Isotope Analysis of Human Remains from Several Mongolian Regions: Discovering the Relationship between the Desertification, Climate Change Impact and the Rise and Fall of the Mongolian Dynasty

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Abstract:

The historically successful Mongolian dynasty was highly sensitive to desertification resulting from climate change affecting their traditional agricultural systems (Neff *et al.* 2001; Fleitmann *et al.* 2003). There was a relationship between the Mongolian region's evolution and the desertification cycle since it could lead to decreases in biological productivity. The dynasty would experience either prosperity or collapse when desertification was declining or expanding (Wang 1996). This paper presents strong evidence for a relationship between the rise and fall of the Mongolian dynasty and the historical desertification cycles, as well as the isotope analysis for several naturally mummified bodies collected from the southern Mongolian Gobi Desert area: the Hets Mountain Cave. Estimating these individuals' residential origins and dietary habits could help evaluate the political and economic turmoil due to the desertification impact on this area.

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Introduction:

Based on Chinese historical documents and other paleoclimate records, the Mongolian Plateau has experienced several desertification cycles during the last several thousand years. Also, there have been reported that several close relationships exist between the expansion of deserts and the collapse of the Mongolian Dynasty during 1250s, 1370s and late 1400s, 1500s, and 1600s (Wang *et al.* 2010; Zhang *et al.* 2007). The desertification of the Mongolian Plateau and food production trends had critical impacts on the rise, decline, and collapse of this historical dynasty.

The dynasty founded in Mongolia region flourished during desertification reversals and the Mongolian empire dominated most of China at that time. On the contrary, the Mongolian Plateau was taken over by other southern dynasties or shared their territory and resources with the adjacent northern dynasties during desertification, when biological productivity of the Mongolian region decreased, bringing more turbulent periods.

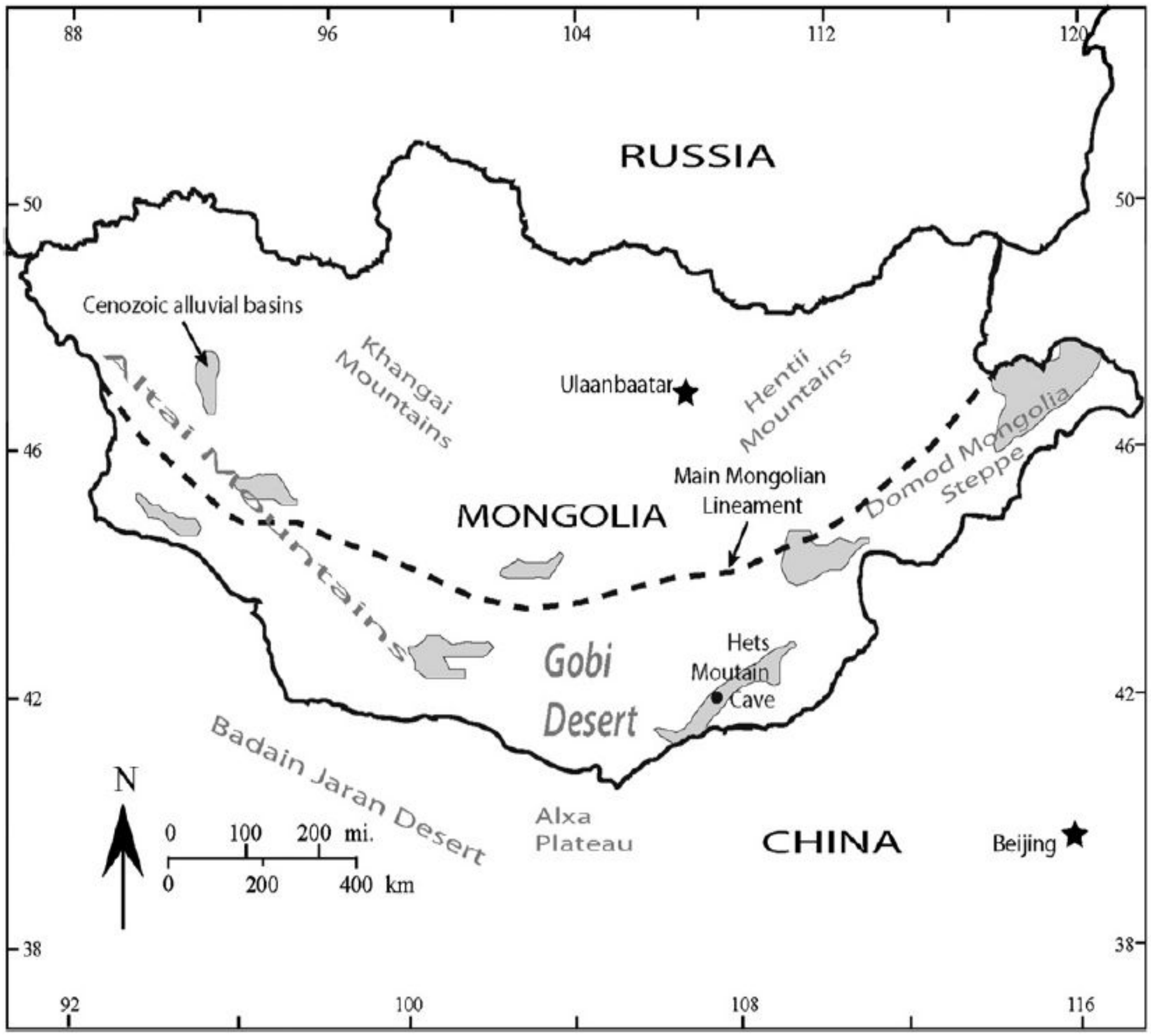


Fig. 1 Map of the Hets Mountain Cave and surrounding regions. (Source: Turner *et al.* 2012)

Since stable carbon and nitrogen isotopes in human or faunal remains are widely used in order to assess dietary patterns within ancient populations, isotope analysis for the mummified human remains from the Tavan Tolgoi, a location of an eastern Mongolian ruling elite (AD 1206-1368) cemetery by Fenner *et al.* (2014), comparison analysis of remains from lesser ranked people at the Tsagaan chuluut cemetery (A.D. 1206-1368), the early Bronze Age cemetery of Ulaanzuukh (about 1500-1100 BC), a post-Empire group from a wider region, and the Hets Mountain Cave site remains (dated to the 15th to 16th century AD) in southern Mongolia by Turner *et al.* (2012) were utilized (Hedges 2007; Lee-Thorp, 2008).

Carbon and nitrogen are integrated into plant tissues during the growing season, growing season environmental conditions are usually better correlated with isotope ratios than such as annual conditions, especially in highly seasonal environments (e.g., Fenner and Frost, 2009). Growing season temperature affects $\delta^{13}C$ and $\delta^{15}N$ in a region where individual variation occurs, also, increasing temperatures can lead to a $\delta^{13}C$ and $\delta^{15}N$ increase (Kuzyakov *et al.* 2006).

Exploring these archaeological samples collected from the Hets Mountain Cave site in southern Mongolia for isotope reconstruction of diet constitutes an important region of bio-archaeological research, which could tell what food types were constituents within these individual diets. Also, the carbon isotope values represent a composite dietary signal including carbohydrates, fats, and protein (Ambrose, 1993).

For example, isotope ratios of carbon from bone and enamel carbonate ($\delta^{13}C_{carbonate}$) have been used as indicators of the carbon absorbed from different sources in diets of terrestrial animals, between C3 and C4 plants. C3 refers to plants like shrubs that could be used by horses and ovicaprids (a domestic sheep or goat), or C4, including the millet, grasses growing in

Mongolia region. Humans whose $\delta^{13}C$ values vary between C3 and C4 ranges, and are unlikely to have consumed Crassulean-acid metabolism (CAM) photosynthetic pathway plants.

The nitrogen isotope composition ($\delta^{15}N$) found in collagen or keratin usually reflects the consumer protein types whether from animal, vegetable, leguminous, terrestrial or marine-based sources incorporated into the diet (DeNiro and Schoeninger, 1983; Petzke *et al.* 2005). The isotope composition can be used to suggest the amount of protein used by different animals and the position within food web (Ambrose and Norr, 1993; Ambrose *et al.* 1997; Lee-Thorp *et al.* 1989).

Owing to the difference between C3/C4 resource consumption, the mummified remains show a variation of their living experiences, and might have some relationship between the immigration to the region surrounding the Hets Mountain Cave and desertification from other areas of Mongolian plateau during that particular time period.

The geodetic location of this cave is 42°33'.75746' North latitude, 108°14'58' East longitude, which is very close to the limit of summer Monsoon.

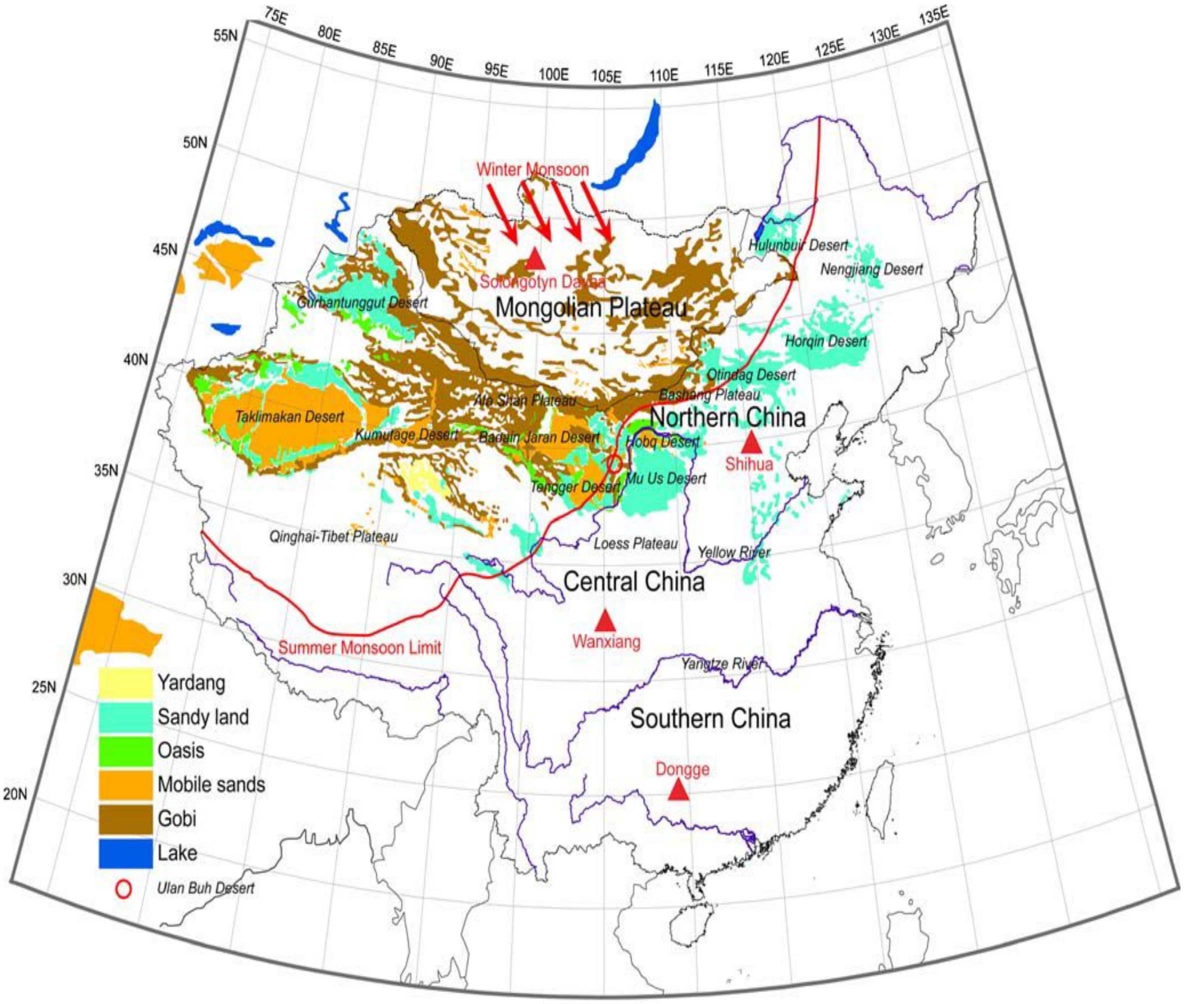


Fig. 2 Geomorphologic map of the Mongolian Plateau region. (Source: Wang *et al.* 2009)

The naturally mummified bodies include three adults, three infants, two adolescents, and one juvenile. In addition, three individuals have been radiocarbon dated (Beta-Analytical from NSF-Arizona AMS Laboratory) among the Ming dynasty (AD 1368-1644), the early Qing (1644-1911) dynasty and the late Great Mongolian Empire.

In order to estimate the dietary proportions on whether it was agricultural plant or animal-based, Turner (2012) assessed $\delta^{13}C$ and $\delta^{15}N$ values of preserved bone (N=8) and hair (N=4). They also examined a shift from animal-based to plants agricultural resources from the dietary changes at different stages of their lifetime.

If these individuals could not live in nomadic fashion, they probably suffered during a famine periods of desertification, and their isotope values should reflect a more plant-based diet such as the presence of C4 energy sources. Another case is these individuals might not show any plant-based evidence because their isotope values only reflected a vast majority of terrestrial animal proteins.

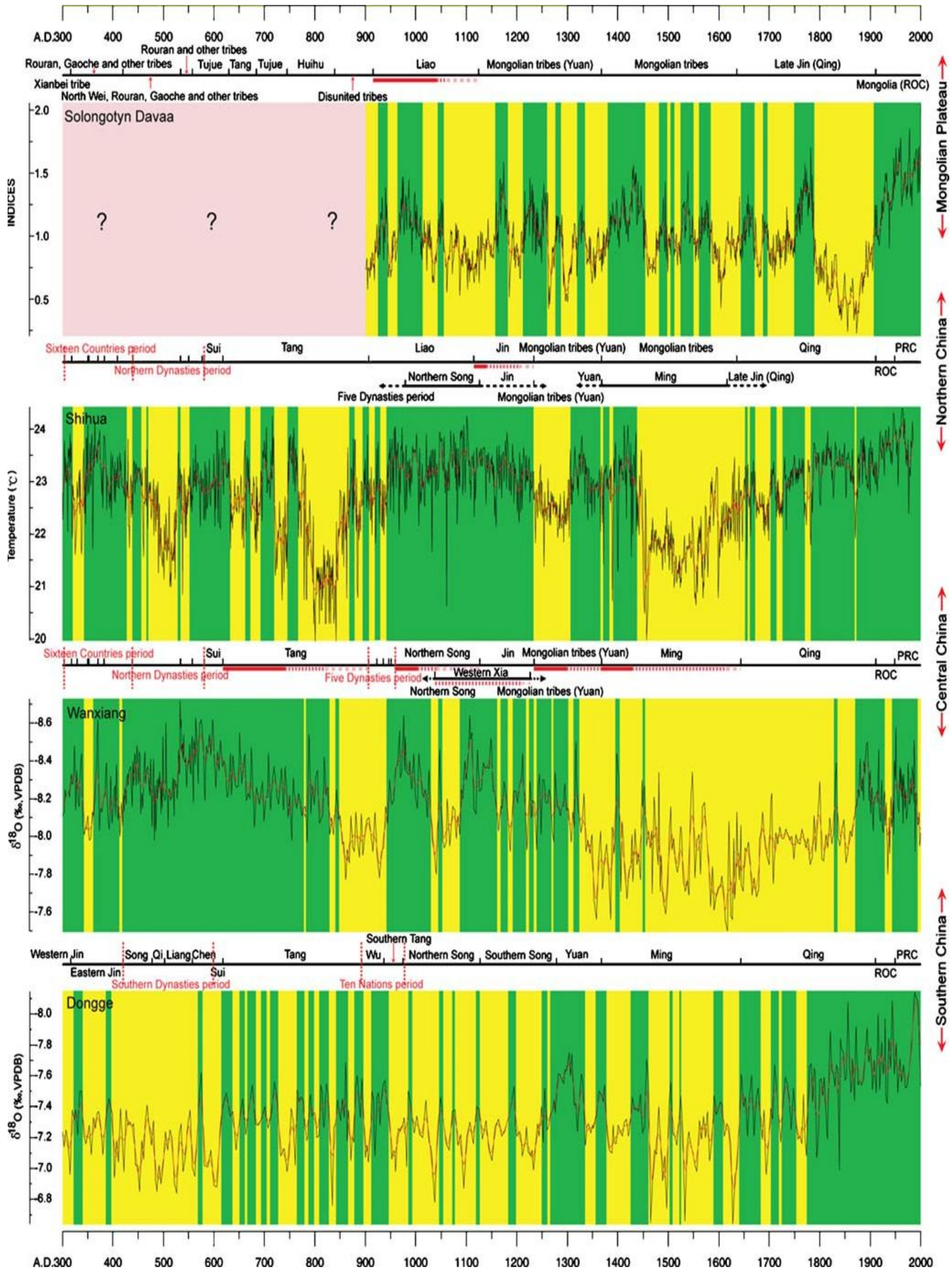
Turner *et al.* (2012) also point out that these individuals were non-local immigrants which were assessed by the dietary patterns through the tooth enamel (N=3), which characterized the residential origin and mobility ($\delta^{18}O$, and $^{87}Sr/^{86}Sr$). This perspective of the Mongolian life course was not only a more comprehensive interpretation about these individuals' geographical displacement before their death, but also tells us the potentially dietary change experienced by these people.

Background:

During warming periods, the dynasties founded in the Mongolian Plateau and northern China, flourished and remained stable until desertification began (Zhu 1973; Yang, 1996; Zhang *et al.* 2007). Warm periods within the Mongolian Plateau occurred periodically between 920 to about 1050, around 1150, between 1200 to 1250, from about 1360 to 1460 and the 1470 to the 1570s, and from the 1650s to 1760s, and after the 1900s (Cai 1965; Fan 1965; Bai 1996; Lu *et al.* 1996; Long 1996; Luo 1996; Yang *et al.* 1996; D'Arrigo *et al.* 2001; Tan *et al.* 2003; Wang *et al.* 2005; Zhang *et al.* 2008).

Fig. 3 Cycles of desertification and biological productivity during historical dynastic periods in the Mongolian Plateau and in northern, central, and southern China from 300 to 2000 A.D (Wang *et al.* 2009).

The red lines show the 10-year smoothing results produced by means of adjacent averaging. Increased desertification and decreased biological productivity are shown in yellow, whereas the reversal of desertification and increased biological productivity are shown in green. These trends were estimated based on published data by Wang *et al.* (2009). Red lines associated with the dynasty names below the graphs indicate periods of flourishing (solid red) and decline (dashed red) for these dynasties based on historical data (Cai 1965; Fan 1965; Bai 1996; Lu *et al.* 1996; Long 1996; Luo 1996; Yang *et al.* 1996; D'Arrigo *et al.* 2001; Tan *et al.* 2003; Wang *et al.* 2005; Zhang *et al.* 2008)


A.D.300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600 1700 1800 1900 2000
Rouran and other tribes
Rouran, Gaoche and other tribes
Tujue Tang Tujue Huihu
Liao
Mongolian tribes (Yuan)
Mongolian tribes
Late Jin (Qing)
Xianbei tribe
North Wei, Rouran, Gaoche and other tribes
Disunited tribes
Mongolia (ROC)
Solongotyn Davaa
INDICES
Mongolian Plateau
Sixteen Countries period
Northern Dynasties period
Sui
Tang
Liao
Jin
Mongolian tribes (Yuan)
Mongolian tribes
Qing
PRC
Northern Song
Jin
Yuan
Ming
Late Jin (Qing)
ROC
Five Dynasties period
Mongolian tribes (Yuan)
Shihua
Temperature (℃)
Northern China
Sixteen Countries period
Northern Dynasties period
Sui
Tang
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Mongolian tribes (Yuan)
Ming
Qing
PRC
Western Xia
ROC
Northern Song
Mongolian tribes (Yuan)
Wanxiang
δ18O (‰,VPDB)
Central China
Southern Tang
Western Jin
Song Qi Liang Chen
Tang
Wu
Northern Song
Southern Song
Yuan
Ming
Qing
PRC
Eastern Jin
Sui
ROC
Southern Dynasties period
Ten Nations period
Dongge
δ18O (‰,VPDB)
Southern China

A significant reversal of desertification occurred on the Mongolian Plateau about 920 A.D., and it ended around 1050 A.D. based on tree-ring records; in addition, very short desertification resurgence occurred between 1020 and 1040 A.D. This reversal of desertification brought flourishing times with increases livestock production for the Khatin Tribe, leading them to take control of the Mongolian Plateau and other parts of northern China, and brought a rise for the Liao Dynasty (Wang *et al.* 2009). Desertification on the Mongolian Plateau brought a truce that ended the war for dominance of Northern China between the Northern Song and Liao dynasty in 1040 A.D. (Fan, 1965), when biological productivity was decreasing in central China.

The Mongols had a great opportunity to flourish with increasing biological productivity on the Mongolian Plateau between 1160 A.D. and 1260 A.D., helped them to win a series of conquests in China, Asia, and even European territory. Although the desertification in the Mongolian Plateau fluctuated between 1180 and 1210 A.D., the northern and central China suffered a significant desertification brought a rapid decrease in biological productivity after 1220 A.D., which meant there was little chance for the Jin dynasty to protect their territories from the Mongolian invaders (Bai 1996; Long 1996). Relying on the occupation of northern and central China's resources, the Mongols ensured that they had an overwhelming advantage to expand their territories throughout Asia and created a widespread empire, the Yuan Dynasty (Cai 1965; Fan 1965; Zhu 1973; Bai 1996; Lu *et al.* 1996; Long 1996; Luo 1996; Yang *et al.* 1996; D'Arrigo *et al.* 2001; Tan *et al.* 2003; Wang *et al.* 2005).

The desertification was unstable on the Mongolian Plateau between 1250 and 1370, with the productivity decreasing in central China. And due to the impact of desertification, the Mongolian government suffered frequent periods of unrest in central China after the 1340 (Fan 1965; Luo

1996), forcing an evacuation back to the Mongolian Plateau and regions of northern China from central and southern China.

Although the Mongols continued to dominate the Mongolian Plateau and shared northern China territories with the Ming dynasty (Yang and Mo, 1996) between 1380 and 1450 A.D., the Mongols were finally conquered by the Late Jin dynasty after the early 1600s, a time period that had frequent desertification occurring on the Mongolian Plateau, and decreasing productivity in central and southern China. The collapse of the Great Mongolian Empire and the subsequent Yuan and Ming Dynasties brought a series of problems including as political conflict, cultural crisis, and economic turmoil.

A civil war affected the succession and control of the Mongol Empire among the progeny of Genghis Khan in the late 13^{th} century. The Great Khan, which was the largest and most powerful empire, had not only occupied many surrounding small villages, but also relocated the empire's administrative center, Qara Qorum (Karakorum), to Dadu, which is renamed as Beijing between 1251 and 1279 (Jagchid *et al.* 1965; Dardess, 1972).

The Great Khan had a weakness which is the restriction of specific economic transitions for the pastoral communities, with adult men moving to Beijing or other remote areas, with the women, children and the elderly staying to breed livestock. Because of the labor force structure, disconnect was created between economic and cultural, aspects of society bringing the majority of the populace into famine (Grousset, 1970; Endicott, 2005). Although the plight of the hungry or poverty could be temporarily eased by receiving the financial support and grain sent from Beijing by Imperial decree (Munkuev, 1977), the situation was very serious since several decrees, were in summer periods, when livestock were not in peak condition because of the food shortage, moreover, some food resources were consumed by the Imperial close relatives (Endicott, 2005).

Owing to the frequent factional conflicts and civil war, as well as natural disasters such as flooding and the Black Death disease in the late 14th century (Dardess, 1973; Luo, 1996), the Yuan dynasty was finally overthrown in the year of 1368, ending the Mongolian rule in China (Morgan, 1986). A decreased ability to access the Chinese agricultural resources led the Mongols into a weaker pastoral population, forcing their further migration into northern China (Wang *et al.* 2010).

Based on other research, several factors might exacerbate the pastoral populations' conditions indirectly between 14th and 17th century. Climate change might have played a major role among them (Endicott, 2005; Zhang *et al.* 2007). Because of Northern China's and Mongolia's geographic features, these regions were affected by the Summer Monsoon, being cold and dry during cool periods (Huang, 1988; Lattimore, 1988). This could lead these areas into a fragile, ecologically weak situation since traditional animal husbandry and agricultural systems are all sensitive by the desertification and productivity changes (Neff *et al.* 2001; Fleitmann *et al.* 2003).

Heavy snows within long-lasting winter periods brought a very high livestock mortality in the modern era (Foster, 2010), also happened in the 13th and 14th centuries, along with large areas of grain die-offs (Endicott, 2005).

Stalagmite and tree ring data show that the Mongolian Plateau has experienced frequent warm and cool phase alternation since 1260. Desertification was aggravated and productivity decreased during cool periods such of the 1250s, 1370s and late 1400, 1500, and 1600s (Zhang *et* *al.* 2007; Wang *et al.* 2010), associated with high livestock mortalities, bringing the Mongols famines and consequent migration (Turner *et al.* 2012).

On the other hand, warm phases in the early 1200s gave the animal husbandry a good opportunity to flourish (Huntington, 1927, Fang, 1990; Fang and Liu, 1992), which gives Mongolian army a good chance to invade other regions such as South Asia and Europe. The Mongols were traditionally pastoral economies which was exacerbated by climate change during the preceding Yuan Dynasty (AD 1271-1368), bringing a wide range of famine and farmland changes (Munkuev, 1977; Endicott, 2005).

Several multi-isotope analyses discussed in Turner *et al.* (2012) given a good top-down historical account to understanding the Mongolian empire's nutrition and migration changes under significant economic and political conflicts.

Stable isotope analysis for the elite Mongol Empire Cemetery (1206-1368)

Research on paleo-diets in China by Fenner *et al.* (2014) used dietary stable isotope analysis to determine if there were large changes related to the impact of desertification. Climate change in the Mongol Empire affected the diet of both the ruling elite and general people in the Mongolian area. Fenner *et al.* (2014) extracted bone collagen from animal and human remains from the Tavan Tolgoi, a location of an eastern Mongolian ruling elite cemetery. Through carbon and nitrogen stable isotope measurements, and comparison analysis of remains from lesser ranked people at the Tsagaan chuluut cemetery, these changes could be evaluated. Bone collagen data will be compared with the Bronze Age cemetery of Ulaanzuukh (about 1500-1100 BC), a post-Empire group from a wider region in this thesis.

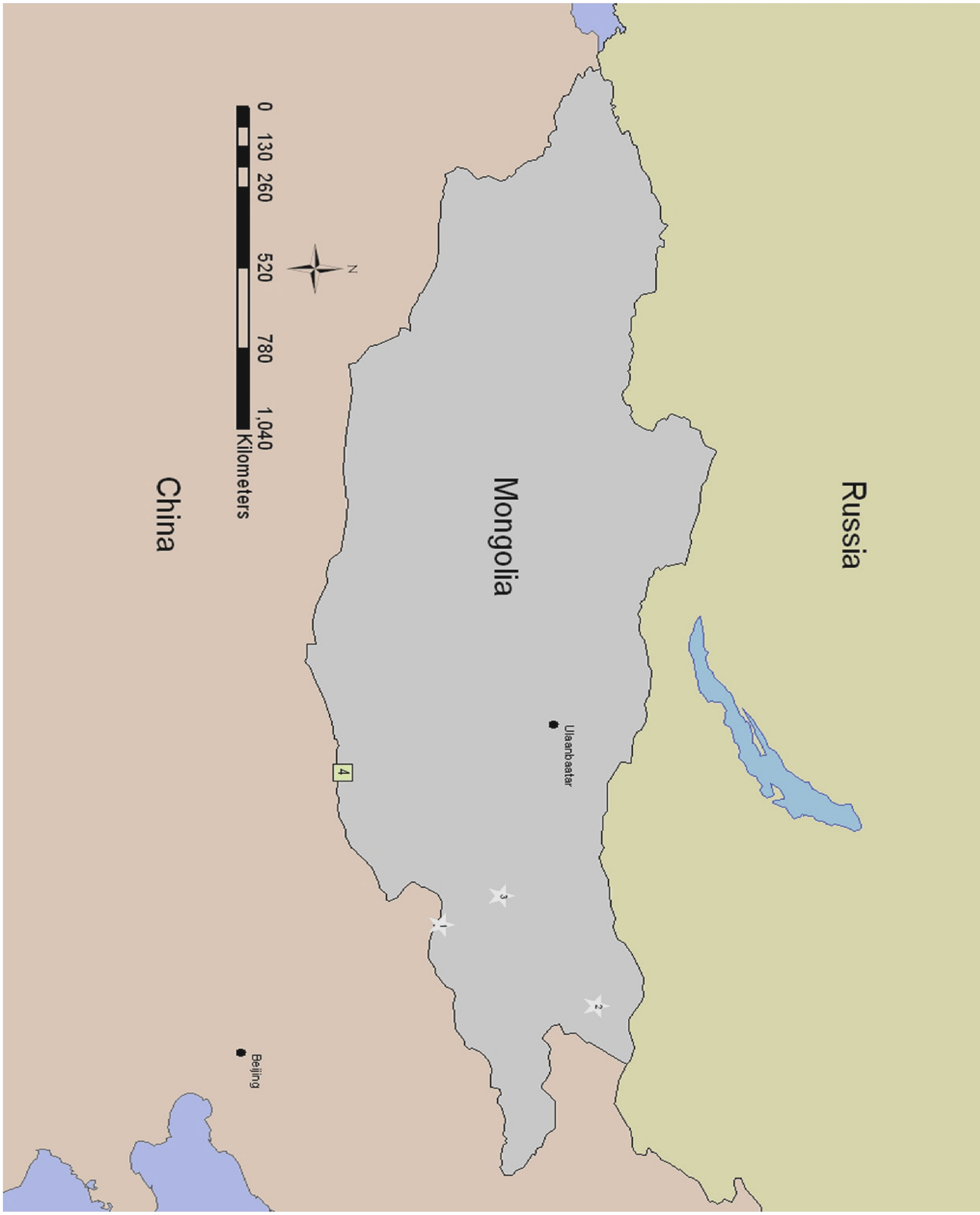

Fig. 4 Map of modern Mongolia and region. Site list: 1. Tavan Tolgoi (South-east Mongolia); 2. Tsagaan chuluut(North-east upper corner of Mongolia); 3. Ulaanzuukh (between Tavan and Tsagaan); 4. Hets Mountain Cave. (Source: Fenner *et al.* 2014)

Among the sample data from the three cemeteries, the ruling elite burials in Tavan Tolgoi have significantly higher isotope values than other two sites. Generally, this could suggest the ruling elite had significantly different dietary sources or proportions of foods. For example, higher $\delta^{15}N$ indicates more animal products were consumed in the diets, which is consistent with historical sources that Mongolians had strong preferences for koumiss, a fermented milk beverage. The elite buried at Tavan Tolgoi were found with gold, silver or jade, which could be used to suggest that they could afford more costly dietary preferences based on their wealth.

The human and animal collagens were extracted based on the modified Longin (1971) method. Generally speaking, approximately 1g of cortical bone from each sample was obtained by using Dremel drill saw. The bone was through ultrasonically cleaned and demineralized in 0.5M HCl.

Next, the samples were cleaned using deionized water in order to rinse to a neutral pH, gelatinized at 75° Celsius, and filtered by using an Ezee filter (Longin, 1971). The supernatant was frozen to –40° Celsius and then lyophilized. The isotope ratios on the extracted sample collagens, as well as the carbon and nitrogen percentages, were all measured by an isotope ratio mass spectrometer.

All bone samples and their stable isotope compositions, as well as relative elemental analyses, used for diagenesis evaluation, show good preservation (Table 1). The mean collagen percentage was between 15 to 18%, with a minimum value of 5.9%. The mean %C was 42.9% with a minimum value 12.7%; the mean %N value is 15.7% with a minimum of 12.7%. The mean C: N atomic ratio is high, consistently at 3.2 with a range between 3.1 and 3.2. Owing to the particularly cold and dry weather in eastern Mongolia, all collagen samples easily met good preservation conditions (Ambrose, 1990).

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 1 Tavan, Tsagaan, and Ulaanzuukh stable isotope results (Source: Fenner *et al.* 2014).

After correction for diet-to-collagen relationship of about 5 ‰ for ^{13}C (Fernandes *et al.* 2012), diet $\delta^{13}C$ values are in the C3 range for both the horses and domestic sheep or goat (Table 1). There is no evidence that their daily diets contained significant amounts of millet fodder; also there is little indication for any wild C4 plants growing in that region (Pyankov *et al.* 2000). Modern wool from sheep raised in the south-east Mongolia area produce similar carbon isotope levels (Auerswald *et al.* 2012).

The Tavan Tolgoi human isotope contents are not only greater than the mean Tavan Tolgoi horse $\delta^{15}N$, but also higher than the mean horse $\delta^{13}C$, at 3.0‰ for both measures, which suggests that the people buried at Tavan Tologi were not consuming a large amount of horse meat (Table 2).

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

Table 2 Tavan, Tsagaan, and Ulaanzuukh stable isotope summary statistics. (Hets Mountain Cave data from Turner *et al.* 2012.)

For ovicaprids (a domestic sheep or goat), the mean human $\delta^{15}N$ value is 5.0‰ higher while the mean human $\delta^{13}C$ is 1.3‰ higher, which tells us that these ovicaprids may have contributed significantly to the humans' diet.

As we can see from the above Table 2, the Tavan Tolgoi human $\delta^{15}N$ values are significantly higher than those from Tsagaan chuluut or Ulaanzuukh. This indicates that the ruling elite living at Tavan Tolgoi consumed more meat and/or the milk beverage than the common people living at Tsagaan chuluut or the Bronze Age residents at Ulaanzuukh, particularly in the desertification period, which would be consistent with historic and modern Mongolian preferences for animal related diets.

Because carbon and nitrogen isotope signals are established in the plant tissues during the growing season, environmental conditions may be able to be correlated with the isotope ratios and reflect annual changes, especially in highly seasonal environments (Fenner *et al.* 2009). The growing season temperature affects $\delta^{13}C$ and $\delta^{15}N$ in a region where individual variation can occur; also, increasing temperatures can lead to a $\delta^{13}C$ and $\delta^{15}N$ increase (Epstein *et al.* 1997). Of course, one cannot neglect indirect effects such as the increased evapotranspiration effects in high temperature areas, which can turn into desertification.

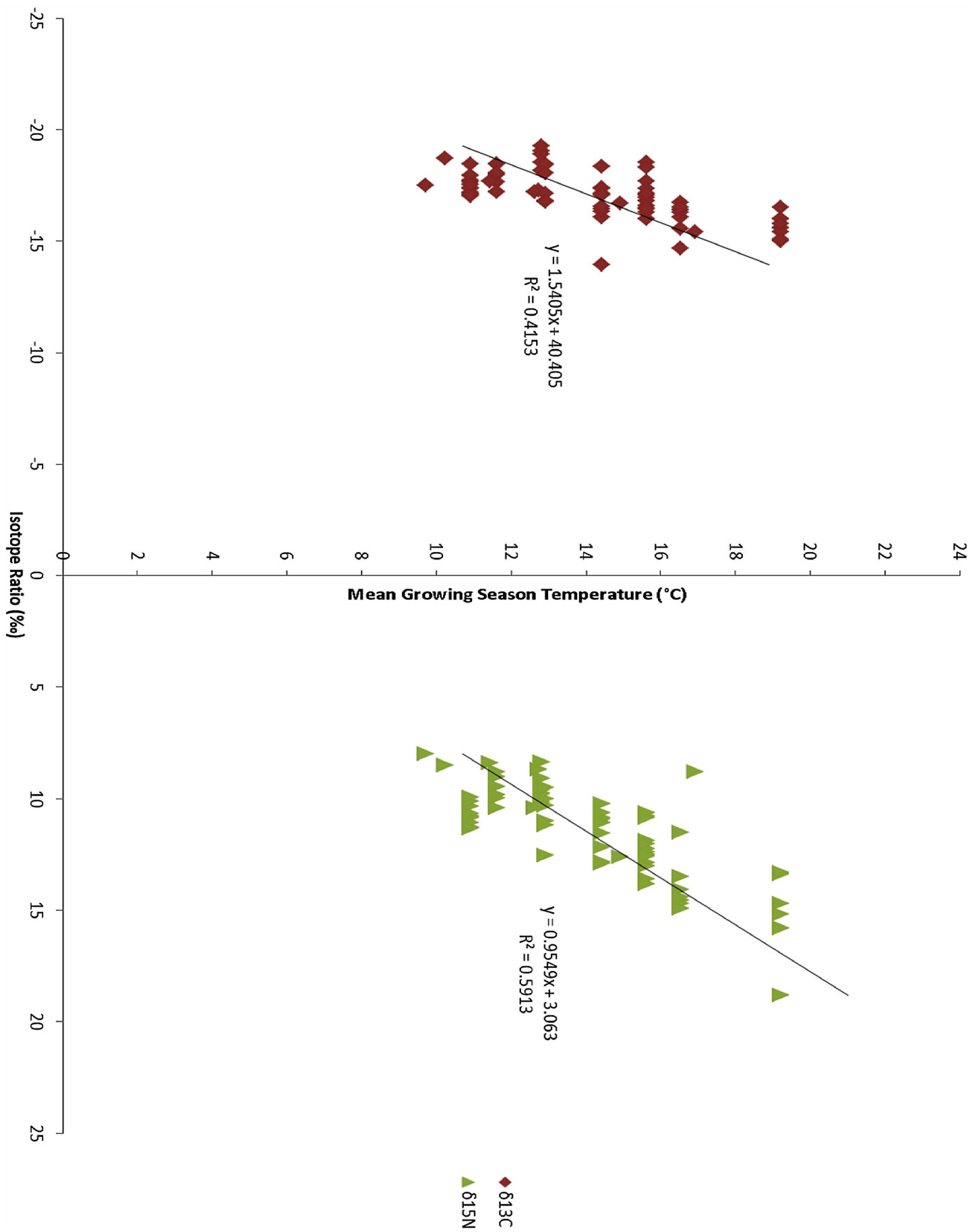

Fig. 5 $\delta^{13}C$ and $\delta^{15}N$ of the elite Mongol Empire cemetery sample correlation with growing season temperature. Samples selected from Mongolia area only (Source: Fenner *et al.* 2014).

By computing the growing season temperature versus $\delta^{13}C$ and $\delta^{15}N$, Fenner *et al.* (2014) found two regression equations; the slopes of these equations were then used to compute $\delta^{13}C$ and $\delta^{15}N$ values for each of these four sites' primary concern if the temperature was adjusted to give an equal contribution to each site. That is, the Mongol Empire and Bronze Age archaeological isotope values were adjusted to compensate for modern growing season temperature differences among these sites (Fenner *et al.* 2014).

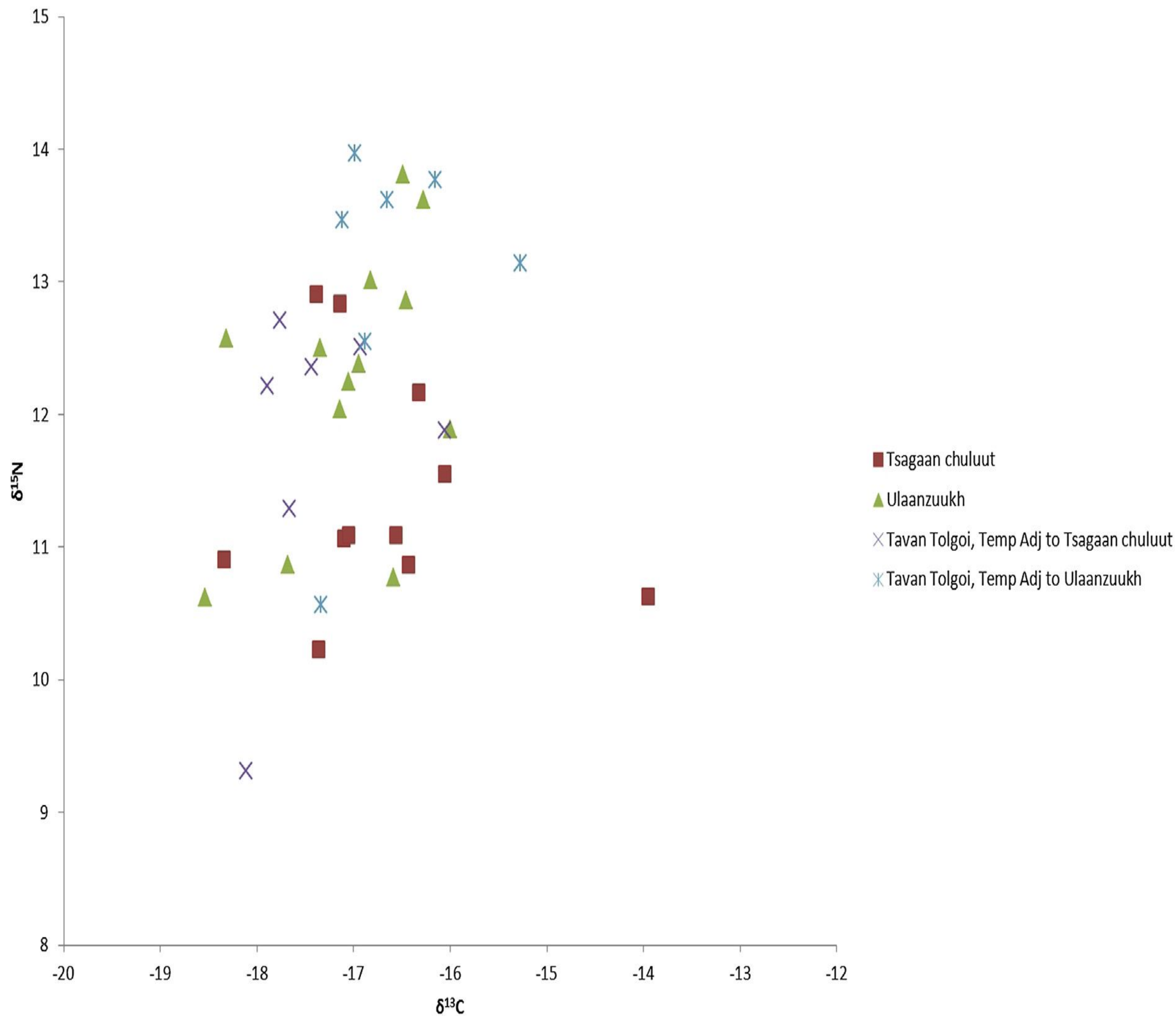

Fig. 6 $\delta^{13}C$ and $\delta^{15}N$ of human bone collagen after adjusting Tavan Tolgoi. $\delta^{13}C$ and $\delta^{15}N$ were using a regression against modern Tsagaan chuluut and Ulaanzuukh growing season temperatures. This is intended to show how environmental aspects can be sufficient to create differences among these group societies of any dietary differences exclusively (Source: Fenner *et al.* 2014).

The impact on isotope compositions under the temperature-influences condition are suggested to be an appropriate approach and magnitude to account for the differences among these sites, and suggest that the isotope differences among these four sites described above, were not just affected by dietary differences, but also were affected by environmental variations. In other words, there was a relationship between the desertification and this historical Mongolian dynasties' rise, decline, and collapse.

Isotope Analysis of Mummified Human Remains

Isotope analyses of mummified human remains were also made by Turner *et al.* (2012); the study samples used were recovered from the Hets Mountain Cave, which was already mentioned by the Fenner *et al.* (2014). It is a 17 meter long cavern that is several meters underground, ten kilometers north away of the border between modern Mongolia and China. These individuals were recovered from two disorganized human remains locations which were missing skeleton components and, included adults, juveniles, and infants. Associated artifacts found by Mongolian archaeologists during a brief inspection of the cave in 1984 included ceramics, wooden plates, and a pair of woman's pants, but these were absent during recovery bodies in 2004.

Based on the macroscopic examination and high-resolution computed tomography (CT) images of these individuals, it has been suggested that they were killed somewhere outside the cave and moved to these caves several months later when their bodies were totally desiccated, resulting in relatively good preservation (10-80%) of the soft tissue intact (Frohlich *et al.* 2005, 2008, 2009).

Several of these individuals show evidence of scavenging by birds, and the preserved tissues desiccated while they were in a different orientation than the one in which they were found (Frohlich *et al.* 2005).

These individuals had also been severely disturbed by thieves prior to recovery since several of the hands, feet, and crania were absent; associated with find were more recent match boxes, on the cave floor, candle wax on the mummies' skin, and the absence of infant crania. Although the disarticulation was severe, scientists assembled these individuals by using macroscopic visual comparison, computed tomography (CT) images, radiographic opacity detection, and short tandem repeat (STR) typing (Frohlich *et al.* 2008, Gareis *et al.* 2008).

Table 3

Sex, estimated age-at-death, estimated AMS date, mtDNA Haplogroup, and summary of osteological and contextual features for each individual included in the Hets Mountain Cave study population. Sex identification was completed using a combination of short-tandem repeat (STR) typing (Gareis *et al.* 2008) and macroscopic examination following Buikstra and Ubelaker (1994). Age-at-death was assessed using long bone metrics and dental eruption, also following Buikstra and Ubelaker (1994). Haplogroup association was assigned according to the positions in the mitochondrial genome where the sequences differ from the Cambridge Reference Sequence (CRS), indicated here by the number sequences in parentheses (Turner *et al.* 2012).

Individual	Age	Sex	AMS Date (cal. $^{14}C \pm 2\sigma$)	mtDNA HpG	Description of Key Osteological Features
3-C	Infant (6 mo.)	n/d		D1 (16223 16325)	Post-crania present; soft tissue present on approx. 70% of body. No evidence of pathologies, activity markers, or skeletal stress indicators on the post-crania. Trauma includes sharp and blunt force trauma to the cranial and cervical regions.
3-B	Infant (12 mo.)	n/d		D1 (16223 16325)	Post-crania present; soft tissue present. No evidence of pathologies, activity markers, or skeletal stress indicators on the post-crania. Trauma includes sharp and blunt force trauma to the cranial and cervical regions.
1-C	8 yrs.	n/d	AD 1456–1651 (323 BP)		Crania, post-crania, dentition, and hair present; soft tissue present on 60% of the body. No evidence of pathologies, activity markers, or skeletal stress indicators. Trauma includes sharp and blunt force trauma to the cranial and cervical regions.
1-F	12 yrs.	M		D1 (16223 16325)	Post-crania present; dentition, hair, and soft tissue present. No evidence of pathologies, activity markers, or skeletal stress indicators on the post-crania. Trauma includes sharp and blunt force trauma to the cranial and cervical regions.
1-B	16 yrs.	M	AD 1434–1528 (399 BP)		Post-crania present; soft tissue present. No evidence of pathologies, activity markers, or skeletal stress indicators on the post-crania. Trauma includes sharp and blunt force trauma to the cranial and cervical regions.
1-D	40 yrs.	F	AD 1439–1524 (393 BP)	C (16223 16298 16319 16327)	Crania and post-crania present; dentition and hair present; minimal soft tissue present on approx. 60% of body. No evidence of pathologies, activity markers, or skeletal stress indicators. Trauma includes sharp and blunt force trauma to the cranial and cervical regions; the latter is compatible with having the head pulled forcibly backwards over a bar placed in the posterior cervical region. Soft tissue evidence that individual involuntarily severed own tongue coincident with the cervical trauma.
1-G	40 yrs.	M			Crania and post-crania present; dentition and hair present; soft tissue present on approx. 50% of body. No evidence of cranial or post-cranial pathologies or activity markers. Oral pathologies include: periapical abscess on RM^2; antemortem loss of LM^3, LM_3, and RM_1; caries in LPM_1 and RPM_2. Trauma includes sharp and blunt force trauma to the cranial and cervical regions; soft tissue evidence that individual involuntarily severed own tongue in the process of being garroted. Garroting cord still present in cervical region

Several of the individuals were also analyzed using mitochondrial DNA at the University of Copenhagen. And one can see from the HVS1 region (16209 - 16356) preliminary results, which was through the amplification, cloning, and sequencing (Table 3), the majority of these sampled individuals are within the same mtDNA haplogroup marked as D1, and thus, most of these individuals might share some degree of genealogical relatedness (Gilbert, 2011).

Exploring these archaeological samples for isotope reconstruction of diet by utilizing biochemical measurements constitutes an important region of bio-archaeological research which tells us what the food types were constituents within these individual diets. Also, the carbon isotope values represent a composite dietary signal including carbohydrates, fats, and protein (Ambrose, 1993).

For example, isotope ratios of carbon from bone and enamel carbonate ($\delta^{13}C_{carbonate}$), has been used as an indicator of the carbon absorbed from different sources in a diet, such as terrestrial and marine animals, or between C3 and C4 plants. Humans whose $\delta^{13}C$ values range between C3 and C4, and less likely consumed Crassulean-acid metabolism (CAM) photosynthetic pathway plants.

The same values of $\delta^{13}C_{collagen}$ and $\delta^{13}C_{keratin}$ in bone collagen and hair keratin, respectively, appear to represent the contribution of carbon found in dietary protein disproportionately, and traditionally, used the differences between bone carbonate and collagen can be used to estimate the type and proportion of protein in the overall diet (Ambrose and Norr, 1993). However, recent research has suggested that it can be very complicated to interpret the different dietary component for individual tissues, and alternate formulae are needed in order to estimate different components in archaeological samples (Kellner and Schoeninger, 2007; Froehle *et al.* 2012).

Owing to the profile of the amino acids between bone/dentin collagen and hair/nail keratin, different diet-tissue can be estimated from distinct isotope effects. Over 30% of collagen is composed of glycine, an essential constituent amino acid which has a higher $\delta^{13}C$ value as compared to other amino acids, lead to the diet-tissue difference of $\delta^{13}C_{collagen}$, approximately +5 ‰, while controlled feeding experiments suggest a +3.5 ‰ difference for $\delta^{13}C_{keratin}$ (O'Connell *et al.* 2001).

Nitrogen isotope values ($\delta^{15}N$) based on collagen or keratin usually reflects the types of consumer protein, whether from animal or vegetable; as well as terrestrial or marine-based sources incorporated into the diet (DeNiro and Schoeninger, 1983; Petzke *et al.* 2005), and represent the trophic-level of the nutrition of the organism position within a food web (Ambrose and Norr, 1993; Ambrose *et al.* 1997; Lee-Thorp *et al.* 1989). Differing from the value of the carbon isotopes, $\delta^{15}N$ indicated that usually there is little difference between bone collagen and hair keratin diet-tissue differences (DeNiro and Epstein, 1978; O'Connell *et al.* 2001).

However, there still are a series of physiological factors that could modify the $\delta^{15}N$ value. For example, the concentration of nitrogen in the diet (O'Connell and Hedges, 1999), water conservation in arid climates through the ^{15}N depleted urine excretion (Ambrose, 1991), or lean tissue catabolism for gluconeogenesis during starvation period all affect the ^{15}N composition (Fuller *et al.* 2005).

The Relationship between the isotope Composition of Substrates and Residential Mobility

The isotope composition of body water, $\delta^{18}O$, is reflected in the stable oxygen isotope of tooth enamel and bone in the carbonate portion of the mineral hydroxyapatite ($Ca_{10}(CO_4)_6(OH)_2$). The oxygen isotopic composition of meteoric water ($\delta^{18}O_{water}$) with predictable fractionation, affects the consumer's body water (Longinelli, 1984; Luz *et al.* 1984). The preferential loss of ^{16}O during evaporation and a progressive change in ^{18}O associated with precipitation during air mass movement inland and upward affects the $\delta^{18}O$ value. The meteoric water isotope composition could be influenced by latitude, altitude, aridity, seasonal temperature differences, and the rainfall fluctuation among the Mongolian region (Dansgaard, 1964; Gat, 1996; White *et al.* 1998).

These ecological processes result in stable isotope ratio of ^{18}O: ^{16}O to be a useful regional environmental measurement, as well as a method to estimate an individual's movement to geographical areas that have been characterized by $\delta^{18}O_{carbonate}$ ranges distinct from those of the original region (White *et al.* 2000; White *et al.* 2002).

The bones of an infant have $\delta^{18}O$ values that reflect the first few years of life and the dietary enrichment in ^{18}O as compared to ^{16}O because of maternal body water equilibration during breastfeeding (Roberts *et al.* 1988; Wright and Schwarcz, 1999), it has been widely used to recognize the movement of an ancient people based on the analyses of $\delta^{18}O$ values in permanent tooth enamel and the bones from infants or young juveniles (Wright and Schwarcz, 1998; 1999; Turner *et al.* 2005).

The combined analysis of oxygen isotopes with other additional analyses help to trace the origin of human skeletal remains, and also can give a larger picture through a geological context in time. Strontium isotope compositions of different geological substrates are variable because of geological age, mineral composition and weathering patterns of surrounding bedrock (Dasch, 1969; Fullagar *et al.* 1971; Faure and Powell, 1972). Older rocks, associated with high Rb/Sr usually have higher $^{87}Sr/^{86}Sr$ than younger rocks (Rogers and Hawkesworth, 1989), and the geological Pb isotope ratios also can vary depending on the ages and the original U/Pb and Th/Pb ratios (Faure, 1986; Gulson, 1986).

Many archaeologists are making use of the abundances of $^{87}Sr/^{86}Sr$ and $^{206}Pb/^{204}Pb$ in the surrounding environment (Hodell *et al.* 2004) and nearby fauna in order to estimate the archeological sites baseline, distinguishing non-local from local individuals and their immigration.

The enamel from two rodent specimens recovered by Turner *et al.* (2012) at archaeological sites near Hets Cave (Fig. 1), were analyzed for $^{87}Sr/^{86}Sr$ and $^{206}Pb/^{204}Pb$ serving as the locally biologically-available Sr and Pb proxies, against the values in human samples.

Since there is a great degree of geological and ecological variation, the surrounding grasslands of the Hets Cave site show a wide range of isotope variations; these individual isotope values would be different only if they came from some other location which had distinct geologically and climatically features. Through the combination of analyses of $\delta^{18}O$ and $^{87}Sr/^{86}Sr$, $^{206/204}Pb$, Turner *et al.* (2012) created a geographic profile from the tooth enamel crowns over the early Mongolian life stages.

Owing to the fact that the Hets Cave is surrounded by Gobi Desert, it shows seasonal temperature variation between summer (24-25 °C) and winter (-15 to -8 °C) (Starkel, 1998) with a mean annual precipitation of less than 50 mm. There is a lack of drinking water sources in this region since the evaporation rate is extremely high and, people are more likely to use the groundwater (Pyankov *et al.* 2000). Modern $\delta^{18}O$ values from precipitation (Bowen and Wilkinson, 2002; Ma and Edmunds, 2006: 1236), which ranges from -9.9 to -7.0 ‰, are consistent with the Hets Mountain Cave surrounding areas.

The $\delta^{18}O$ value (Turner *et al.* 2012) from the surface lakes and shallow groundwaters located at the Badain Jaran Desert of the Alxa Plateau (Fig. 1) to the south-west of Hets Mountain Cave show that the lake represented a warmer and wetter climate, with $\delta^{18}O$ signatures of -12‰ which was filled by groundwater. With lake $\delta^{18}O$ values around 3.6 to 7.0‰, because of the low precipitation rate and evaporative processes, while groundwater extracted from springs or wells in the same area turns out the $\delta^{18}O$ range between -3.8 and +3.0‰ (Ma and Edmunds, 2006: 1238).

Moreover, there was a trend of increased cooling and drying starting 4.5 Ka, with wet periods ca. 1340-1450, 1500-1610, 1710-1820 based on the paleoclimatic evidence (Starkel, 1998; Ma and Edmunds, 2006), when desertification was aggravated and bio-productivity diminished (Wang *et al.* 2010; Zhang *et al.* 2007) and was associated with higher livestock mortalities, bringing the Mongols into famine situations, consequent migration based on Turner *et al.*'s study. Hence, individuals who grew up in the Hets Cave region are expected to have heavier $\delta^{18}O_{carbonate}$ than others who living in place that were wetter and less seasonal environments.

Overall, it is still necessary when using multiple isotopes progress to analyze the origin of the Mongols since they are the individuals who were living among the relatively wet periods and drinking the groundwater directly which may have contained lower $\delta^{18}O_{carbonate}$ than expected.

Table 4

Summary of isotope results for the Hets Mountain Cave (Turner *et al.* 2012).

Carbon isotope values are expressed in permil (‰) relative to Pee Dee Belemite (PDB) standard. Nitrogen isotope values are expressed in permil (‰) relative to atmospheric standard (AIR). Oxygen isotope values are expressed in permil (‰) relative to standard marine ocean water (VSMOW). *duplicate for confirming analytical integrity. Summary statistical abbreviations: E = Enamel, B = Bone, H = Hair (E/H = Enamel or Hair).

Individual	Age	Sex	Tissue	C/N	$\delta^{13}C_{ap}$	$\delta^{13}C_{col}$	$\delta^{15}N_{col}$	$\delta^{13}C_{ker}$	$\delta^{15}N_{ker}$	$\delta^{18}O_{ap}$	$\delta^{18}O_{water}$	$^{87}Sr/^{86}Sr$	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$
1-B	16	M	Bone	2.8	−12.4	−15.0	13.4			24.5	−8.6				
1-C	8	NA	Rm_1 enamel		−11.5					25.5	−7.4	0.70941	18.0	15.6	37.6
			RM_2 enamel		−9.9			−17.3	13.4	23.5	−9.9	0.70944	18.6	15.6	38.7
			RM_2 enamel*									0.70945	17.8	15.6	37.6
			$Hair^0$					−17.4	13.4						
1-D	40	F	RM^1 enamel		−9.3					25.9	−6.8	0.71057	17.8	15.6	37.6
			PM1 enamel		−9.0					24.7	−8.4				
			Bone	2.7	−12.7	−15.6	15.2			24.4	−8.8				
			$Hair^0$					−17.4	11.6						
			$Hair^1$					−16.7	10.9						
			$Hair^2$					−17.0	12.6						
			$Hair^3$					−16.7	11.6						
1-F	12	M	Bone	2.8	−11.6	−15.4	14.7			26.1	−5.9				
			$Hair^0$					−17.2	14.5						
			$Hair^1$					−16.1	13.7						
			$Hair^2$					−16.6	13.4						
			$Hair^3$					−16.7	14.5						
			$Hair^4$					−17.1	11.4						
1-G	40	M	LM_2 enamel		−9.6					23.0	−10.5	0.70977	18.4	15.6	38.3
			PM^1 enamel									0.71002	18.6	15.7	38.8
			Bone	2.8	−10.8	−15.1	15.8			24.7	−8.3				
			Bone*	2.8		−15.1	15.9								
			$Hair^0$					−17.1	13.6						
			$Hair^1$					−16.7	13.4						
			$Hair^2$					−16.6	13.5						
3-B	1.0		Bone	2.7		−16.0	15.8								
3-C	0.5	NA	Bone	2.7	−12.8	−15.8	18.8			28.1	−3.98				
Mean(N)					E/H: −9.9 (5)	.	.	−16.9 (12)	12.9 (12)	24.5 (5)	−8.6 (5)	0.70980	18.1	15.6	38.1
					B: −12.0 (5)	−15.4 (7)	15.6 (7)	.	.	25.7 (5)	−7.1 (5)				
Std. Dev.					E/H: 0.95	.	.	0.4	1.2	1.2	1.6	0.00054	0.41	0.04	0.59
					B: 0.84	0.39	0.4	.	.	1.6	2.1				
MZ1 *Spermophilus* sp.			Incisor enamel									0.70817	17.98	15.55	37.86
MZ2 *Ochotonidae* sp.			Incisor enamel									0.70831			

The isotope values of these individuals' tissues were collected from the Hets Mountain cave by Turner *et al.* (2012) (Table 4). The range of enamel $\delta^{13}C_{carbonate}$ was from -11.5‰ to -9.0‰, and the bone $\delta^{13}C_{carbonate}$ shows a range from -12.8‰ and -10.8‰. The $\delta^{18}O$ values range of enamel and bone are between 23.0‰ and 28.1‰.

The bone $\delta^{13}C_{collagen}$ value was ranged from -16.0‰ to -15.0‰, while the hair $\delta^{13}C_{keratin}$ showed a slightly bigger range at -17.4‰ and -16.1‰. The $\delta^{15}N_{collagen}$ values range for bone (excluding the infant (3-C) individual) was between +13.4‰ and +15.9‰, which was narrower than the hair $\delta^{15}N_{keratin}$ value, +10.9‰ to +14.5‰ (Fig. 7).

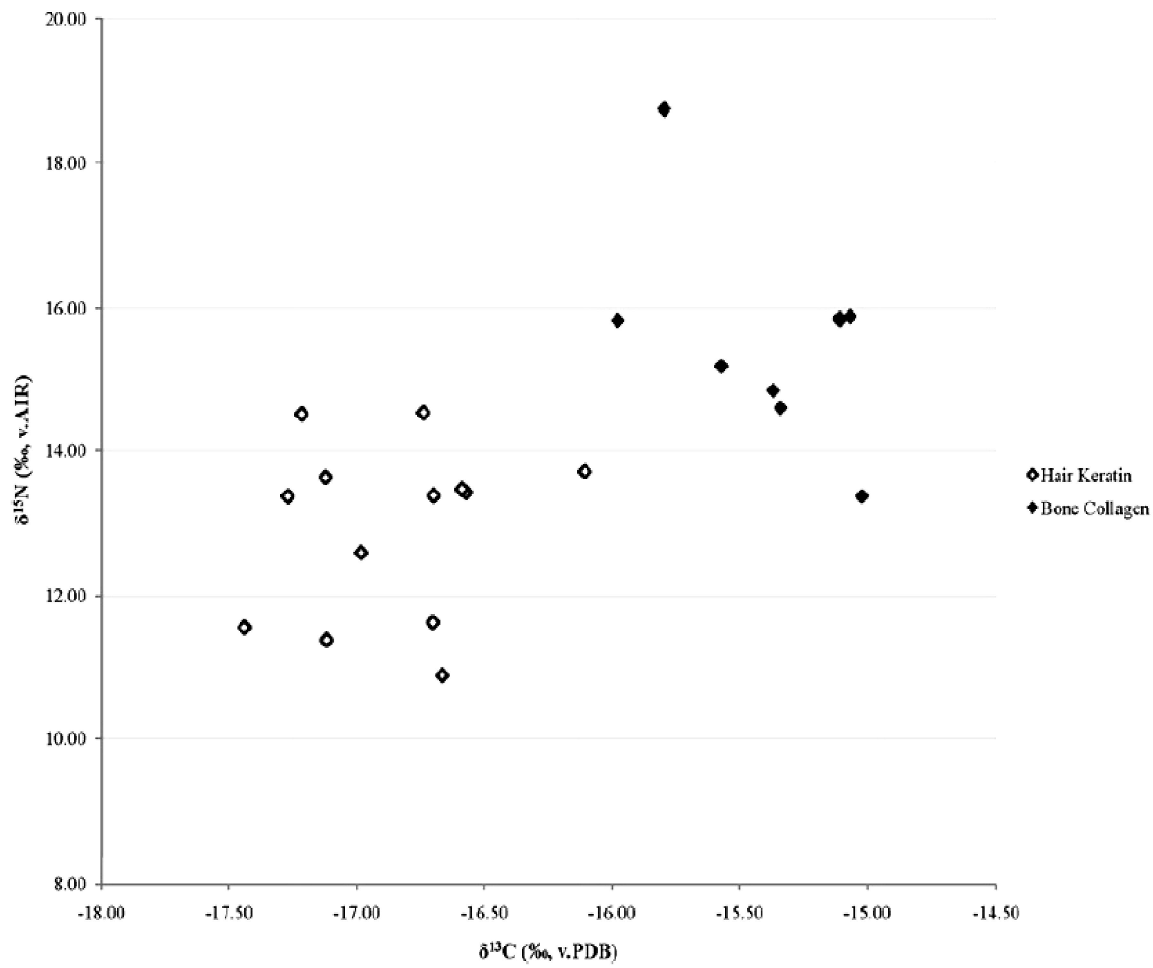

Fig. 7 Bone collagen and hair keratin $\delta^{13}C$ and $\delta^{15}N$ scatterplot from the Hets Cave samples. (Source: Turner *et al.* 2012)

Several individuals marked as 1-C, 1-D and 1-G (Table 4) contained sufficient enamel for analyses and light isotope characterization of $^{13}C_{carbonate}$ and heavy isotope characterization of $^{87}Sr/^{86}Sr$. For example, the range of $^{87}Sr/^{86}Sr$ value was between 0.70941 and 0.71057, and the isotope ratios of lead such as $^{206}Pb/^{204}Pb$ ranged between 17.8 and 18.6, $^{207}Pb/^{204}Pb$ ranged from 15.6 to 15.7, and the $^{208}Pb/^{204}Pb$ ranged between 37.6 and 38.7, these values suggested some divergence that different residential origins between the humans and rodents (Turner *et al.* 2012).

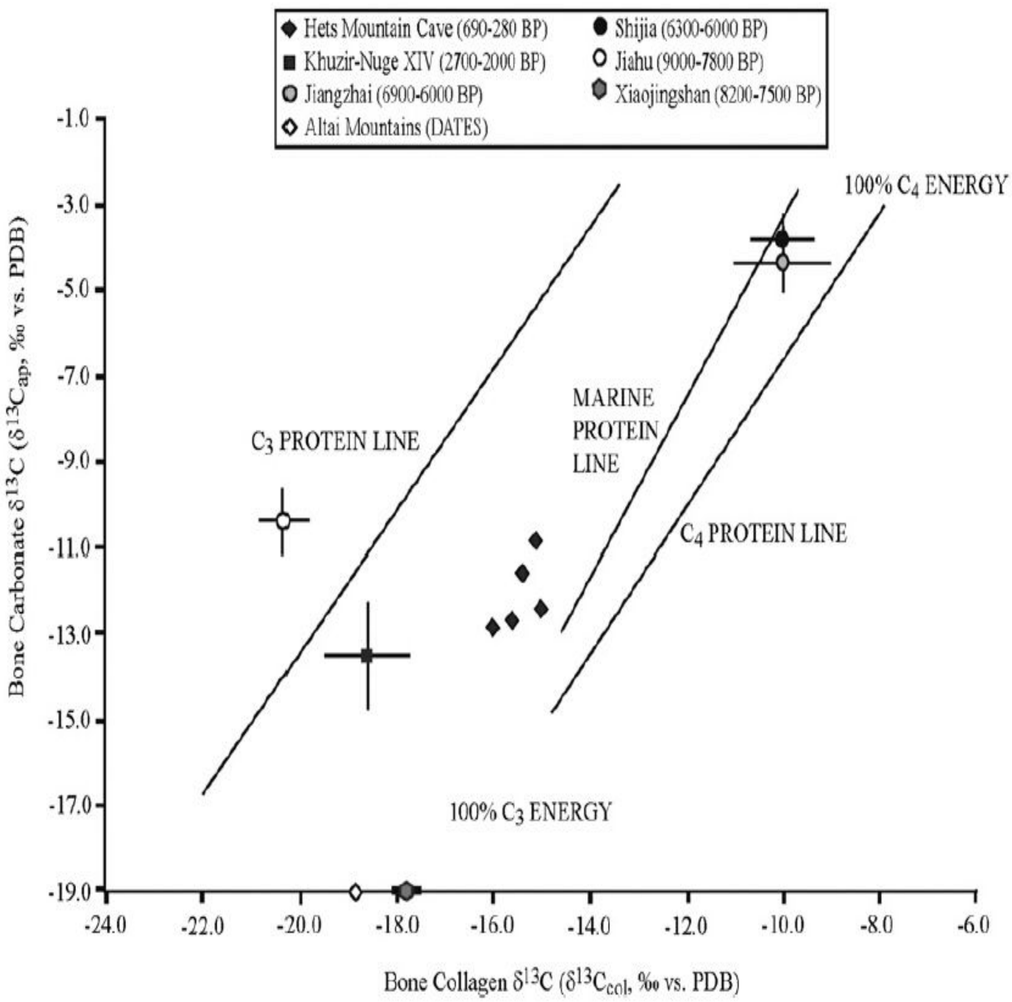

Fig.8 The bone carbonate and collagen $\delta^{13}C$ comparisons between Hets Mountain Cave and other regions. Khuzir-Nuge XIV data from Katzenberg *et al.* (2009); Jianzhai and Shijia data from Pechenkina *et al.* (2005); Jiahu and Xiaojingshan data from Hu *et al.* (2006, 2008). Altai datum from hair keratin from a single individual from Wilson (2008). Data are plotted against regression formulae from Kellner and Schoeninger (2007). (Source: Turner *et al.* 2012)

These multiple isotope data on the samples collected from the Hets Mountain Cave and other locations show what could be expected for variations within an individual's lifetime (Turner *et al.* 2012), and give us a comprehensive view about these region's dietary habits. As can be seen (Fig. 8), there are different regression lines in the comparison between bone $\delta^{13}C_{carbonate}$ and bone $\delta^{13}C_{collagen}$ values (Kellner and Schoeninger, 2007), and also other locations (Pechenkina *et al.* 2005; Hu *et al.* 2006).

These individual assemblages, recovered from the Hets Mountain cave, are all close to the C3 plant range, which suggests that the majority of their resources consuming were from C3 plants. Moreover, other samples have isotope values that occur in the middle of the C3 and C4 protein lines, and very close to the marine protein line, which is consistent with the result from $\delta^{13}C_{keratin}$. It is suggested that the diet $\delta^{13}C$ comparison from collagen and hair keratin were roughly at -20‰ range (Fig. 9).

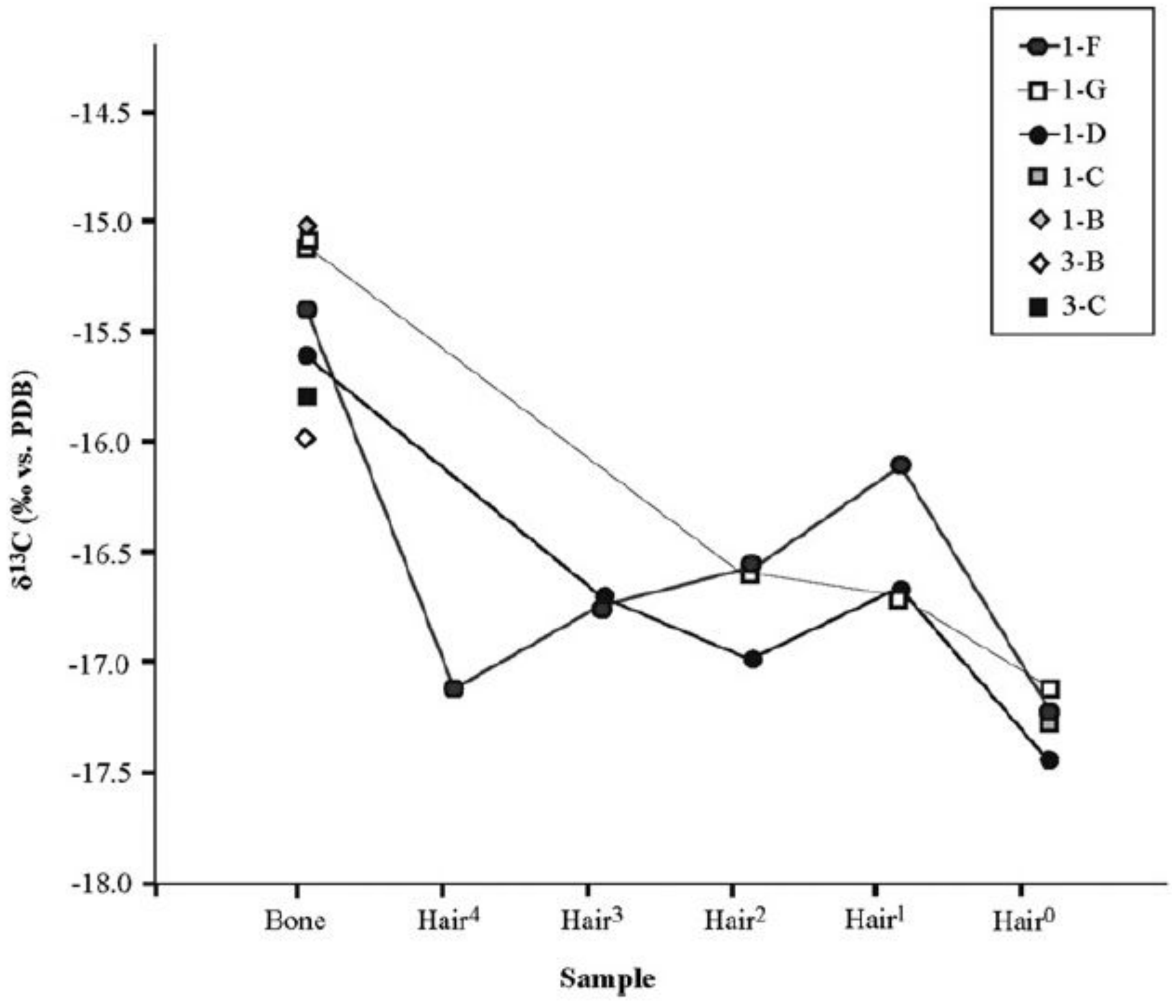

Fig. 9 Bone collagen and hair keratin's individual δ^{13}C estimates from the Hets Mountain Cave. (Source: Turner *et al.* 2012)

The average $\delta^{13}C$ values of terrestrial C3 plants is about -25.6‰, and the value of terrestrial C4 plant is -12.5‰ (O'Leary, 1988), however, certain environmental conditions could affect these results including desertification, aridity can increase the plant $\delta^{13}C$ value by 1.5‰ (Marshall and Zhang, 1994). Owing to the limited presence of fish skeletons at the Hets Mountain Cave and other surrounding sites (Frohlich, 2005), it tells us that this regions' residents are less likely to consume the marine based materials as their diets, hence, the Mongolian dynasty was influenced by the production of livestock, and these livestock were affected by the climatic conditions, and also the C4 plant richness.

The C4 plants, such as grasses are relatively efficient at photosynthesis in the hot climate of the Mongolia region, and are very important for the deserts and steppes ecologically (Pyankov *et al.* 2000). This region's livestock has relatively abundant ^{13}C within their tissues, consistent with animals that were consuming significant C4 plants during summer season (Makarewicz *et al.* 2006). The weighted average for $\delta^{13}C$ of plant samples which were collected from the central Mongolian ecoregion was around -19.3‰, and +6.4‰ for $\delta^{15}N$. These values are consistent evidence for the influence of C4 in both wild-ranging and foddered animals (Makarewicz *et al.* 2006).

Because of the diet $\delta^{13}C$ average was about -20‰, and these samples' isotope data shows a heavy incorporation of C4 energy sources and C4 protein (Fig. 8, Fig. 9), it turns out that these residents who lived around the Hets Mountain Cave might not only based on C3 plants and C3 browser meats, but also C4 plants as dietary resource decreased during the desertification season.

In addition, Turner *et al.* (2012) described other reasons why the $\delta^{15}N_{collagen}$ and $\delta^{15}N_{keratin}$ are both higher than the value normally seen from the mainly plant-based protein consumers

(Fuller *et al.* 2005). First of all, these samples, including 6-month and 12-month old infants who were likely to contain systematic $\delta^{15}N$ enriched from breastfeeding during the formation of their bones collagen prior to their death. However, instead of simply breastfeeding on relative high $\delta^{15}N$ values among these infants, the mother's $\delta^{15}N$ value was influenced by the dietary of the region.

A desert like the Gobi is quite arid, so its environmental condition will likely increase the $\delta^{15}N$ values within this terrestrial biota from enriched ^{15}N desert soils and physiological mechanisms by surrounding water resources (Ambrose, 1991; Schwarcz *et al.* 1999). Moreover, the enrichment of ^{15}N may also reflect not only the consumption of terrestrial herbivore-based meats, but also other freshwater related fish consumptions since their ^{15}N enrichment are relative to terrestrial animals (Schoeninger and DeNiro, 1984).

The above explanation, supported by $\delta^{15}N_{collagen}$ values from goat dentin as their range is between +5.5‰ and +12.9‰, and the domesticated goat which used provender plants with $\delta^{15}N$ values as high as 10.7‰ (Makarewicz and Tuross, 2006). All of these values including the $\delta^{13}C$ data (Fig. 8) suggest a heavy reliance on C3 plants and terrestrial/aquatic animal proteins, and there appears to be no dietary difference among the individuals' 1-D, 1-G and 3-C with bone or hair values after accounting the diet-tissue difference between $\delta^{13}C_{collagen}$ and $\delta^{13}C_{keratin}$.

The female individual marked as 1-D (Table 4) shows a higher $^{87}Sr/^{86}Sr$ as compared to 1-G and 1-C, tells us that she might have lived in an area distinct from the others during her early life. The $^{87}Sr/^{86}Sr$ of the 40 year-old male (1-G) was slightly lower than 1-D but higher than 1-C, and he might have moved more during his childhood since his $^{87}Sr/^{86}Sr$ shows slight differences between his teeth.

The third individual sample was an eight year-old child, who has an isotope composition similar to 1-C, and shows a relatively low first and/or second permanent molars (M1 and/or M2) values as compared to others (Table 4), but because of the M1 and M2 are roughly the same, tells us that this individual have spent most of his life in an isotopically region that was distinct from the other adult individuals. Overall, these values collected by Turner *et al.* (2012), might not suggest a long distance migration among these individuals directly, but imply the different histories of Mongolian residential mobility, such individuals likely originated from other regions which were under desertification which made their substandard living conditions even worse.

Conclusion:

Overall, a dynasty like the Mongol empire during 13th and 14th centuries, could not survive for a long time if adverse condition such as desertification climate occurred to prevent its people from producing sufficient food to maintain a strong economy and capable military force to defending this dynasty or even expanding its territory. Higher temperatures during desertification among the Mongolian steppe brought along with a low precipitation and higher evaporation during this time period, decreased the production of C3 plants and livestock based on this food wholly, this could have led to the Mongolian dynasty into decay and collapse, forced their residents to migration to a more suitable place.

The individuals collected around the Hets Mountain Cave region by Turner *et al.* (2012) shows the evidence that their dietary was mainly relied on C3-dominated sources of energy and mixed C3/C4 protein such as terrestrial herbivores. There is no isotope indication of the dietary carbon shifts prior to their death, and they were not likely consuming anything like the millet C4 grain. Although some individuals show a shift to lower trophic-level protein sources, there is no evidence from the $\delta^{15}N_{keratin}$ data that these Mongolian samples had suffered acute nutritional stress which would lead them into a leaner tissue catabolism.

According to the $\delta^{18}O$ signals of these individuals, they had experienced broad changes of original residence, and moreover, some of the individuals might have immigrated to Hets Mountain Cave surrounding area fairly late during their lives; their early-life $^{87}Sr/^{86}Sr$ values showed a geologically different trend as compared to the after-death $^{87}Sr/^{86}Sr$ value. Hence, based on these individuals' residential origin and dietary habits, there was a relationship between the political and economic turmoil due to the desertification impact on this area.

Since these above results (Turner *et al.* 2012) and other researchers could not use as a unified reference to other samples within the Mongolian Plateau because of the residential origins variation, more isotopic studies from a wider range of the Mongolian population during the Yuan and Ming Dynasties desertification period are still required.

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