particular interest would be analysis of collagen amino acid $\delta^{15}N$, which can provide particularly strong evidence of relative trophic level (Naito et al., 2013). The link between collagen $\delta^{13}C$ and $\delta^{15}N$ and environmental parameters is intriguing, especially considering the linked depleted isotope ratios between horse and human in Tavan Tolgoi grave 10. Collagen isotope analysis could help identify immigrants to a population and to reduce the number of potential origin locations. This could be further investigated using enamel strontium isotope ratios to assess geologically-based variation (e.g., Bentley, 2006; Theden-Ringl et al., 2011), and bone and tooth apatite could also provide environmental information through the analysis of oxygen isotope ratios, which relate to temperature and precipitation levels (Bowen et al., 2009; Chenery et al., 2012; Levin et al., 2006). The investigation would also benefit greatly from larger sample sizes, both from the three cemeteries of primary interest and more broadly across eastern Mongolia. We plan to initiate a project that will locate more human and faunal remains and use multi-element stable isotope analyses to reveal more about ruling elite and non-elite Mongolian behaviour during the Mongol Empire period, one of the most important episodes in human history.

7. Acknowledgements

The authors thank Dr Rebecca Fraser and Dr Rachel Wood for helpful discussions about the collagen extraction procedure. Dr Ayato Kohzu kindly provided individual isotope data for the mammals summarised in Kohzu et al. (2009). Partial funding for this project was provided by a Research Development Grant from the Research School of Asia and the Pacific, College of Asia and the Pacific, The Australian National University.

8. References

Ambrose, S.H., 1990. Preparation and characterization of bone and tooth collagen for isotopic analysis. J. Archaeol. Sci. 17, 431–451.

Ambrose, S.H., 2000. Controlled Diet and Climate Experiments on Nitrogen Isotope Ratios of Rats, in Ambrose, S.H. and Katazenberg, M.A. (Eds), Biogeochemical Approaches to Paleodietary Analysis. Kluwer Academic, New York, pp. 243–259.

Ambrose, S.H., Norr, L., 1993. Experimental Evidence for the Relationship of the Carbon Isotope Ratios of Whole Diet and Dietary Protein to Those of Bone Collagen and Carbonate in Lambert, J.B. and Grupe, G. (Eds), Prehistoric Human Bone: Archaeology at the Molecular Level. Springer-Verlag, Berlin, pp. 1–37.

Arens, N.C., Jahren, A.H., Amundson, R., 2000. Can C3 plants faithfully record the carbon isotopic composition of atmospheric carbon dioxide? Paleobiology 26, 137–164.

Auerswald, K., Wittmer, M.H.O.M., Tungalag, R., Bai, Y., Schnyder, H., 2012. Sheep Wool delta C-13 Reveals No Effect of Grazing on the C-3/C-4 Ratio of Vegetation in the Inner Mongolia-Mongolia Border Region Grasslands. PLoS One 7.

Baatar, S., 2006. Tombs of Chingisids Are Still Being Found... An Interview with Senior Archaeologist, Professor Dorjpagma Navaan (M. Saruul-Erdene, Tran.). The Silk Road 4, 55–60.

Beckwith, C.I., 2009. Empires of the Silk Road : a history of Central Eurasia from the Bronze Age to the present. Princeton University Press, Princeton.

Bentley, R.A., 2006. Strontium Isotopes from the Earth to the Archaeological Skeleton: A Review. J. Archaeol. Method Theory 13, 135–187.

Bonafini, M., Pellegrini, M., Ditchfield, P., Pollard, A.M., 2013. Investigation of the ‘canopy effect’ in the isotope ecology of temperate woodlands. J. Archaeol. Sci. 40, 3926–3935.

Bowen, G.J., Ehleringer, J.R., Chesson, L.A., Thompson, A.H., Podlesak, D.W., Cerling, T.E., 2009. Dietary and physiological controls on the hydrogen and oxygen isotope ratios of hair from mid-20th century indigenous populations. Am. J. Phys. Anthropol. 139, 494–504.

Boyle, J.A., 1968. Kirakos of Ganjak on the Mongols. Cent. Asiatic J. 8, 199–214.

Braun, A., Schneider, S., Auerswald, K., Bellof, G., Schnyder, H., 2013. Forward Modeling of Fluctuating Dietary C-13 Signals to Validate C-13 Turnover Models of Milk and Milk Components from a Diet-Switch Experiment. PLoS One 8, e85235.

Buell, P.D., 1990. Pleasing the Palate of the Qan: Changing Foodways of the Imperial Mongols. Mongolian Stud. 13, 57–81.

Buell, P.D., Anderson, E.N., 2000. A soup for the Qan: Chinese dietary medicine of the Mongol era as seen in Hu Szu-Hui's Yin-shan cheng-yao: introduction, translation, commentary and Chinese text. Kegan Paul International, London.

Chenery, C.A., Pashley, V., Lamb, A.L., Sloane, H.J., Evans, J.A., 2012. The oxygen isotope relationship between the phosphate and structural carbonate fractions of human bioapatite. Rapid Commun. Mass Spectrom. 26, 309–319.

Climate Source, 2013. Data packages mn_precip and mn_tmean obtained August, 2013. http://www.climatesource.com/products.html.

Dawson, C., 1955. The Mission to Asia : narratives and letters of the Franciscan missionaries in Mongolia and China in the thirteenth and fourteenth centuries. Sheed & Ward, London.

de Rachewiltz, I., 2004. The secret history of the Mongols: a Mongolian epic chronicle of the thirteenth century. Brill, Leiden.

Deines, P., 1980. The Isotopic Composition of Reduced Organic Carbon. In Fritz, P. and Fontes, J. C. (Eds), Handbook of Environmental Isotope Geochemistry. Elsevier Scientific, Amsterdam, pp. 329–406.

Fenner, J.N., Frost, C.D., 2009. Modern Wyoming plant and pronghorn isoscapes and their implications for archaeology. J. Geochemical Exploration 102, 149–156.

Fernandes, R., M.-J. Nadeau, and P.M. Grootes, 2012. Macronutrient-based model for dietary carbon routing in bone collagen and bioapatite. Archaeol. Anthropol. Sci. 4(4), 291–301.

Fraser, R.A., Bogaard, A., Heaton, T., Charles, M., Jones, G., Christensen, B.T., Halstead, P., Merbach, I., Poulton, P.R., Sparkes, D., Styring, A.K., 2011. Manuring and stable nitrogen isotope ratios in cereals and pulses: towards a new archaeobotanical approach to the inference of land use and dietary practices. J. Archaeol. Sci. 38, 2790–2804.

Froehle, A.W., Kellner, C.M., Schoeninger, M.J., 2010. FOCUS: effect of diet and protein source on carbon stable isotope ratios in collagen: follow up to Warinner and Tuross (2009). J. Archaeol. Sci. 37, 2662–2670.

Golden, P.B., 2011. Central Asia in world history. Oxford University Press, Oxford ; New York.

Hedges, R.E.M., Stevens, R.E., Koch, P.L., 2005. Isotopes in Bones and Teeth, in Leng, M.J. (Ed), Isotopes in Palaeoenvironmental Research. Springer, Dordrecht, The Netherlands, pp. 117–145.

Hou, L., Hu, Y., Zhao, X., Li, S., Wei, D., Hou, Y., Hu, B., Lv, P., Li, T., Song, G., Wang, C., 2013. Human subsistence strategy at Liuzhuang site, Henan, China during the proto-Shang culture (~2000–1600 BC) by stable isotopic analysis. J. Archaeol. Sci. 40, 2344–2351.

Huelsemann, F., Koehler, K., Braun, H., Schaenzer, W., Flenker, U., 2013. Human dietary $\delta^{15}N$ intake: Representative data for principle food items. Am. J. Phys. Anthropol. 152, 58–66.

Iacumin, P., Nikolaev, V., Genoni, L., Ramigni, M., Ryskov, Y.G., Longinelli, A., 2004. Stable isotope analyses of mammal skeletal remains of Holocene age from European Russia: A way to trace dietary and environmental changes. Geobios 37, 37–47.

Jackson, P., 1990. The mission of Friar William of Rubruck : his journey to the court of the Great Khan Möngke 1253-1255. Hakluyt Society, London.

Jim, S., Jones, V., Ambrose, S.H., Evershed, R.P., 2006. Quantifying dietary macronutrient sources of carbon for bone collagen biosynthesis using natural abundance stable carbon isotope analysis. Br. J. Nutr. 95, 1055–1062.

Johannesson, E.G., 2011. Landscapes of Death, Monuments of Power: Mortuary Practice, Power, and Identity in Bronze-Iron Age Mongolia. Unpublished PhD Dissertation, University of North Carolina, Chapel Hill.

Jones, S., Quinn, R., 2009. Prehistoric Fijian diet and subsistence: integration of faunal, ethnographic, and stable isotopic evidence from the Lau Island Group. J. Archaeol. Sci. 36, 2742–2754.

Katzenberg, M.A., McKenzie, H.G., Losey, R.J., Goriunova, O.I., Weber, A., 2012. Prehistoric dietary adaptations among hunter-fisher-gatherers from the Little Sea of Lake Baikal, Siberia, Russian Federation. J. Archaeol. Sci. 39, 2612–2626.

Kelly, J.F., 2000. Stable isotopes of carbon and nitrogen in the study of avian and mammalian tropic ecology. Can. J. Zool. 78, 1–27.

Kohzu, A., Iwata, T., Kato, M., Nishikawa, J., Wada, E., Amartuvshin, N., Namkhaidorj, B., Fujita, N., 2009. Food webs in Mongolian grasslands: The analysis of 13C and 15N natural abundances. Isotopes Env. Health Stud. 45, 208–219.

Lane, G., 2009a. Daily life in the Mongol empire. Hackett Pub. Co, Indianapolis.

Lane, G., 2009b. Genghis Khan and Mongol rule. Hackett Pub. Co, Indianapolis.

Lee-Thorp, J.A., 2008. On Isotopes and Old Bones. Archaeometry 50, 925–950.

Levin, N.E., Cerling, T.E., Passey, B.H., Harris, J.M., Ehleringer, J.R., 2006. A stable isotope aridity index for terrestrial environments. Proc. Nat. Acad. Sci. 103, 11201–11205.

Liu, X., Jones, M.K., Zhao, Z., Liu, G., O'Connell, T.C., 2012. The earliest evidence of millet as a staple crop: New light on neolithic foodways in North China. Amer. J. Phy. Anthropol. 149, 283–290.

Longin, R.,1971. New method of collagen extraction for radiocarbon dating. Nature 230(5291), 241–242.

Makarewicz, C., Tuross, N., 2006. Foddering by Mongolian pastoralists is recorded in the stable carbon (d13C) and nitrogen (d15N) isotopes of caprine dentinal collagen. J. Archaeol. Sci. 33, 862–870.

Man, J., 2004. Genghis Khan: life, death, and resurrection. Thomas Dunne Books, New York.

Mannino, M.A., Di Salvo, R., Schimmenti, V., Di Patti, C., Incarbona, A., Sineo, L., Richards, M.P., 2011. Upper Palaeolithic hunter-gatherer subsistence in Mediterranean coastal environments: an isotopic study of the diets of the earliest directly-dated humans from Sicily. J. Archaeol. Sci. 38, 3094–3100.

Millard, A.R., Jimenez-Cano, N.G., Lebrasseur, O., Sakai, Y., in press. Isotopic Investigation of Animal Husbandry in the Welsh and English Periods at Dryslwyn Castle, Carmarthenshire, Wales. Intern. J. Osteoarchaeol.

Murphy, E.M., Schulting, R., Beer, N., Chistov, Y., Kasparov, A., Pshenitsyna, M., 2013. Iron Age pastoral nomadism and agriculture in the eastern Eurasian steppe: implications from dental palaeopathology and stable carbon and nitrogen isotopes. J. Archaeol. Sci. 40, 2547–2560.

Navaan, D., Tumen, D., Erdene, M., Khatanbaatar, D., Ankhsanaa, G., 2009. Archaeological Fieldwork in 2009 within the Research Project “Eastern Mongolia”. Mongolian J. Anthrop. Archaeol. Ethnology 5(1), 1-53. (in Mongolian)

Naito, Y.I., Chikaraishi, Y., Ohkouchi, N., Drucker, D.G., Bocherens, H., in press. Nitrogen isotopic composition of collagen amino acids as an indicator of aquatic resource consumption: insights from Mesolithic and Epipalaeolithic archaeological sites in France. World Archaeol. 45, 338-359.

O’Connell, T.C., Kneale, C.J., Tasevska, N., Kuhnle, G.G.C., 2012. The diet-body offset in human nitrogen isotopic values: A controlled dietary study. Amer. J. Phy. Anthropol. 149, 426–434.

Pate, F.D., Anson, T.J., 2008. Stable Nitrogen Isotope Values in Arid-Land Kangaroos Correlated with Mean Annual Rainfall: Potential as a Paeloclimatic Indicator. Intern. J. Osteoarchaeol. 18, 317–326.

Privat, K., 2004. Investigation of the Diet of Eurasian Bronze and Iron Age Populations, Focusing on Terrestrial versus Freshwater Resources. Unpublished PhD Dissertation, University of Oxford.

Pyankov, V.I., Gunin, P.D., Tsoog, S., Black, C.C., 2000. C4 plants in the vegetation of Mongolia: Their natural occurrence and geographical distribution in relation to climate. Oecologia 123, 15–31.

Ramsey, C.B., 2001. Development of the Radiocarbon Program OxCal. Radiocarbon 43, 355-363

Ramsey, C.B., 2009. Bayesian Analysis of Radiocarbon Dates. Radiocarbon 51, 337-360.

Reimer, P., Bard E., Bayliss, A., Beck, J.W., Blackwell, P.G., Ramsey, C.B., Grootes, P.M., Guilderson, T.P., Haflidason, H., Hajdas, I., Hatte, C., Heaton, T., Hoffman, D.L., Hogg, A.G., Hughen, K.A., Kaiser, K.F., Kromer, B., Manning, S.W., Niu, M., Reimer, R.W., Richards, D.A., Scott, E.M., Southon, J.R., Staff, R.A., Turney, C.S.M., van der Plicht, J., 2013. IntCal13 and Marine13 Radiocarbon Age Calibration Curves 0–50,000 Years cal BP. Radiocarbon 55, 1869–1887.

Reitsema, L.J., 2013. Beyond diet reconstruction: Stable isotope applications to human physiology, health, and nutrition. Am. J. Hum. Biol. 25, 445–456.

Ruxton, G.D., 2006. The unequal variance t-test is an underused alternative to Student's t-test and the Mann-Whitney U test. Behav. Ecol. 17: 688–690.

Svyatko, S.V., Schulting, R.J., Mallory, J., Murphy, E.M., Reimer, P.J., Khartanovich, V.I., Chistov, Y.K., Sablin, M.V., 2013. Stable isotope dietary analysis of prehistoric populations from the Minusinsk Basin, Southern Siberia, Russia: a new chronological framework for the introduction of millet to the eastern Eurasian steppe. J. Archaeol. Sci. 40, 3936–3945.

Tieszen, L.L., Fagre, T.,1993. Carbon Isotope Variability in Modern and Archaeological Maize. J. Archaeol. Sci. 20: 25–40.

Theden-Ringl, F., Fenner, J.N., Wesley, D., Lamilami, R., 2011. Buried on foreign shores: Isotope analysis of the origin of human remains recovered from a Macassan site in Arnhem Land. Aust. Archaeol. 73, 41–48.

Thompson, A.H., Chesson, L.A., Podlesak, D.W., Bowen, G.J., Cerling, T.E., Ehleringer, J.R., 2010. Stable isotope analysis of modern human hair collected from Asia (China, India, Mongolia, and Pakistan). Amer. J. Phy. Anthropol. 141, 440–451.

Tumen, D., Navaan, D., Erdene, M., 2006. Archaeology of the Mongolian Period: A Brief Introduction. The Silk Road 4, 51–55.

Tumen, D., 2009. 2008/2009 Research Project Report, Eastern Mongolia: Anthropological and Archaeological Approach. Department of Archaeology and Anthropology, National University of Mongolia, Ulaanbaatar. Available from the author.

Tumen, D., 2010. 2009/2010 Research Project Report, Eastern Mongolia: Anthropological and Archaeological Approach. Department of Archaeology and Anthropology, National University of Mongolia, Ulaanbaatar. Available from the author.

Tumen, D., 2011. 2010/2011 Research Project Report, Eastern Mongolia: Anthropological and Archaeological Approach. Department of Archaeology and Anthropology, National University of Mongolia, Ulaanbaatar. Available from the author.

Turner, B.L., Klaus, H.D., Livengood, S.V., Brown, L.E., Saldaña, F., Wester, C., 2013. The variable roads to sacrifice: Isotopic investigations of human remains from Chotuna-Huaca de los Sacrificios, Lambayeque, Peru. Amer. J. Phy. Anthropol. 151, 22–37.

Turner, B.L., Zuckerman, M.K., Garofalo, E.M., Wilson, A., Kamenov, G.D., Hunt, D.R., Amgalantugs, T., Frohlich, B., 2012. Diet and death in times of war: isotopic and osteological analysis of mummified human remains from southern Mongolia. J. Archaeol. Sci. 39, 3125–3140.

Tykot, R.H., 2002. Contribution of Stable Isotope Analysis to Understanding Dietary Variation among the Maya. In: Jakes, K.A. (Ed.), Archaeological Chemistry: Materials, Methods and Meaning, ACS Symposium Series. American Chemical Society, pp. 214–230.

Tykot, R.H., 2004. Stable isotopes and diet: You are what you eat. Phys. Methods Archaeometry, Proceedings of the International School of Physics. IOS Press, Amsterdam, pp. 433–444.

Ugan, A., Coltrain, J., 2011. Variation in collagen stable nitrogen values in black-tailed jackrabbits (Lepus californicus) in relation to small-scale differences in climate, soil, and topography. J. Archaeol. Sci. 38, 1417–1429.

Valentin, F., Bocherens, H., Gratuze, B., Sand, C., 2006. Dietary patterns during the late prehistoric/historic period in Cikobia island (Fiji): insights from stable isotopes and dental pathologies. J. Archaeol. Sci. 33, 1396–1410.

Ventresca Miller, A., Usmanova, E., Logvin, V., Kalieva, S., Shevnina, I., Logvin, A., Kolbina, A., Suslov, A., Privat, K., Haas, K., Rosenmeier, M., 2014. Subsistence and social change in central Eurasia: stable isotope analysis of populations spanning the Bronze Age transition. J. Archaeol. Sci. 42, 525–538.

Weatherford, J.M., 2010. The secret history of the Mongol queens: how the daughters of Genghis Khan rescued his empire. Broadway Paperbacks, New York.

Webb, E., White, C., Longstaffe, F., 2013. Dietary shifting in the Nasca Region as inferred from the carbon- and nitrogen-isotope compositions of archaeological hair and bone. J. Archaeol. Sci. 40, 129–139.

Weber, A.W., White, D., Bazaliiskii, V.I., Goriunova, O.I., Savel'ev, N.A., Anne Katzenberg, M., 2011. Hunter–gatherer foraging ranges, migrations, and travel in the middle Holocene Baikal region of Siberia: Insights from carbon and nitrogen stable isotope signatures. J. Anthropol. Archaeol. 30, 523–548.

Youn, M., Kim, J.C., Kim, H.K., Tumen, D., Navaan, D., Erdene, M., 2007. Dating the Tavan Tolgoi site, Mongolia: Burials of the nobility from Genghis Khan's era. Radiocarbon 49, 685–691.

Table 1. Human Bone Samples Analysed and Associated Grave Goods.

Site	Grave	Id	Bone Analyzed	Excavation Year	Estimated Age and Sex	Associated Burial Goods
Tavan Tolgoi	1	2A	humerus	2004	Adult Female	Headless horse; Saddle with gold bow; Two gold rings, each with the image of a falcon on the inner surface
	2	2B	radius	2004	Adult Male	Silk material; *jins* (large pearl set on flower-shaped base; high status marker)
	4	2D	tibia	2004	Adult; Probable Male	Sheep and horse bones; stirrup; birchbark quiver with four arrowheads.
	5	5D	humerus	2005	Adult Female	Horse head with harness; Horse with saddle with golden bow-plate with a dragon image; gold ring; gold crown; gold earrings; golden container with black powder inside; silver pot, bowl containing grain; jade image of a human; bronze mirror wrapped in cloth; silk garment; leather boots.
	7	5E	radius	2005	Adult; Probable Male	Grave disturbed. Golden earring; saddle with bone trim; copper and iron buttons and belt buckle; birch bark
	10	3A	ulna	2007	Adult Male	Earring
	11	3B	humerus	2007	Adult Male	Crystal necklace
Tsagaan chuluut	1	4B	radius	2009	Adult Male	Silver bowl; birch bark quiver with three arrows; iron loop.
	2	4A	radius	2009	Unknown	Bronze buckle; corroded iron objects; pottery fragments; animal bones.
	4	4D	tibia	2009	Unknown	Two silver earrings; scissors.
	6	7B	ulna	2010	Unknown	Disturbed. Three arrow points; iron knife.
	10	7F	femur	2010	Adult Male	Disturbed. Arrow weight; Green spot on skull probably result of degraded bronze object.
	18	7A	femur	2010	Unknown	Three beads; scissors; iron knife; bronze mirror; birch bark; animal scapula and tibia.
	126	4C	humerus	2008	Adult Male	7 iron arrowheads; one bone arrowhead; horse bit; sheep bone.
	163	4E	femur	2009	Unknown	Bronze mirror; small scissors; 2 bronze arrowheads; stone beads; felt.
	164	7C	ulna	2010	Adult Male	Blacksmith tool; 15 arrow heads; bone arrow weight; 6 iron nails; 2 iron decorations; iron belt buckle; 5 bronze belt decorations; bone bow handle; birch bark; sheep tibia.
	165	7E	tibia	2010	Unknown	Iron knife; small bronze mirror; degraded iron object.
	166	7D	tibia	2010	Child	Disturbed. Iron knife; sheep tibia.
Ulaanzuukh	3	9B	radius	2010	Unknown	No artefacts.
	3a	9A	ulna	2010	Unknown	Stone and bone beads
	4	9C	ulna	2010	Unknown	Disturbed. No artefacts.

5A	8A	humerus	2009	Adult Male	No artefacts.
5B	9D	femur	2010	Adult Male	Disturbed. No artefacts.
6	8B	femur	2009	Child	No artefacts.
6	9E	tibia	2010	Adult Female	Pottery fragments; stone pestle.
7	6A	radius	2011	Child	No artefacts.
8	6B	tibia	2011	Child	No artefacts.
21	6C	femur	2011	Unknown	Pottery fragments.
41	1A	humerus	2008	Child	Disturbed. No grave goods.
42	1B	humerus	2008	Adult Male	Smoothed stone pendant.
63	6D	ulna	2011	Unknown	Birch bark object

Table 2. Radiocarbon Dates from Ulaanzuukh.

Grave	Sample Id	RCYBP	2σ Calibrated Date Range	Lab Id
3	9B	3006 ± 30	1382 to 1127 BC	IAAA-103373
5	8A	3082 ± 31	1420 to 1264 BC	IAAA-103368
6	8B	3101 ± 30	1431 to 1284 BC	IAAA-103369
6	9E	3127 ± 29	1493 to 1300 BC	IAAA-103372

Calibrated using OxCal v4.2 (Ramsey 2009) with the IntCal13 calibration curve (Reimer et al. 2013). All samples were from human bone.

Table 3. Tavan Tolgoi, Tsagaan chuluut, and Ulaanzuukh Stable Isotope Ratio Results.

Site	Grave	Species	ANU Id	Collagen Percent	%C	%N	C:N	$\delta^{13}C$	$\delta^{15}N$
Tavan Tolgoi	1	Human	2A	16	42.3	15.4	3.2	-16.1	14.6
	2	Human	2B	16	36.5	13.5	3.2	-15.6	14.7
	4	Human	2D	21	42.6	15.7	3.2	-14.7	14.1
	5	Human	5D	15	43.1	15.9	3.2	-16.4	14.9
	7	Human	5E	13	43.1	16.0	3.1	-16.5	14.4
	10	Human	3A	21	43.3	15.8	3.2	-16.8	11.5
	11	Human	3B	16	41.4	15.2	3.2	-16.3	13.5
Tsagaan chuluut	1	Human	4B	19	43.4	15.8	3.2	-16.3	12.2
	2	Human	4A	20	43.0	15.7	3.2	-16.1	11.5
	4	Human	4D	14	40.2	15.0	3.1	-17.4	12.9
	6	Human	7B	14	42.8	15.7	3.2	-17.1	12.8
	10	Human	7F	19	41.3	15.2	3.2	-13.9	10.6
	18	Human	7A	16	41.8	15.4	3.2	-17.4	10.2
	126	Human	4C	14	43.0	15.7	3.2	-18.3	10.9
	163	Human	4E	14	42.3	15.4	3.2	-16.4	10.9
	164	Human	7C	19	42.3	15.6	3.2	-16.6	11.1
	165	Human	7E	11	40.6	14.9	3.2	-17.1	11.1
	166	Human	7D	19	41.7	15.4	3.2	-17.1	11.1
Ulaanzuukh	3	Human	9B	16	42.1	15.5	3.2	-17.1	12.3
	4	Human	9C	17	41.5	15.2	3.2	-17.4	12.5
	5	Human	8A	14	41.4	15.2	3.2	-16.9	12.4
	5	Human	9D	9	38.7	14.1	3.2	-18.3	12.6
	6	Human	8B	19	42.8	15.7	3.2	-16.5	13.8
	6	Human	9E	6	34.9	12.7	3.2	-17.1	12.0
	7	Human	6A	11	40.5	14.8	3.2	-16.5	12.9
	8	Human	6B	18	41.9	15.5	3.2	-16.3	13.6
	21	Human	6C	16	41.0	15.1	3.2	-16.8	13.0
	41	Human	1A	14	42.2	15.5	3.2	-16.6	10.8
	42	Human	1B	13	42.6	15.5	3.2	-17.7	10.9
	63	Human	6D	15	41.1	14.9	3.2	-16.0	11.9

	3a	Human	9A	16	41.3	15.2	3.1	-18.5	10.6
Tavan Tolgoi	2	Horse	2C	NR	41.3	15.3	3.2	-18.0	7.6
	4	Horse	5A	16	37.6	13.9	3.1	-17.4	7.6
	10	Horse	5F	15	41.4	15.4	3.1	-19.3	4.9
	85	Horse	5G	13	41.2	15.4	3.2	-19.8	5.7
	4	Ovicaprid	5B	12	40.6	14.9	3.2	-15.8	10.2
	5	Ovicaprid	5C	14	42.9	15.8	3.2	-18.7	7.8

$\delta^{13}C$, $\delta^{15}N$, collagen percent and C:N atomic ratio are averages of multiple sample runs. %C and %N are minimum values of multiple sample runs. NR: Not recorded.

Table 4. Tavan Tolgoi, Tsagaan chuluut, and Ulaanzuukh Stable Isotope Ratio Summary Statistics

Site	Species	n	Mean $\delta^{13}C \pm 1\sigma$	Minimum $\delta^{13}C$	Maximum $\delta^{13}C$	$\delta^{13}C$ Inter-Quartile Range	Mean $\delta^{15}N \pm 1\sigma$	Minimum $\delta^{15}N$	Maximum $\delta^{15}N$	$\delta^{15}N$ Inter-Quartile Range
Tavan Tolgoi	Human	7	-16.0 ± 0.7	-16.8	-14.7	0.96	14.0 ± 1.2	11.5	14.9	1.22
Tsagaan chuluut	Human	11	-16.7 ± 1.1	-18.3	-14.0	1.03	11.4 ± 0.9	10.2	12.9	1.30
Ulaanzuukh	Human	13	-17.1 ± 0.8	-18.5	-16.0	1.04	12.3 ± 1.0	10.6	13.8	1.56
Tavan Tolgoi	Horse	4	-18.6 ± 1.1	-19.8	-17.4	-	6.5 ± 1.4	4.9	7.6	-
Tavan Tolgoi	Ovicaprid	2	-17.3 ± 2.1	-18.7	-15.8	-	9.0 ± 1.7	7.8	10.2	-
Hets Mtn Cave	Human	5	-15.4 ± 0.4	-16.0	-15.0	0.78	15.0 ± 1.0	13.4	15.9	2.18

Hets Mountain Cave data from Turner et al. (2012).

Table 5. Mongolian Site Human Collagen Isotope Ratio Mean Value Comparison Tests

	Tavan Tolgoi	Tsagaan chuluut w/ 7F	Tsagaan chuluut w/o 7F	Ulaanzuukh	Hets Mtn Cave
Tavan Tolgoi	-	**0.00**	**0.00**	**0.01**	0.14
Tsagaan chuluut w/ 7F	0.14	-	-	**0.04**	**0.00**
w/o 7F	**0.02**	-	-	0.07	**0.00**
Ulaanzuukh	**0.01**	0.28	0.59	-	**0.00**
Hets Mountain Cave	0.08	**0.01**	**0.00**	**0.00**	-

Values shown are probabilities for rejecting the default hypothesis of no difference between group means. $\delta^{13}C$ probabilities are shown below the diagonal; $\log_{10}\delta^{15}N$ probabilities are shaded and above the diagonal. Based on *t* tests not assuming equal variance. Tests were run with and without outlier Tsagaan chuluut 7F. All analyses exclude samples Hets Mountain Cave 3C and Ulaanzuukh 6D (see text). Tests which reject the null hypothesis at the 0.05 level are shown in bold.

Figures

Figure 1. Map of modern Mongolia and region. Sites mentioned in the text: 1. Tavan Tolgoi; 2. Tsagaan chuluut; 3. Ulaanzuukh; 4. Hets Mountain Cave.

Figure 2. Precious goods found at Tavan Tolgoi. A,B: Gold rings from Grave 1. C,D: Front and back views of golden bogtog hat worn by elite Mongolian women from Grave 5. E: Natural crystal belt decorations from Grave 11. Color image is available on the online edition.

Figure 3. Images of falcons on the inside of gold rings from Tavan Tolgoi grave 1. The outside of these rings are shown in Figure 2. Color image is available on the online edition.

Figure 4. Stable carbon and nitrogen isotope ratio results for four Mongolian sites. Data for Hets Mountain Cave site from Turner et al. (2012); all other data from this project.

Figure 5. Regional $\delta^{13}C$ and $\delta^{15}N$ data. Data and references are provided in Supplemental Table S2-1.

Figure 6. $\delta^{13}C$ and $\delta^{15}N$ correlation with growing season temperature. Human samples from within Mongolia only.

Figure 7. $\delta^{13}C$ and $\delta^{15}N$ after adjusting Tavan Tolgoi $\delta^{13}C$ and $\delta^{15}N$ using a regression against modern Tsagaan chuluut and Ulaanzuukh growing season temperatures. This is intended only to show how one aspect of the environment can be sufficient to create differences among groups exclusive of any dietary differences.

Supplements

Supplemental Appendix A: Radiocarbon Analysis of Tavan Tolgoi

Supplemental Table S2-1: Detailed Mongolia Region Isotopic and Environmental Data

Food Fit for a Khan: Stable Isotope Analysis of the Elite Mongol Empire Cemetery at Tavan Tolgoi, Mongolia

Jack N. FENNER, TUMEN Dashtseveg and KHATANBAATAR Dorjpurev

Supplemental Appendix 1

Radiocarbon Analysis of Tavan Tolgoi

As noted in the text, Youn et al. (2007) provide seven radiocarbon dates for the Tavan Tolgoi site, six of which likely date the internments in the cemetery. We have used these radiocarbon dates with OxCal Boundary functions to create posterior density functions (PDF) for the start and end dates of the cemetery (Ramsey, 2001). The OxCal version 4.2 code used is shown in Figure A1-1. The resulting PDF 2-σ range for the start of the cemetery spans the period from AD 1048 to 1255, while the termination of the cemetery dates to A.D. 1175 to 1347. A closer look at the probabilities associated with the PDFs is provided in in Figure A1-2, in which the area under the curves has been integrated at sequential dates to show the probability that the date range begins and ends for dates from the period. Most importantly there is a 50% chance the latest date represented by the radiocarbon data is before AD 1260, and a 90% chance it is before A.D. 1300. This indicates that the Tavan Tolgoi internments most likely happened during the early Mongol Empire period.

It also appears to have only been in use for a relatively short time span, with a 2σ span of 142 years and a 50% probability of only 35 years.

```
Plot()
 {
  Curve("IntCal09","IntCal09.14c");
  Sequence()
  {
   Boundary("Tavan Tolgoi Start");
   Phase()
   {
    R_Date("SNU05-016",860,60);
    R_Combine("Grave 1")
    {
       // Combine two dates from bones in
       // the same grave.
       R_Date("SNU05-040",890,40);
       R_Date("SNU05-537",670,90);
    };
    R_Date("SNU05-536",770,200);
    R_Date("SNU05-538",790,40);
    // Omit SNU05-539 due to likely
    // old or heritage wood problem
    // R_Date("SNU05-539",1680,60);
    R_Date("SNU05-540",830,40);
    // Compute the span or duration function
    Span("Tavan Tolgoi Span");
   };
   Boundary("Tavan Tolgoi End");
  };
 };
};
```

Figure A1-1. OxCal code used in creating the TavanTolgoi Start and End posterior density functions.

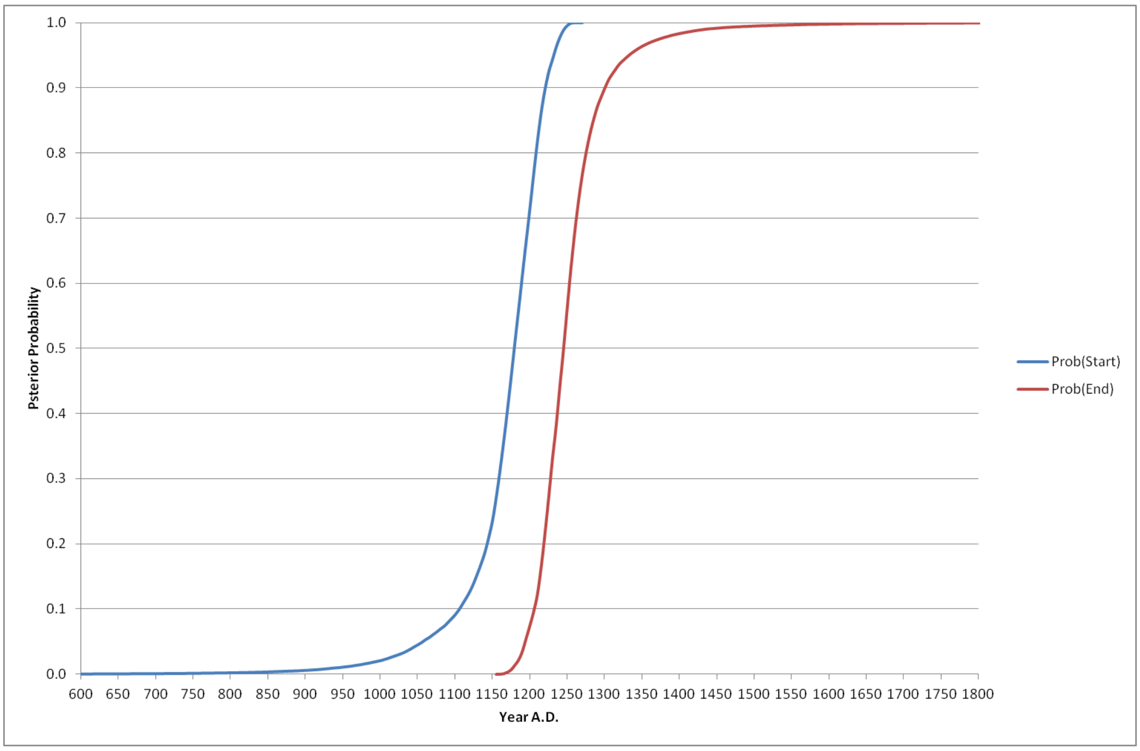

Figure A1-2. Probability functions of the Tavan Tolgoi cemetery start and end dates. Based on integrating (summing the probabilities) of prior years for each year from AD 600 to 1800. Based on six radiocarbon dates which are assumed to represent the cemetery use period.

Reference

Ramsey, C.B., 2001. Development of the radiocarbon program OxCal. Radiocarbon 43, 355–363.

Food Fit for a Khan: Stable Isotope Analysis of the Elite Mongol Empire Cemetery at Tavan Tolgoi, Mongolia

Jack N. FENNER, TUMEN Dashtseveg and KHATANBAATAR Dorjpurev

Supplemental Appendix 2

Table S2-1. Detailed Mongolia Region Isotopic and Environmental Data

Location	Species	Id	n	δ^{13}C	δ^{15}N	Longitude	Latitude	Growing Season Temp. (°C)	Growing Season Precip. (mm)	Source
Tavan Tolgoi	Human	2A-A	1	-16.07	14.56	112.72	45.1	16.5	165	This study
Tavan Tolgoi	Human	2B-A	1	-15.57	14.71	112.72	45.1	16.5	165	This study
Tavan Tolgoi	Human	2D-A	1	-14.69	14.08	112.72	45.1	16.5	165	This study
Tavan Tolgoi	Human	3A-A	1	-16.75	11.51	112.72	45.1	16.5	165	This study
Tavan Tolgoi	Human	3B-A	1	-16.30	13.49	112.72	45.1	16.5	165	This study
Tavan Tolgoi	Human	5D-A	1	-16.40	14.91	112.72	45.1	16.5	165	This study
Tavan Tolgoi	Human	5E-A	1	-16.53	14.41	112.72	45.1	16.5	165	This study
Tavan Tolgoi	Horse	2C-A	1	-18.01	7.64	112.72	45.1	16.5	165	This study
Tavan Tolgoi	Horse	5A-1-A	1	-17.50	7.69	112.72	45.1	16.5	165	This study
Tavan Tolgoi	Horse	5A-2-A	1	-17.23	7.54	112.72	45.1	16.5	165	This study
Tavan Tolgoi	Horse	5A-3-A	1	-17.40	7.54	112.72	45.1	16.5	165	This study
Tavan Tolgoi	Horse	5F-A	1	-19.27	4.88	112.72	45.1	16.5	165	This study
Tavan Tolgoi	Horse	5G-A	1	-19.77	5.71	112.72	45.1	16.5	165	This study
Tavan Tolgoi	Caprid	5B-A	1	-15.78	10.16	112.72	45.1	16.5	165	This study
Tavan Tolgoi	Caprid	5C-A	1	-18.74	7.81	112.72	45.1	16.5	165	This study

Location	Species	Id	n	δ13C	δ15N	Longitude	Latitude	Growing Season Temp. (°C)	Growing Season Precip. (mm)	Source
Tsagaanchuluut	Human	4A-A	1	-16.06	11.55	115.04	49.09	14.4	274	This study
Tsagaanchuluut	Human	4B-A	1	-16.33	12.17	115.04	49.09	14.4	274	This study
Tsagaanchuluut	Human	4C-A	1	-18.34	10.91	115.04	49.09	14.4	274	This study
Tsagaanchuluut	Human	4D-A	1	-17.39	12.91	115.04	49.09	14.4	274	This study
Tsagaanchuluut	Human	4E-A	1	-16.43	10.87	115.04	49.09	14.4	274	This study
Tsagaanchuluut	Human	7A-A	1	-17.36	10.23	115.04	49.09	14.4	274	This study
Tsagaanchuluut	Human	7B-A	1	-17.14	12.84	115.04	49.09	14.4	274	This study
Tsagaanchuluut	Human	7C-A	1	-16.56	11.09	115.04	49.09	14.4	274	This study
Tsagaanchuluut	Human	7D-A	1	-17.10	11.07	115.04	49.09	14.4	274	This study
Tsagaanchuluut	Human	7E-A	1	-17.05	11.09	115.04	49.09	14.4	274	This study
Tsagaanchuluut	Human	7F-A	1	-13.95	10.63	115.04	49.09	14.4	274	This study
Ulaanzuukh	Human	1A-A	1	-16.59	10.77	111.86	46.65	15.6	211	This study
Ulaanzuukh	Human	1B-A	1	-17.68	10.87	111.86	46.65	15.6	211	This study
Ulaanzuukh	Human	6A-A	1	-16.46	12.86	111.86	46.65	15.6	211	This study
Ulaanzuukh	Human	6B-A	1	-16.28	13.62	111.86	46.65	15.6	211	This study
Ulaanzuukh	Human	6C-A	1	-16.82	13.01	111.86	46.65	15.6	211	This study
Ulaanzuukh	Human	6D-A	1	-16.00	11.89	111.86	46.65	15.6	211	This study
Ulaanzuukh	Human	8A-A	1	-16.95	12.38	111.86	46.65	15.6	211	This study
Ulaanzuukh	Human	8B-A	1	-16.49	13.81	111.86	46.65	15.6	211	This study
Ulaanzuukh	Human	9A-A	1	-18.54	10.62	111.86	46.65	15.6	211	This study
Ulaanzuukh	Human	9B-A	1	-17.05	12.25	111.86	46.65	15.6	211	This study
Ulaanzuukh	Human	9C-A	1	-17.35	12.50	111.86	46.65	15.6	211	This study
Ulaanzuukh	Human	9D-A	1	-18.32	12.57	111.86	46.65	15.6	211	This study

Location	Species	Id	n	δ13C	δ15N	Longitude	Latitude	Growing Season Temp. (°C)	Growing Season Precip. (mm)	Source
Ulaanzuukh	Human	9E-A	1	-17.14	12.04	111.86	46.65	15.6	211	This study
Gacchurrt nomad	Human	Kohzu071	1	-18.47	9.03	107.18	48.02	11.6	247	Kohzu et al., 2009
Gacchurrt nomad	Human	Kohzu072	1	-17.67	8.81	107.18	48.02	11.6	247	Kohzu et al., 2009
Gacchurrt nomad	Human	Kohzu073	1	-18.47	9.96	107.18	48.02	11.6	247	Kohzu et al., 2009
Gacchurrt nomad	Human	Kohzu074	1	-17.22	10.40	107.18	48.02	11.6	247	Kohzu et al., 2009
Gacchurrt nomad	Human	Kohzu075	1	-17.97	9.83	107.18	48.02	11.6	247	Kohzu et al., 2009
Gacchurrt nomad	Human	Kohzu076	1	-18.07	9.45	107.18	48.02	11.6	247	Kohzu et al., 2009
Harahorin person	Human	Kohzu094	1	-18.17	9.78	102.84	47.2	12.8	250	Kohzu et al., 2009
Harahorin person	Human	Kohzu095	1	-19.05	9.77	102.84	47.2	12.8	250	Kohzu et al., 2009
Harahorin person	Human	Kohzu096	1	-18.90	10.16	102.84	47.2	12.8	250	Kohzu et al., 2009
Harahorin person	Human	Kohzu097	1	-19.28	9.62	102.84	47.2	12.8	250	Kohzu et al., 2009
Harahorin person	Human	Kohzu098	1	-18.18	9.11	102.84	47.2	12.8	250	Kohzu et al., 2009
Harahorin person	Human	Kohzu099	1	-18.55	8.35	102.84	47.2	12.8	250	Kohzu et al., 2009
Khangai Mountains	Wolf	Kohzu103	1	-18.06	8.43	100.9	47.5	10.8	269	Kohzu et al., 2009
Khangai Mountains	Wolf	Kohzu104	1	-18.45	7.79	100.9	47.5	10.8	269	Kohzu et al., 2009
Khangai Mountains	Wolf	Kohzu105	1	-17.86	8.47	100.9	47.5	10.8	269	Kohzu et al., 2009
Khangai Mountains	Wolf	Kohzu106	1	-18.56	8.17	100.9	47.5	10.8	269	Kohzu et al., 2009
Khangai Mountains	Wolf	Kohzu107	1	-18.06	8.67	100.9	47.5	10.8	269	Kohzu et al., 2009
Khangai Mountains	Wolf	Kohzu108	1	-17.81	8.62	100.9	47.5	10.8	269	Kohzu et al., 2009
Khangai Mountains	Wolf	Kohzu109	1	-17.90	8.68	100.9	47.5	10.8	269	Kohzu et al., 2009
Khangai Mountains	Wolf	Kohzu110	1	-17.79	8.49	100.9	47.5	10.8	269	Kohzu et al., 2009
Khangai Mountains	Wolf	Kohzu111	1	-18.10	6.79	100.9	47.5	10.8	269	Kohzu et al., 2009
Khangai Mountains	Wolf	Kohzu112	1	-18.12	6.85	100.9	47.5	10.8	269	Kohzu et al., 2009

Location	Species	Id	n	$\delta^{13}C$	$\delta^{15}N$	Longitude	Latitude	Growing Season Temp. (°C)	Growing Season Precip. (mm)	Source
Khangai Mountains	Wolf	Kohzu113	1	-18.12	7.82	100.9	47.5	10.8	269	Kohzu et al., 2009
Khangai Mountains	Wolf	Kohzu114	1	-17.84	7.33	100.9	47.5	10.8	269	Kohzu et al., 2009
Khangai Mountains	Wolf	Kohzu115	1	-17.93	8.31	100.9	47.5	10.8	269	Kohzu et al., 2009
Khangai Mountains	Wolf	Kohzu116	1	-17.91	8.25	100.9	47.5	10.8	269	Kohzu et al., 2009
Khangai Mountains	Wolf	Kohzu117	1	-18.23	8.84	100.9	47.5	10.8	269	Kohzu et al., 2009
Khangai Mountains	Wolf	Kohzu118	1	-18.21	8.53	100.9	47.5	10.8	269	Kohzu et al., 2009
Khangai Mountains	Wolf	Kohzu119	1	-18.12	7.49	100.9	47.5	10.8	269	Kohzu et al., 2009
Khangai Mountains	Wolf	Kohzu120	1	-17.91	7.66	100.9	47.5	10.8	269	Kohzu et al., 2009
Khangai Mountains	Wolf	Kohzu121	1	-18.75	7.60	100.9	47.5	10.8	269	Kohzu et al., 2009
Khangai Mountains	Wolf	Kohzu122	1	-17.81	8.86	100.9	47.5	10.8	269	Kohzu et al., 2009
Khangai Mountains	Fox	Kohzu100	1	-18.87	8.03	100.9	47.5	10.8	269	Kohzu et al., 2009
Khangai Mountains	Fox	Kohzu101	1	-19.02	7.85	100.9	47.5	10.8	269	Kohzu et al., 2009
Khangai Mountains	Fox	Kohzu102	1	-19.39	7.33	100.9	47.5	10.8	269	Kohzu et al., 2009
Khangai nomad	Human	Kohzu077	1	-17.04	10.34	100.93	47.52	10.9	288	Kohzu et al., 2009
Khangai nomad	Human	Kohzu078	1	-17.36	10.12	100.93	47.52	10.9	288	Kohzu et al., 2009
Khangai nomad	Human	Kohzu079	1	-17.19	11.07	100.93	47.52	10.9	288	Kohzu et al., 2009
Khangai nomad	Human	Kohzu080	1	-17.40	11.34	100.93	47.52	10.9	288	Kohzu et al., 2009
Khangai nomad	Human	Kohzu081	1	-17.73	11.31	100.93	47.52	10.9	288	Kohzu et al., 2009
Khangai nomad	Human	Kohzu082	1	-17.12	10.77	100.93	47.52	10.9	288	Kohzu et al., 2009
Khangai nomad	Human	Kohzu083	1	-17.64	11.28	100.93	47.52	10.9	288	Kohzu et al., 2009
Khangai nomad	Human	Kohzu084	1	-18.45	10.86	100.93	47.52	10.9	288	Kohzu et al., 2009
Khangai nomad	Human	Kohzu085	1	-17.11	11.31	100.93	47.52	10.9	288	Kohzu et al., 2009
Khangai nomad	Human	Kohzu086	1	-17.94	9.95	100.93	47.52	10.9	288	Kohzu et al., 2009

Location	Species	Id	n	δ13C	δ15N	Longitude	Latitude	Growing Season Temp. (°C)	Growing Season Precip. (mm)	Source
Khangai nomad	Human	Kohzu087	1	-17.12	10.83	100.93	47.52	10.9	288	Kohzu et al., 2009
Khangai nomad	Human	Kohzu088	1	-17.54	10.67	100.93	47.52	10.9	288	Kohzu et al., 2009
Ulaanbaatar person	Human	Kohzu089	1	-18.41	10.00	106.9	47.9	12.9	223	Kohzu et al., 2009
Ulaanbaatar person	Human	Kohzu090	1	-18.46	11.18	106.9	47.9	12.9	223	Kohzu et al., 2009
Ulaanbaatar person	Human	Kohzu091	1	-18.07	10.32	106.9	47.9	12.9	223	Kohzu et al., 2009
Ulaanbaatar person	Human	Kohzu092	1	-17.14	11.00	106.9	47.9	12.9	223	Kohzu et al., 2009
Ulaanbaatar person	Human	Kohzu093	1	-16.77	12.54	106.9	47.9	12.9	223	Kohzu et al., 2009
Baga Gazara´in Chuluu	Ovis aries	(all teeth)	25	-16.00	11.20	106	46.2	14.0	164	Makarewicz and Tuross, 2006
Baga Gazara´in Chuluu	Ovis ammon	(all teeth)	17	-17.70	11.20	106	46.2	14.0	164	Makarewicz and Tuross, 2006
Baga Gazara´in Chuluu	Capra sibirica	(all teeth)	7	-18.00	11.20	106	46.2	14.0	164	Makarewicz and Tuross, 2006
Baga Gazara´in Chuluu	Capra hircus	(all teeth)	9	-16.70	11.20	106	46.2	14.0	164	Makarewicz and Tuross, 2006
Ai-Dai, Siberia	Human	K1 M1 Sk1	1	-14.40	10.20	91.8	53			Murphy et al., 2013
Ai-Dai, Siberia	Human	K2 M1 Sk 4	1	-15.00	11.80	91.8	53			Murphy et al., 2013
Ai-Dai, Siberia	Human	K3 M1 Sk R	1	-13.80	11.50	91.8	53			Murphy et al., 2013
Ai-Dai, Siberia	Human	K3 M1 Sk2	1	-15.20	11.00	91.8	53			Murphy et al., 2013
Ai-Dai, Siberia	Human	K3 M2 Sk4	1	-14.60	10.20	91.8	53			Murphy et al., 2013
Ai-Dai, Siberia	Human	K4 M3 Sk 2	1	-14.70	10.20	91.8	53			Murphy et al., 2013
Ai-Dai, Siberia	Human	K4 M3 Sk 4	1	-12.80	9.90	91.8	53			Murphy et al., 2013
Ai-Dai, Siberia	Human	K4 M3 Sk 5	1	-14.20	10.40	91.8	53			Murphy et al., 2013
Ai-Dai, Siberia	Human	K4 M3 Sk7	1	-15.60	10.20	91.8	53			Murphy et al., 2013
Ai-Dai, Siberia	Human	K4 Sk1	1	-15.20	11.20	91.8	53			Murphy et al., 2013
Ai-Dai, Siberia	Human	K5 M1 Sk 3	1	-15.30	10.60	91.8	53			Murphy et al., 2013
Ai-Dai, Siberia	Human	K5 M1 Sk8	1	-15.50	10.80	91.8	53			Murphy et al., 2013

Location	Species	Id	n	δ13C	δ15N	Longitude	Latitude	Growing Season Temp. (°C)	Growing Season Precip. (mm)	Source
Ai-Dai, Siberia	Human	K6 M2 Sk2	1	-16.60	11.20	91.8	53			Murphy et al., 2013
Ai-Dai, Siberia	Human	K8 M2A Sk 1	1	-16.20	10.20	91.8	53			Murphy et al., 2013
Ai-Dai, Siberia	Human	K8 M2A Sk 2	1	-16.10	10.30	91.8	53			Murphy et al., 2013
Ai-Dai, Siberia	Human	K8 M2A Sk 3	1	-16.60	10.60	91.8	53			Murphy et al., 2013
Ai-Dai, Siberia	Human	K8 M2B Sk1	1	-15.30	10.40	91.8	53			Murphy et al., 2013
Ai-Dai, Siberia	Human	K8 M2B Sk2	1	-15.30	11.00	91.8	53			Murphy et al., 2013
Ai-Dai, Siberia	Dog	Ai-Dai IV, Trench 1	1	-15.70	9.30	91.8	53			Murphy et al., 2013
Ai-Dai, Siberia	Cattle	Ai-Dai II K4 M2	1	-20.80	6.30	91.8	53			Murphy et al., 2013
Aymyrlyg, Siberia	Human	??XXIII	1	-16.20	13.20	92.9	51.8			Murphy et al., 2013
Aymyrlyg, Siberia	Human	D. 7. Sk1(i)	1	-14.20	13.00	92.9	51.8			Murphy et al., 2013
Aymyrlyg, Siberia	Human	No context	1	-16.10	13.40	92.9	51.8			Murphy et al., 2013
Aymyrlyg, Siberia	Human	VI. 16. Sk4	1	-15.20	12.80	92.9	51.8			Murphy et al., 2013
Aymyrlyg, Siberia	Human	VII. 8. Sk1	1	-15.30	14.00	92.9	51.8			Murphy et al., 2013
Aymyrlyg, Siberia	Human	VIII. 17. Sk1	1	-14.70	13.50	92.9	51.8			Murphy et al., 2013
Aymyrlyg, Siberia	Human	VIII. 17. Sk2	1	-15.70	13.80	92.9	51.8			Murphy et al., 2013
Aymyrlyg, Siberia	Human	VIII. 54. Sk5	1	-13.60	13.00	92.9	51.8			Murphy et al., 2013
Aymyrlyg, Siberia	Human	XX. 10. Sk2	1	-16.20	13.90	92.9	51.8			Murphy et al., 2013
Aymyrlyg, Siberia	Human	XX. 10. Sk4	1	-16.80	13.60	92.9	51.8			Murphy et al., 2013
Aymyrlyg, Siberia	Human	XX. 7. Sk1	1	-13.90	12.30	92.9	51.8			Murphy et al., 2013
Aymyrlyg, Siberia	Human	XX. 7. Sk2	1	-13.90	12.90	92.9	51.8			Murphy et al., 2013
Aymyrlyg, Siberia	Human	XX. 7. Sk5	1	-13.20	11.80	92.9	51.8			Murphy et al., 2013
Aymyrlyg, Siberia	Human	XX. 8. Sk2	1	-15.50	13.30	92.9	51.8			Murphy et al., 2013
Aymyrlyg, Siberia	Human	XX. 9. Sk4	1	-17.20	14.00	92.9	51.8			Murphy et al., 2013

Location	Species	Id	n	δ13C	δ15N	Longitude	Latitude	Growing Season Temp. (°C)	Growing Season Precip. (mm)	Source
Aymyrlyg, Siberia	Human	XXI. 4. Sk4	1	-14.10	13.00	92.9	51.8			Murphy et al., 2013
Aymyrlyg, Siberia	Human	XXIII. 11. Sk1	1	-14.90	13.10	92.9	51.8			Murphy et al., 2013
Aymyrlyg, Siberia	Human	XXIII. 11. Sk3	1	-17.20	12.90	92.9	51.8			Murphy et al., 2013
Aymyrlyg, Siberia	Human	XXIII. 4	1	-17.50	13.80	92.9	51.8			Murphy et al., 2013
Aymyrlyg, Siberia	Human	XXIII. 8	1	-15.00	13.20	92.9	51.8			Murphy et al., 2013
Aymyrlyg, Siberia	Human	XXV. 16. Sk1	1	-15.10	13.10	92.9	51.8			Murphy et al., 2013
Aymyrlyg, Siberia	Horse	Aymyrlyg M35	1	-20.90	7.20	92.9	51.8			Murphy et al., 2013
Aymyrlyg, Siberia	Caprid	Aymyrlyg II K13	1	-19.00	9.40	92.9	51.8			Murphy et al., 2013
Aymyrlyg, Siberia	Caprid	Aymyrlyg XXXI	1	-19.10	7.10	92.9	51.8			Murphy et al., 2013
Beijing, Chi	Human	Thompson_001	12	-16.80	7.40	116.4	39.9			Thompson et al., 2010
Changchun, Chi	Human	Thompson_004	4	-16.50	8.40	125.3	43.8			Thompson et al., 2010
Chifeng, Chi	Human	Thompson_005	5	-15.40	7.50	118.9	42.3			Thompson et al., 2010
Duguitala, Chi	Human	Thompson_007	1	-16.30	8.60	108.7	40.6			Thompson et al., 2010
Dund Shandny, Mongolia	Human	Thompson_035	1	-16.70	12.60	107	46.2	14.9	154	Thompson et al., 2010
Erdenet, Mongolia	Human	Thompson_036	1	-17.30	8.70	104.1	49	12.7	317	Thompson et al., 2010
Heng yang, Chi	Human	Thompson_009	5	-18.50	9.00	112	43.6			Thompson et al., 2010
Kharkhorin, Mongolia	Human	Thompson_037	1	-17.20	10.40	102.8	47.2	12.6	254	Thompson et al., 2010
Lanzhou, Chi	Human	Thompson_011	5	-18.50	7.30	103.8	36.1			Thompson et al., 2010
Mandal Ovoo, Mongolia	Human	Thompson_038	1	-16.50	13.30	104	44.6	19.2	102	Thompson et al., 2010
Ri zhao, Chi	Human	Thompson_016	4	-17.20	7.60	119.5	35.4			Thompson et al., 2010
Toilogt, Mongolia	Human	Thompson_039	2	-17.50	8.00	100.3	50.7	9.7	250	Thompson et al., 2010
Tsegeen Nuur, Mongolia	Human	Thompson_040	1	-17.70	8.40	101.87	49.1	11.4	333	Thompson et al., 2010

Location	Species	Id	n	δ13C	δ15N	Longitude	Latitude	Growing Season Temp. (°C)	Growing Season Precip. (mm)	Source
Tsenkher Sum, Mongolia	Human	Thompson_041	1	-18.70	8.50	101.6	47.1	10.2	289	Thompson et al., 2010
Ulaanbaatar, Mongolia	Human	Thompson_042	11	-16.80	9.50	106.9	47.9	12.9	223	Thompson et al., 2010
Uus, Mongolia	Human	Thompson_043	1	-15.40	8.80	93	50.4	16.9	110	Thompson et al., 2010
Yinchuan, Chi	Human	Thompson_020	3	-16.90	8.80	106.2	38.5			Thompson et al., 2010
Hets Mountain Cave	Human	1-B Bone	1	-15.00	13.40	108.25	42.55	19.2	137	Turner et al., 2012
Hets Mountain Cave	Human	1-D Bone	1	-15.60	15.20	108.25	42.55	19.2	137	Turner et al., 2012
Hets Mountain Cave	Human	1-F Bone	1	-15.40	14.70	108.25	42.55	19.2	137	Turner et al., 2012
Hets Mountain Cave	Human	1-G Bone	1	-15.10	15.80	108.25	42.55	19.2	137	Turner et al., 2012
Hets Mountain Cave	Human	3-B Bone	1	-16.00	15.80	108.25	42.55	19.2	137	Turner et al., 2012
Hets Mountain Cave	Human	3-C Bone	1	-15.80	18.80	108.25	42.55	19.2	137	Turner et al., 2012

Modern $\delta^{13}C$ have been adjusted to remove the fossil fuel effect by adding +1.5‰. Hair $\delta^{13}C$ values have been adjusted to be comparable to collagen values by adding +1.5‰. Sites outside of Mongolia were not used in environmental modelling and do not have temperature and precipitation values in this table. They are, however, shown in Figure 3 in the main text. Latitude and longitude data were either given in the source or determined by comparison of a site location map shown in the source to Google Earth mapping. See the text for discussion on how the modern growing season temperature and precipitation data were calculated.

References

Makarewicz, C., Tuross, N., 2006. Foddering by Mongolian pastoralists is recorded in the stable carbon (d13C) and nitrogen (d15N) isotopes of caprine dentinal collagen. J. Archaeol. Sci. 33, 862–870.

Thompson, A.H., Chesson, L.A., Podlesak, D.W., Bowen, G.J., Cerling, T.E., Ehleringer, J.R., 2010. Stable isotope analysis of modern human hair collected from Asia (China, India, Mongolia, and Pakistan). Amer. J. Phy. Anthropol.141, 440–451.