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REPORT TITLE: Isotopic and Elemental Analysis of the William Bass Donated Skeletal Collection and Other Modern Donated Collections

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AUTHORS:
Nicholas P. Herrmann, Zheng-Hua Li, and Monica M. Warner with contributions from Willa Trask, Daniel Weinand and Miriam Soto

PI: Richard L. Jantz, Ph.D.
Department of Anthropology
University of Tennessee
Knoxville, TN 37996-0925
Email: rjantz@utk.edu
Phone: 865-974-4408

Co_PI: Nicholas P. Herrmann, Ph.D.
Department of Anthropology and Middle Eastern Cultures
Mississippi State University
Mississippi State, MS 39762
Email: nph29@msstate.edu
Phone: 662-325-1781

Co_PI: Zheng-Hua Li, Ph.D.
Center for Space Plasma & Aeronomic Research
NSSTC 2069, 320 Sparkman Dr.
Huntsville AL 35805
Email: Zheng-Hua.Li@nasa.gov
Phone: (256) 961-7655 (o), (256) 961-7921

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Abstract

Isotopic and elemental characteristics of human bone, teeth, and hair have been demonstrated as useful biomarkers for forensic anthropologists and criminal investigators. These biomarkers trace locations and movements of the individuals, and aid in the identification of human remains. This project analyzed multiple isotopes (carbon, oxygen, hydrogen, strontium, and nitrogen), and trace elements in modern human bone, teeth, and hair from the William Bass Donated Skeletal Collection (WBDSC), the Maxwell Museum Documented Skeletal Collection (UNM), and the Texas State University-San Marcos Forensic Research Facility (TSU-SM). The WBDSC represents the largest modern donated osteological collection in the United States and is located at the University of Tennessee Forensic Anthropology Center. Samples from individuals with self-or family-reported birth locations and movement histories were used for this study. In addition, individuals with unknown natal histories were compared against the known residential history data set. Sample preparation and isotope analyses were conducted at the University of Tennessee Stable Isotope Laboratory, the University of Alabama-Huntsville, the R. Ken Williams '45 Radiogenic Isotope Geosciences Laboratory at Texas A&M University, and the University of Alabama Stable Isotope Laboratory in Tuscaloosa. Trace element analysis was conducted at the Mississippi State University Department of Chemistry Laser Ablation Unit. A total of 290 individuals were sampled for a combination of stable isotope and trace element analyses. The samples included: powdered enamel for strontium analysis, bone collagen extraction for carbon and nitrogen analyses, bone apatite and Ag_3PO_4 enamel precipitate for oxygen analysis, and bulk hair samples for hydrogen analysis. Results from the study indicate that the enamel $\delta^{18}O$ values from the WBSC collection are overall reflective of individuals' birth locations, whereas hair keratin $\delta^{2}H$ values are influenced by individuals' death locations, which is consistent with isotope studies of forensically derived human samples. This suggests that the application of dual isotopes (O and H) provides a clear picture of residential history by spatially locating the beginning (tooth) and the ending (hair) of the individual life journey. Although the correlation coefficient of the enamel $\delta^{18}O$ values with local water is not as high as the previously reported values, the relationship does follow the trend of earlier results. A potential influence of the elevated $\delta^{18}O$ values may result from the isotopic pattern of tap water when compared to precipitation. Isotope results were built into a publically available database, Forensic Isotopes Nation Database (FIND), which is accessible to various researchers that can serve as a repository for human derived isotopic information from anatomical collections with residential histories or for resolved forensic cases involving bone, enamel, or hair isotope data. This project has generated a national isotope database derived from the WBDSC and the other donated skeletal collections; provided forensic anthropologists and criminal investigators a comparative isotopic database of known residence from various sampled tissues; and has evaluated the effectiveness of implementing multiple isotopic analyses to estimate movement histories for modern forensic cases.

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Executive Summary

Isotopic and elemental characteristics of human bone, teeth, and hair have been demonstrated as useful biomarkers for forensic anthropologists and criminal investigators. These biomarkers trace locations and movements of individuals and aid in the identification of human remains. This project analyzed multiple isotopes (carbon, oxygen, hydrogen, strontium, and nitrogen) and trace elements in modern human bone, teeth, and hair from the William Bass Donated Skeletal Collection (WBDSC) at the University of Tennessee-Knoxville (UTK), the Maxwell Museum Documented Skeletal Collection at the University of New Mexico (UNMMM) and the Texas State University-San Marcos (TSU-SM) Forensic Research Facility. The WBDSC represents the largest modern osteological collection in the United States and is located at the University of Tennessee Forensic Anthropology Center. Samples from individuals with self-reported or family-reported origins and movement histories were used for this study. In addition, individuals with unknown natal histories were examined against the known residential history data set. Sample preparation and isotope analyses were conducted at the University of Tennessee Stable Isotope Laboratory, the University of Alabama-Huntsville, the R. Ken Williams '45 Radiogenic Isotope Geosciences Laboratory at Texas A&M University, and the University of Alabama Stable Isotope Laboratory in Tuscaloosa. Trace element analysis was conducted at the Mississippi State University Department of Chemistry Laser Ablation Unit.

In total, samples from 290 individuals were tested for biogeochemical analysis. The samples included: powdered enamel for strontium analysis, bone collagen extraction for carbon and nitrogen analyses, bone apatite and Ag_3PO_4 enamel precipitate for oxygen analysis, and bulk hair samples for hydrogen analysis.

Table 1: Samples Analyzed (290 individuals)

Isotopes	**Samples Processed**
Bone	290 (Apatite) / 221 (Collagen)
Enamel (O)	216
Hair	14
Enamel (Sr)	55
Trace Elements	**Samples Processed**
Enamel	19*
Total Assays	796

* LA-ICP-MS results are preliminary data and are included in FIND as counts per second (cps)

Multiple constituents including bone collagen, bioapatite (phosphate and carbonate), and hair keratin from 290 donors from WBDSC, UNMMM, and TSU-SM were prepared for $\delta^{13}C$, $\delta^{18}O$, $\delta^{15}N$, $^{87}Sr/^{86}Sr$, and $\delta^{2}H$ analysis using refined protocols. The protocols were enhanced by shortening the cycle of each sample preparation period for collagen extraction utilizing a filter-bag method assisted by an ultrasonic water bath, and modifying a Thermo TC/EA for improving analysis precision of phosphate $\delta^{18}O$. Dental enamel was sampled using a NewWave Micromill and analyzed for $\delta^{18}O$ of phosphate. The averaged $\delta^{18}O$ value for a select sample of the dental enamel was 16.91±2.21‰ VSMOW (n=215) (see Table 5). Our initial correlation analysis of the dental $\delta^{18}O$ values with meteoric water $\delta^{18}O$ at birth location (modeled) yielded the equation

($\delta^{18}O_{tooth}=0.62*\delta^{18}O_{water}+21.74$, r=0.63, n=45) (Figure 2) (Herrmann et al., 2010), which was similar to the equation ($\delta^{18}O_{bone}=0.64*\delta^{18}O_{water}+22.37$, r=0.98) generated by Longineli (1983). With the addition of the new samples from TSU-SM and UNMMM the correlation reduced significantly ($\delta^{18}O_{tooth}=0.349*\delta^{18}O_{water}+20.164$, r=0.36, n=120) and appears to vary by collection with TSU-SM and UNMMM showing poor relationships.

Non-exchangeable δ^2H of hair keratin was also analyzed using a Thermo TC/EA. The averaged δ^2H was -83.35± 6.36‰ VSMOW (n=14). The δ^2H values exhibited a positive correlation with the meteoric water $\delta^{18}O$ at death location (r=0.81), and a negative correlation with altitude (r=-0.73), which is consistent with the isotope "Altitude Effect".

In addition, bioapatite carbonates samples (n=290) were analyzed for $\delta^{13}C$ and $\delta^{18}O$. The averaged value was -9.53±1.28‰ (VPDB) for $\delta^{13}C$, and -11.23± 4.00‰ (VPDB) for $\delta^{18}O$. These values vary by collection with marked differences between the TSU-SM samples as compared to both UTK and UNMMM for $\delta^{13}C$ and a significant difference between UTK as compared to both TSU-SM and UNMMM. In addition, the samples show regional differences in the range of $\delta^{18}O$ values with the UNMMM samples exhibiting a substantial range and the UTK range being far more limited.

Bone collagen samples (n=215) were extracted for $\delta^{13}C$ and $\delta^{15}N$ analysis. In addition, N%, C%, N/C ratios were recorded for a subset of these samples (Figure 8). The averaged carbon content in human phalanx (both hand and foot) bone collagen was 32.93±6.87%, 11.31±3.32% for nitrogen content. The averaged C/N ratio was 3.133±1.04. The averaged $\delta^{13}C$ value was -16.32±1.25‰ (VPDB), and 11.24±0.53‰ (AIR) for $\delta^{15}N$.

Powdered enamel samples (n=57) were collected for $^{87}Sr/^{86}Sr$ analysis. Sr results are available for 55 samples and were combined with the results presented by Regan (2006) for military personnel. The $^{87}Sr/^{86}Sr$ ratios were then converted to epsilon values (Beard and Johnson 2000). The resulting epsilon values were compared to modeled bedrock and modeled drainage and bedrock epsilon values based on Beard and Johnson (2000) and Bataille and Bowen (2012), respectively. In addition, the values were plotted on the available GIS coverages for both models and specific point values based on birth locations were extracted from the raster coverages of these two models. The two extracted values were plotted to assess the relationship of the measured vs. location expected (or modeled) position. Both models provide poor fits to the modeled values. The data does appear to follow the pattern relative to birth location. The plot of ratios organized by value from low to high shows general patterning at the state level.

The data from this study suggests that the dental enamel $\delta^{18}O$ values from the WBSC collections are overall reflective of individuals' birth locations, whereas hair keratin δ^2H values are influenced by individuals' death locations, which is consistent with several other isotopic studies of forensically derived human samples. This suggests that the application of the dual isotopes (O and H) could provide a better picture of residential history by spatially locating the beginning (tooth) and the ending (hair) of the individual life journey. Although the correlation coefficient of the dental $\delta^{18}O$ with local water is not as high as reported by several other researchers, the relationship, however, does follow the trend of the earlier study. The isotopic pattern of tap water as compared to precipitation could be a potential factor. It is also suspected that the WBDSC does not represent a more geographically heterogeneous sample and it is likely that self- or family-reported residential histories as is the practice at the UTK FAC are more variable.

This study has implications for law enforcement, practicing forensic geochemists, and forensic anthropologists interested in isotope and trace element research. This study also

provides a large isotope dataset from three donated human skeletal collections currently used as reference samples for active forensic anthropologists. These data enhance our understanding of the isotopic variation in modern humans, specifically modern US residents. The isotopic variation observed in these samples is greater than typical controlled laboratory studies, but the results do conform to current isotopic models, specifically for $\delta^{18}O$, and is therefore useful for estimating residential histories. Future isotopic work with unidentified decedents could be linked to their NamUs record and used to provide potential matches within the system based on geographic histories.

Broader impacts of the study relate to the Forensic Isotopic National Database (FIND). The data generated by this study will be made available to researchers through FIND, where researchers can also submit their own results from forensic casework and modern donated collections. FIND is accessible at http://find.msstate.edu/fmi/webd with a user name and password of FINDUser and FindUSer, respectively. FIND will serve as a repository of forensic isotopic data for human skeletal, dental, and hair studies.

This project generated a national isotope database derived from the WBDSC and the other donated skeletal collections; provided forensic anthropologists and criminal investigators a comparative isotopic database of known residence from various sampled tissues; and has evaluated the effectiveness of implementing multiple isotope analyses to estimate the movement histories of modern humans for forensic cases.

The study has also contributed to the training and laboratory experiences of both graduate and undergraduate students at the University of Tennessee- Knoxville, Mississippi State University, University of Alabama-Huntsville, University of New Mexico, and Texas State University-San Marcos. The PIs on the project have also reached out to the medicolegal community to provide these services for a nominal fee during the process of the grant. Dr. Li has processed several bone and enamel samples for $\delta^{18}O$ as well as carbon and nitrogen. Isotopic analysis is now viewed as an important step in the analysis of unidentified decedents in some agencies.

As the donated collections at UTK, UNM, and TSSU as well as several new body donation programs across the country grow, it is essential that reliable residential histories be collection from the donors and that isotopic data be collected (specifically adequate hair samples for research requests). These expanding collections combined with recent forensic isotope surveys and recently published isotope data will provide a much better picture of the isotopic and trace element variation across the United States. It is anticipated that this study will provide a foundation for future research with these collections.

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Introduction

Isotopic and elemental characteristics of human bone, teeth, and hair have been demonstrated as useful biomarkers for forensic anthropologists and criminal investigators. These biomarkers trace locations and movements of individuals and aid in the identification of human remains. This project analyzed multiple isotopes (carbon, oxygen, hydrogen, strontium, and nitrogen) and trace elements in modern human bone, teeth, and hair from the William Bass Donated Skeletal Collection (WBDSC), the Maxwell Museum Documented Skeletal Collection and the Texas State University-San Marcos Forensic Research Facility. The WBDSC represents the largest modern donated osteological collection in the United States and is located at the University of Tennessee Forensic Anthropology Center. Samples from individuals with self- or family-reported birth location and movement histories were used for this study. In addition, individuals with unknown natal histories were examined against the known residential history data set. Sample preparation and analysis was conducted at the University of Tennessee Stable Isotope Laboratory, the University of Alabama-Huntsville, and the University of Alabama Stable Isotope Laboratory in Tuscaloosa. Trace element analysis was conducted at the Mississippi State University Department of Chemistry Laser Ablation Unit. Strontium analysis was performed by Texas A&M University Radiogenic Isotope Geochemistry Laboratory.

In total, samples from 290 individuals were prepared for analysis. Samples included: powdered enamel samples for strontium analysis, apatite and collagen extractions from bone, Ag_3PO_4 precipitate from powdered dental enamel, and a limited number of bulk hair samples. Our study indicates that the dental enamel $\delta^{18}O$ values from the WBSC collections are overall reflective of the individual's birth location, whereas hair keratin $\delta^{2}H$ values are influenced by the individual's death location, which is consistent with several other isotopic studies of forensically derived human samples and suggests that the application of dual isotopes (O, H) could provide better constraint on the residential history by pinpointing the beginning (tooth) and the ending (hair) of the individual life journey. Although the correlation coefficient of the dental $\delta^{18}O$ with local water is not as high as reported by several other researchers, the relationship, however, does follow the trend of the earlier study. This could result from the potential influence of the isotopic pattern of tap water as compared to precipitation. In addition, these results have been built into a basic publically available database, Forensic Isotopes Nation Database (FIND), which is accessible to various researchers and can serve as a repository for human derived isotopic information from anatomical collections with residential histories or for resolved forensic cases involving bone, enamel or hair isotope data. This project has generated a national isotope database derived from the WBDSC and the other donated skeletal collections; provided forensic anthropologists and criminal investigators a comparative isotopic database of known residence from various sampled tissues; and it has evaluated the effectiveness of implementing multiple isotopic analyses to estimate the movement histories for modern forensic cases.

Statement of the problem

This study examines the isotopic compositions of various modern human tissues within three donated human skeletal collections from across the United States. The study attempts to discover better constraints for tracing the birth locations, movement histories, and living environments of modern individuals through the examination of multiple isotope data ($\delta^{13}C$, δD, $\delta^{18}O$, $^{87}Sr/^{86}Sr$, and $\delta^{15}N$) and trace elements. The William M. Bass Donated Skeletal Collection

(WBDSC), housed at the University of Tennessee (UTK) Forensic Anthropology Center (FAC), served as the primary sample for the project. In addition to WBDSC, numerous tissue samples from the Maxwell Museum Documented Skeletal Collection at University of New Mexico (MMDSC) and the Texas State University-San Marcos Donation Program (TSSM) were obtained and analyzed. The regional variation in birth (including foreign born individuals) and death locations and demographic diversity of these donated skeletal collections provided an ideal opportunity to examine isotope and trace element variation across the United States.

The goals and objectives of this study were: 1) to build a national database of isotope and trace element profiles for human ossified and soft tissues of known origins derived from WBDSC, MMDSC and TSSM, 2) to provide forensic anthropologists and criminal investigators a comparative database to determine location of residence of unidentified decedents based on the tissue sampled, and 3) to refine laboratory and analytical methods for constraining the locations and movement histories of modern individuals by implementing multiple isotope data. For example, isotope profiles could be highly complicated by individuals who consume global range food products or pre-packaged foods.

Previous studies of isotopic and elemental signatures from human bone, hair, and teeth in a forensic context have typically focused on a limited number of samples or have examined foreign-born individuals. By testing a large number of natural born individuals this study should provide a baseline data set for examining isotopic and elemental variation in these three tissues from a modern US sample. Ideally, this study will allow forensic anthropologists and investigators to identify age-specific residential range for the unidentified decedent based on the isotopic signature of the tissue examined. In total, 290 individuals from these three collections have been examined including 796 individual elemental assays. These results are all included in Forensic Isotopic National Database (FIND, available at http://find.msstate.edu/fmi/webd).

Literature Review of Forensic Applications of Biogeochemistry

The identification of unknown persons is of the utmost importance for the forensic anthropologist. Positive identification of human remains is determined when unique characteristics known to exist are established (Ubelaker, 2008), and are typically based on traditional identification methods. These methods include personal documentation, dental records, radiographs, morphology, pathology, and establishing a biological profile. The biological profile is especially important in countries where dental records are not obtainable or when individuals are found skeletonized without documentation. Molecular methods aid in the identification process and may even assist in the arrest of the perpetrator.

Recent methods that have become increasingly popular in assisting with the identification process are stable isotopes and trace elements. Vast amounts of isotope and trace element data are being collected to demonstrate the validity of the methods. Geochemistry methods have aided in forensic cases relating to environmental accidents, food authenticity, distinguishing drugs, elucidating explosives, geo-referencing materials, and provided supporting evidence for the biological profile (Meier-Augenstein, 2010; Pye and Croft, 2004). Isotopes are an informative tool when DNA is absent, or beneficial when used in conjunction with other reliable identification methods. Isotopes and trace elements are especially important when remains are highly fragmented, as in cases of natural disasters or incineration. Data generated from the WBDSC, MMDSC, and TSSM collections provides further supporting evidence for the application of biogeochemistry in the identification of human remains.

Unlike DNA 'fingerprinting' that is immutable, stable isotopes and trace elements change over time. This variability is advantageous for compiling a multi-variable stable isotope profile (SIP). Isotopes are extraordinary due to the different numbers of neutrons that reveal information about the local environment and surrounding ecosystems (Fry, 2006). Isotopes essentially divulge the geographic signatures of humans, since isotopes from local drinking water and food sources are incorporated into human enamel, bone hydroxyapatite phosphate and carbonate, hair keratin, and nails. Both 'light' and 'heavy' isotopes are used for diet reconstruction and/or residential history, but 'heavy' isotopes have several advantages. 'Heavy' isotopes barely exhibit any fractionation and can also tolerate high temperatures after incineration (Harbeck et al., 2011). Trace elements also aid in the SIP, by revealing environmental toxin exposure or medical treatments. Some have even suggested that trace elemental compositions may provide individual provenance despite similar diet composition (Burton et al., 2003; Cucina et al., 2011). There are advantages and disadvantages to every method, including biogeochemistry methods. Many have expressed concern over the effect globalization has on modern human signatures. From a review of the literature, we found studies with both positive and negative results, but it appears that despite globalization, modern humans retain the local isotope signature, regardless of the consumption of bottled water and foreign products.

Previous biogeochemistry studies in forensic anthropology demonstrate the usefulness of stable and radiogenic isotopes and trace elements of modern human remains. FIND is the beginning of standardization in the United States and provides a baseline for narrowing the geographic range for forensic investigators using isotope signatures for the identification process. This review section demonstrates the importance of biogeochemistry in forensic anthropology through the description and recent application of isotopes and trace elements in the field, and is followed by a review of the modern globalization concern.

'Light' Stable Isotopes

'Light' isotopes are elements on the periodic table with small atomic masses. Carbon (C) and nitrogen (N) were the first 'light' stable isotopes used by anthropologists to study dietary trends of archaeological populations (Katzenberg, 2008). Since the 1970's, the use of 'light' isotopes expanded to include oxygen (O), hydrogen (H), and sulfur (S), enabling studies of residential histories for past and modern skeletal assemblages. Variation in stable isotopes allows researchers to study the amount in certain ecosystems, and therefore human populations residing in specific regions. This variation is caused by kinetic or equilibrium physiochemical processes that fractionate isotopes called isotope fractionation (Meier-Augenstein, 2010). In nature, abundance variation has been well documented for 10 elements having 2 or more stable isotopes, C, N, O, H, and S being five commonly used in anthropology. Therefore, the upper and lower bounds of the atomic weights have been determined in naturally occurring terrestrial environments (Brand and Copeland, 2012). Environmental processes, such as evaporation and condensation that effect the hydrogen cycle, allow these small isotopic signatures to be quantified for O and H. Another important process of stable isotope variation in the environment is isotope mixing. Isotope mixing occurs after the fractionation process, where the fractionated material is transported over large distances mixing with other fractionated or non-fractionated materials. These geochemical processes are the bases behind the use of 'light' stable isotopes for the study of human residential histories.

Variation of isotopic abundances in the environment is retained in human tissues and has the ability to be quantified for forensic science purposes. 'Light' isotope profiles of C, N, H, and O have been determined using teeth, bones, hair, and nails from modern human remains. In human tissues stable isotope signatures are determined from the ratio of the isotope values ingested by a person during the ages that the skeletal tissues are formed (Wright, 2005). Both collagen and apatite are used for stable isotope analysis depending on the isotope the forensic anthropologist is interested. For instance, collagen is the preferred biochemical fraction when conducting a dietary analysis of C and N, due to the large amount of collagen contained in bone (Ambrose, 1993). Tooth enamel is generally preferred over dentine, because of the hard hydroxyapatite composition of enamel, and its resistance to digenetic alterations from soil and other surrounding materials. There are also advantages to using both bones and teeth for the same forensic case. Human teeth are formed early in development, locking in the isotope signature. Bone, on the other hand, remodels over time, revealing the later isotope signatures of individuals, approximately the last 10-15 years of their life (Katzenberg, 2008). A large number of studies using hair have been generated in recent years, ranging from residential histories of the dead to starvation and malnutrition in the living. Hair strains are less invasive making the method more attractive to forensic investigators (Santamaria-Fernandez et al., 2009). Recent forensic case studies have generated SIPs that aided in the determination of the unknown individual using a combination of tissue samples and multiple 'light' stable isotopes.

Selected Isotope Case Studies of Diet

In forensic cases, studies of diet may be used as an unbiased biomarker to infer information about specific foodstuffs and location. 'Light' isotopes have been used to establish malnourishment and neglect in child abuse cases. For instance, Neuberger et al. (2013) measured daily $\delta^{13}C$ and $\delta^{15}N$ values in human hair to reconstruct nutritional histories of deceased individuals. Their study showed that elevated $\delta^{15}N$ values were associated with very low BMI indicating the catabolism of bodily protein, and changes in $\delta^{13}C$ values indicative of low energy and the loss of fat deposits. Although carbon and nitrogen stable isotopes are successful in analyzing dietary inputs, $\delta^{13}C$ and $\delta^{15}N$ values of hair are not significant for documenting geospatial patterns of human movements. However, data documented from Valenzuela et al. (2011) did suggest that residents of the northeastern continental United States consume a higher C_3 plant based diet, whereas the average U.S. diet is high in C_4 plant based foods.

Selected Isotope Case Studies for Residential Histories

The use of stable hydrogen and oxygen isotopes in forensic anthropology increased over the last decade (Copeland and Qi, 2012). O and H gained popularity due to the fact that they provide insight into human residential history patterns. Hydrogen and oxygen abundances of precipitation and waterways form the basis of isotope hydrology, which is reflected in the tap water consumed by humans across the globe. ^{18}O and ^{2}H or deuterium (D) signatures are well-established proxies of climate and source water, and are reliable methods for determining the provenance of human remains. In particular, the use of oxygen isotope composition was proposed as the most dependable method for forensic provenance studies at the 2008 American Academy of Forensic Sciences meeting on new geochemical techniques for geographic and forensic identification. Hydrogen isotopes are also useful proxies depending on the tissue type

sampled for analysis. Although in a pilot study by Holobinko et al. (2011) demonstrated that D in tooth enamel was not a useful proxy for geographic origin. On the other hand, sulfur has been shown to be a useful biomarker for determining the residential histories of modern populations. Valenzuela et al. (2011) found that geospatial patterns of sulfur in the continental United States had detectable regional variations, with lower values in the plains region and higher $\delta^{34}S$ values closer to the coast. Similar results were observed in European studies of sulfur in lamb, beef, and dairy products (Camin et al., 2007; Perini et al., 2009).

'Heavy' Stable Isotopes

The application of 'heavy' stable isotopes, such as strontium (Sr), lead (Pb), and neodymium (Nd), have a more recent history in forensic science. Forensic scientists apply these isotopes towards litigation when the identification of source material is warranted. 'Heavy' stable isotopes are used in cases for determining bullet material, soil composition, drug sourcing, or for provenance of unidentified human remains. Forensic geochemistry relies on the subtle differences of the chemical composition and isotope abundances. A particular material is characterized then compared to potential source materials (Aggarwal et al., 2008). In the case of human remains the potential sources are the locations on the earth or the residential history of the individual.

Large variations of isotopes exist in nature due to the initial abundance of the isotope at the time of the Earth's formation and the change in the amount over time (Pye, 2004). For instance, the isotope ^{87}Sr results from the radioactive decay of ^{87}Rb and overtime the ratio of ^{87}Sr to the stable isotope ^{86}Sr in rock increases with time as a function of the rocks Rb/Sr ratio (Bataille and Bowen, 2012). The strontium signature at the time of the Earth's formation 4.5 billion years ago was calculated as 0.699 and over time the strontium signature has increased with slight variations depending on the parent material of the rock: igneous, metamorphic, or carbonate rich bedrock. Old metamorphic rock has $^{87}Sr/^{86}Sr$ ratios near 0.715, where recent volcanic rocks have values approximately 0.704 (Wright, 2005). Variations in the underlying bedrock, due to time, type of parent material, and weathering have contributed to specific geographic strontium signatures which enable the forensic anthropologist to track the movements of humans on the landscape.

The ability for certain elements to withstand high temperatures is advantageous for the forensic investigator. Fire is often used in attempt to destroy forensic evidence in criminal cases, commonly in attempt to prevent the identification of the victim (Ubelaker, 2009). DNA degrades over time and can only withstand low temperatures. Harbeck et al. (2011) conducted a study to determine when DNA and certain isotopes can be retrieved from burned bone. Stable isotope values of carbon, nitrogen, and oxygen could withstand temperatures up to 200°C. However, strontium isotopes were reliable up to temperatures reaching 1000°C. This method is accurate and unaltered by cremation environments. This demonstrates the effectiveness of 'heavy' stable isotopes, and the usefulness of Sr for mass disasters and homicide investigations.

'Heavy' stable isotopes also enable forensic scientists to perform studies without the worry of determining all of the foods consumed by the population. There is no measurable fractionation of Sr isotopes like there are for 'light' stable isotopes. This advantage eases the interpretation of stable isotope results. Although 'heavy' isotopes appear advantages to 'light' stable isotopes, acquiring a combination of results enables a clearer assessment of the unknown individuals in forensic cases.

Selected Isotope Case Studies for Residential Histories

The majority of biogeochemistry research in forensic anthropology applies Sr or a combination of Sr and O, C, and N. An influential forensic biogeochemistry study using Sr was conducted by Juarez (2008) at the University of California, Santa Cruz that examined the remains of undocumented border crossers in the United States. Due to the lack of a well-developed missing persons database for Mexican-born individuals, many unidentified immigrants' remains stored in coroners or medical examiners offices in border communities await identification. The Sr research successfully narrowed the search of several individuals down to specific regions within Mexico.

Outside the United States, stable isotopes have been used in conjunction with other identification methods to identify human remains. For instance, Rauch et al. (2009) used Sr and Pb in a forensic investigation of an individual found near a highway in Germany with gunshot trauma to the cranium, along with trauma fractures on the maxilla and mandible. Odontology results suggested that the individual was from Eastern Europe or the Russian Federation, and the 'heavy' stable isotope data narrowed the birth-location to Romania. Upon further assessment of the Romanian missing persons database, the unknown individual was confirmed by family member DNA. The evidence in this investigation also led to the arrest and confession of the victim's killers. Although isotope research presented in these case studies do not provide a direct 'fingerprint' for identification, the region of origin was narrowed, which allowed the search efforts for missing persons to be centered on smaller geographic areas.

Isoscapes

Isoscapes are maps created to visualize the geographic distributions of stable isotopes. They were first used by geologists interested in the anthropogenic effects of pollutants, and ecologists monitoring the migrations of organisms. In the mid-twentieth century, the International Atomic Energy Agency (IAEA), in cooperation with the World Meteorological Organization, launched a global survey to measure the isotopic composition of precipitation to monitor climate change. This project was known as the Global Network of Isotopes Project (GNIP), and influenced the collection of large climate and hydrology datasets of groundwater isotopes throughout the globe. These early isotope maps pioneered the way for isoscapes used in many scientific disciplines today. For instance, Wassenaar et al. (2009) inspired by the GNIP project, went beyond the scope of the early research to refine δD and $\delta^{18}O$ of groundwater in Mexico. Their isoscapes were tested in an ecological study of household songbirds to compare the hydrogen isotopes in feathers to the refined groundwater isoscape of Mexico (Hobson et al., 2009). Results from this study suggested that baseline isoscapes are needed for the species of interest.

In forensic anthropology, baseline isoscapes of tap water, body water, and rainwater have been created for the study of human residential histories. Isoscapes in forensic science are typically generated from the collection of stable isotope data, and modeled using geo-statistical applications, such as ArcGIS. Many of the recent isoscape studies mimic the first national-level survey of tap water ratios by Bowen et al. (2007). For example, the temporal variation of oxygen isotopes ($\delta^{18}O$) in drinking water over a two-year period in the United States was conducted by Kennedy et al. (2011) following the methods of this earlier work. The isoscape generated from

the 2011 study applied robust Bayesian statistics that successful linked human hair from an unidentified female to four possible regions in the western United States of America.

Isoscapes focusing on stable oxygen and hydrogen isotopes have to consider factors affecting the variation of tissue absorption into consideration. One factor influencing isotopic variation is body water. A sophisticated predictive model with equations to estimate the turnover time for non-residents to reach isotopic equilibrium in a new geographic region was estimated by Podlesak et al. (2012). They predicted the variation of stable oxygen and hydrogen in drinking and body water and the time it would take an individual to 'absorb' the geographic signature in the United States. More controlled isotopic research experiments are needed to test predictive models, such as these.

GIS models have also helped test hypotheses for Sr isoscapes, using Silicate Model Theory. For instance, Bataille and Bowen (2012) applied this theory to model Sr of bedrock and water throughout the continental United States. Large-scale baseline isoscapes are useful for the forensic anthropologist, aiding in the identification of human remains. These large-scale isoscapes are now being refined for individual states in order to pinpoint individuals to more specific locations. For instance, Beasley (2013) presented a recent refinement of stable oxygen isotopes and an isoscape of northern California at the American Academy of Forensic Sciences meeting.

Isoscapes are a useful resource for comparison when developing a stable isotope profile. Awareness of open source networks, such as http://isomap.org, a web-GIS cyber infrastructure where researchers can analyze, visualize, and share spatiotemporal isotopic models and derived data, has been address by Bowen et al. (2009), and in academic circles. The $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ results from this NIJ project may be compiled into isoscapes and shared with the open source isoscape community.

Trace Elements

Trace elements of bone and teeth have aided in the identification of unknown individuals due to unique elemental patterns associated with specific locations. Trace elements have been used to identify Mozart's skull, the last domicile of Ötzi the iceman, and monitor toxic metals in human hair (Stadlbauer et al., 2007; Hoogewerff et al., 2001). Forensic anthropologists use trace elements when human remains are found at crime scenes, mass burials, and mass disasters. Trace element analysis operates similarly to stable isotope analysis, but is complicated by the physiochemical processes of living organisms. Complications affecting the relative elemental abundances found in bones and teeth are trophic-level biopurification of nutrients, metabolic activity, selective diffusion according to element, and physiochemical characteristics, such as the element's charge and the ionic radius (Ezzo, 1994). For instance, Sr and barium (Ba) are positively charged ions with large ionic sizes that are similar to calcium (Ca), therefore Sr and Ba can replace Ca ions in the hydroxyapatite (inorganic portion) of bones and teeth (Burton, 2008). Trace elements are incorporated into human tissues by soil and dust inhalation. Some have suggested, such as the EPA, that certain elements are strongly linked to soil and dust ingestion, making food preparation and cleanliness a factor for certain elemental concentrations, such as Ba (Kohn et al., 2013). Trace element concentrations also depend on the tissue type: enamel, primary dentine, secondary dentine, trabecular bone, or cortical bone. If tissue type is not considered, the interpretation of trace element results may bias the study. If all 'complications' are factored into the concentration values received from the laboratory or mass

spectrometer, trace element analysis is a reliable biogeochemistry method. It can be used for environmental contaminates, exposure biomarkers, health and diet, and residential history. Trace element analysis has also been used to unravel diagenetic processes that occur postmortem (Tütken et al., 2011). There is great potential for trace element analysis in forensic anthropology as an addition to the SIP.

Environmental Contaminates as Exposure Biomarkers

High levels of certain trace elements may aid in the identification of an individual. For instance, if an individual was exposed to environmental contaminates, occupational hazards, elevated elemental signatures may be detected in their bones, teeth, and hair. Anthropogenic emissions or toxic metal pollutants are discharged into soils and aquatic ecosystems in high levels annually. These pollutants result from coal combustion, sewage sludge, agricultural production, and commercial production. Cd, Cu, Pb, Cr, and Zn are found in fertilizers, pigments, lubricants, and chemicals. In the 1980's, approximately 80-90% of the arsenic (As) produced was applied to soil as an agricultural 'organic' pesticide (Nriagu and Pacyna, 1988). Arsenic poisoning may result from working and living downwind from smelters or drinking water from contaminated wells. Geographic regions at risk from well-water arsenic contamination include: Taiwan (southwest coast), South America (Argentina and Chile), India (Bengal), Mexico, Bangladesh, China (Inner Mongolia), Alaska, and some parts of the southwestern United States (Hindmarsh, 2002). Lead has served as a biomarker for many different types of exposure events. High levels of Pb in primary teeth are a well-established indicator of environmental Pb exposure in children and adolescents, which has also been linked to several neurodevelopmental health outcomes (Hare et al., 2011). These are a few examples of how trace element analysis may be used as biomarkers, and assist in the identification of human remains of individuals who once lived in geographic areas where they were exposed to environmental contaminates.

Medical Treatments as Exposure Biomarkers

Elevated levels of trace metals and rare earth elements (REE's) analyzed from human tissue may also result from medical treatments. Throughout history metals were added to medicines for certain illnesses or to treat symptoms. For instance, Mozart stated on his deathbed that he had been poisoned by acqua toffana, a mixture of arsenic and lead oxide, used to treat severe stomach disease and served as a pain killer in the 18th and 19th centuries (Stadlbauer et al., 2007). High concentrations of As and Pb were found in the bones and teeth thought to be his remains. Hair can be used as a biomarker for exposure later in life, and identify any recent medical treatments. Several drugs containing noble metals like platinum (Pt) are the major constituents used in pharmaceutical cancer treatments. Trace element analysis of Pt in cancer patients' hair was monitored throughout the treatment, and raised Pt levels were observed in the hair strain when the individual received a cisplatin treatment (Pozebon et al., 2008). Advancements in laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) eases sample preparation and trace element analysis of teeth and hair. LA-ICP-MS is also a powerful tool for mapping small changes over time, like in the Pozebon et al. (2008) study, and is a less destructive method then the typical MC-ICP-MS or IRMS mass spectrometers. Gadolinium (Gd) is a REE that is toxic and used in small doses as a contrast agent in medical

images, such as MRIs. It was found that cortical bone concentration of Gd in exposed patients was as high as 31nmol/g, which is approximately 1000 times higher than individuals who were not exposed (Darrah, 2008). Another REE used for radionuclide therapy during painful bone metastases is Samarium (Sm) (Darrah, 2011). Gd, Pt, As, Sm and Pb are potentially useful for forensic identification of human remains when medical records are available for comparison.

Trace Elements as Biomarkers for Residential Histories

The use of trace elements as biomarkers for determining geographic provenance has been debated. In geochemistry, trace element ratios are used to distinguish geological formations by examining the chemical processes over time and the variation of trace elements from mixing depending on the geologic setting. Since trace element patterns vary according to the upper continental crust and geologic processes, trace elements may be useful for forensic geographic provenance studies. However, trace element incorporation into bone depends on natural abundances, along with dietary and metabolic processes, as discussed above. Despite these biological processes, Burton et al. (2003) argued that different bedrock geology can result in different bone and teeth trace elemental compositions despite similar diets, therefore indicating, to some extent, individual provenance (Cucina et al. 2011). Some have argued against this theory, suggesting that the evidence of different metabolically active tissues have significantly different concentrations of trace elements (Kohn et al., 2013). Elements that are metabolically regulated, such as Sr, Sc, Ti, Co, Fe, and Cr, may not be directly linked to geographic provenance because fractionation of these elements is large. Ba, Pb, Al, REE's, and the transition metals V and Mn are not metabolically regulated and thus may be useful for residential histories. Darrah (2008) specifically noted the success of La/ Dy, Mn/ La, and Al/ La ratios in distinguishing non- locals in a sample population from New York. Overall, the trace element composition retains the elemental signature of the previous domicile for several years following migration, which is useful for residential histories in forensic studies when bones and hair are available.

The Effects of Globalization on Isotope Signatures

The association between geography and isotopic signatures is directly linked by diet. Therefore, the concern of how globalization affects the modern human isotope signature is relevant to the forensic investigator. The modern diet is full of fast food, bottled water, imported fruits and vegetables, and foreign beverages. This 'food footprint' is larger than it was a generation ago, justifying the need for further investigations of the isotope global network. Is the isotope signature of modern humans altered due to globalization? Recent studies of fast food, beef, bottled water, and milk suggests that most consumables retain their place-of-origin signature. Therefore despite an increasingly global homogenized diet, studies analyzing hair, nails, and teeth from the United States, Canada, and Europe have found dietary heterogeneity (Valenzuela et al., 2012; Engel, 2010; Ehleringer et al., 2008).

The fact that food and beverages retain their place-of-origin signature may complicate the isotope signature of modern humans. A large number of useful food and beverage sourcing studies have been conducted outside forensic anthropology. For instance, Chesson et al. (2008) analyzed H, C, N, and O of fast food meals in the United States, and concluded that $\delta^{18}O$ and $\delta^{2}H$ of beef exhibited large geographic variation. A more in depth study of restaurant and

supermarket foods, suggested that there was no correlation between carbohydrates, such as potatoes and wheat, and the signature of tap water, whereas a direct link could be established between beef and place of origin (Chesson et al., 2010a). Chesson et al. (2010b) also noted a promising correlation between non-local beverages, such as milk, and the $\delta^{18}O$ signature of the local tap water supply. Another geographic region where the sourcing of bottled waters has received considerable attention is South Korea. Bong et al. (2009) examined 50 different brands of bottled water available in South Korea, and found only slight correlations between marine and sparkling waters. Strontium stable isotopes have also been tested in Korean bottled waters that suggested Sr as a useful biomarker for bottle d water origin (Kim et al., 2013).

As seen from the literature review, countless factors complicate the modern human isotope signature. Since some foods retain the place of origin signature, studies of geolocation are still possible in the United States. Individual life histories play a major role in the ability for isotopes to be used to source human migration patterns. Trends drive the American lifestyle, whether the trend is to consume bottled water or eat/shop locally. For instance, the more locally-grown food an individual consumes, the less bias the SIP. Social economic status would also factor into the reliability of the SIP, assuming individuals with limited economic means would have less access foreign products. Also, the ($\delta^{18}O$) tap water signature of the region should substantially correlate with the isotope signature of modern humans because tap water is still ingested when cooking.

Forensic anthropologists rely on comparative skeletal collections to determine age, sex, and ancestry of human remains. Past databases of comparative anatomical skeletal collections were compiled for the purpose of skeletal identification research (Jantz and Moore-Jansen, 1988). In addition to comparative skeletal collections, baseline biogeochemistry results of known individuals amplify the chance for the correct identification of missing and unknown persons. Complimentary methods associated with the standard biological profile are becoming increasingly important for law enforcement officials, and methods borrowed from biogeochemistry provide additional evidence in a court of law. Stable isotopes and trace elements aid in the identification of unknown individuals through the determination of birth and death locations, along with visualizing human movements across the globe. Database expansion supports the method acceptability (Ubelaker, 2008) of isotopes and trace element analysis.

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Statement of hypothesis or rationale for the research

Forensic scientists routinely examine animal and human hair, human bone and enamel, and food remains in an effort to determine the origin of these materials. Stable isotope and elemental analysis as an emerging technique has increasingly received attention in criminal investigations and forensic anthropology in recent years (Bol and Pflieger 2002; Petzke et al. 2005; Benson et al. 2006; Schwarcz 2007; Cerling et al. 2007; Ehleringer et al. 2007; Fraser and Meier-Augenstein 2007; Meier-Augenstein and Fraser 2008). The various stable isotopes and elements, and the tissue from which they are derived, provide a wealth of information on the dietary and residential history of an individual (Table 1). The goals of this study are to assess the level of variation in different isotopes for a series of donated skeletal collections from across the United State. Stable C and N isotope analyses of human bone collagen and apatite can allow quantitative estimates of dietary components because bone collagen is disproportionately produced from the protein portion of the diet. Bone apatite on the other hand is deposited from dissolved bicarbonate in the human body system, which is drawn from all dietary components and digested waters (DeNiro and Epstein 1980; Fricke and O'Neil 1996; Muldner and Richard 2005; Hedges et al. 2005). The level of consumption of terrestrial and marine plants and animals will alter the isotopic signature. Higher N and C isotope values are presumed to be associated with a greater intake of animal proteins (Schoeninger et al. 1984), and thus imply higher social status within historical communities.

Stable O, and H isotope analyses of bone and teeth enamel phosphate and carbonate provide environmental water isotope information and diet history, because the $\delta^{18}O$ values of ingested drinking water are directly related to bone phosphate $\delta^{18}O$ values (Muldner and Richards 2007). Due to the remarkable geographical differences in $\delta^{18}O$ of meteoric waters and tap waters, the analysis of $\delta^{18}O$ can provide information about geographical locations and the movement history of the individuals (Bowen et al., 2007).

The alkaline earth metal element Strontium (Sr) in human and animal bone and tooth minerals is inherited through dietary items which uptake the element from the residual parent material, sea water and/or soil. The biologically-available signature of the organism is proportional to the local Sr level. In addition, Sr isotope compositions vary regionally, and there is little isotopic fractionation observed through trophic level (Beard et al. 2000). Diagenetic alteration of bone can replace strontium with extended exposure to soil or sea water, but these changes typically do not affect enamel. The Strontium isotopes consist of four stable isotopes (^{88}Sr, ^{87}Sr, ^{86}Sr and ^{84}Sr) with natural isotope abundance of 82.53%, 7.04%, 9.87%, and 0.56%, respectively. These distinct isotopes vary geographically and are related to food and water supply

source. The Sr isotope ratio ($^{87}Sr/^{86}Sr$) in various geological and biological products exhibits geographical characteristics.

Rare earth elements (REE) and other trace elements have proven to be regionally specific and provide evidence of medical treatments and environmental exposure. Darrah (2009) has demonstrated the utility of laser ablation for the examination of Sr, REEs and other trace elements in bone. The level of lead (Pb) within a sample is clearly related to exposure, and these levels can be examined geographically.

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Table 2. Isotope and trace element analysis information matrix.

Isotope Set	**Collagen** Bone	**Apatite Phosphate** Bone, Enamel	**Apatite Carbonate** Bone, Enamel	**Amino Acid** Bone collagen	**Hair Keratin** Hair	**Bulk Sample** Bone, Enamel, Hair
$\delta^{18}O$ / H (δD)		Residential History	Residential History	Residential History	Residential History	
δ^{13} C	Diet and Residential Specificity		Diet and Residential Specificity	Diet and Residential Specificity	Diet and Residential Specificity	
δ^{15} N	Diet and Residential Specificity			Diet and Residential Specificity	Diet and Residential Specificity	
C%, N%, C/N ratio	Diet and Residential Specificity			Diet and Residential Specificity	Diet	
Sr ($^{87}Sr/^{86}Sr$ ratio), Sr/Ca ratio						Geographical Specificity and Diet
Various Other Trace Elements (Ba, Mg, Zn, etc.)						Geographical Specificity, Exposure and Diet

Methods

The methods for bone collagen extraction, bone apatite preparation, tooth Ag_3PO_4 preparation, and stable isotope analysis are described in detail in this section. Strontium isotope analysis and trace element samples and methods are also discussed below. An aggregate count of the samples used for this report is presented in Table 3. A detailed listing of the samples is presented in Tables 5-11.

Table 3. Summary of the estimated sizes and actual sample used for the project.

Isotopes		
Sample Type	**Projected Totals in Proposal**	**Samples Processed or Prepared as of 6/25/2013**
Bone	200-225	290 (Apatite) / 221 (Collagen)
Enamel	100-125	216
Hair	50-100	15
Trace Elements (Teeth – enamel)		
Sr	~60	55
Trace Elements (LA-ICP-MS)	~60	19

Bone collagen extraction (Filter Bag Method)

The filter bag method was developed specifically for this project to increase yield and reduced sample preparation times. Bone samples were limited to middle hand and foot phalanges from the donated collections. Sample selection for UNM and TSU-SM was decided by the collection manager and often their concern was sample size. As a result, UNM submitted middle foot phalanges and UTK and TSU-SM submitted middle hand phalanges.

Preparation of Bone Samples

Bone was sampled at the University of Alabama-Huntsville in the Stable Isotope Laboratory. Sample batches of sixteen were prepared in 50 ml beakers. Approximately 40 ml of chloroform:acetone solution was added to each beaker, and placed in the sonicator for 3 hours to clean and remove lipids. The chloroform:acetone solution was decanted, and beakers were filled with hot 1000ml of DI water. Samples were sonicated in DI water for approximately 30 minutes, and then drained. Samples were then dried at 50°C overnight. When samples were thoroughly dry, powdered samples were obtained using a Dremel with a bone-cutting bit. The portion of the outer surface of the sample was removed with the Dremel, as well as any medullary bone, and discarded. Drill bits were cleaned with 1M HCL and rinsed with DI water in between samples. Using the bone-cutting bit with the acetate shield in place 1.0 g of bone powder was sampled, and then the powder was sieved using a 75 μm screen. Approximately 0.5 g of the >75 μm

powder fraction was used for collagen extraction, and <75 μm powder was reserved for apatite extraction.

Preparation of Filter Bags

Teflon fabric was cut into 3.5" (~9 cm) wide strips, and folded in half, lengthwise, to create a 1.75" wide strip. The fabric was sealed at one end of the strip, ~1/8" from end, using an impulse sealer set at "4". The bags were measured 1" (2.5 cm) from this sealed line and a third line, 0.25" away from the second one was sealed. This step was repeated along the entire strip. The bags were cut between the second and third lines (the ones separated by 0.25") in order open the bags, measuring 1.5" x 1.75" (~ 4 x 4.5 cm) each. Nylon monofilament line was used to attach labels to the collagen samples. All material, Teflon fabric bags and nylon lines, were placed in a 600ml beakers filled with ~500ml of acetone for sterilization. Beakers were sonicated for 1 hour. Acetone was then decanted and boiled in DI water for 15 minutes. DI water was then drained, and sample bags were dried at 50°C overnight.

Clean filter-bags were weighed, and then 0.5 g of the collagen sample was added to each bag and weighed to calculate the sample weight. Sample labels for each bag were attached to the end of clean nylon lines, and sealed with an impulse sealer. Bags were then placed into previously cleaned and annealed (600°C furnace for 3 hours) 50 ml beakers for collagen extraction.

Collagen Extraction Procedure

Collagen was extracted by first adding 50 ml of 0.2 M HCl to each beaker with a prepared filter-bag. Samples were sonicated for 2 hours, and then rinsed with several washes of DI water. Samples were redissolved in 50 ml of 0.125 NaOH, and sonicated for two hours. NaOH solution was decanted and rinsed several times with DI water, and redissolved in 50 ml of 10^{-3} M HCl, neutralize any remaining NaOH. The HCl was replaced with 50 ml of fresh 10^{-3} M HCl, and sonicated for an additional three hours. Collagen samples were then topped off with 10^{-3} M HCl, and placed in a 95°C oven, overnight. After 24 hours, the filter-bags were removed from the beakers, and the beakers were returned to the oven for three hours in order for the collagen solution to condense. Collagen solution was transferred into a labeled, pre-weighed 20 ml scintillation vial, and returned to the oven for the solution to condense to 1 ml, and placed in the freezer. Frozen samples were immediately transferred to the freeze-dryer for 24 hours.

Bone apatite preparation

Bone powder with particle size <0.25 mm obtained from the collagen sample preparation were used to prepare the bone apatite. Bone powder samples were loaded into 1.7ml micro-centrifuge tubes and placed into vials filled with DI water. The samples were dissolved in 1.5ml 5-6% NaOCl sonicated for three hours, decanted, and redissolved in NaOCl for 24 hours. Samples were placed in the centrifuge, decanted, and dissolved in 0.1M acetic for four hours. Bone apatite samples were centrifuged, decanted, and repeated six times. Once the samples were frozen, they were immediately transferred to the vacuum line and dried to 10^{-3} Torr. After reaching the expected vacuum, the samples were ready for stable isotope analysis.

Tooth Ag_3PO_4 preparation

The protocol for tooth Ag_3PO_4 preparation was adopted from Stephan (2000), with minor modifications that included the application of the ultrasonic water bath, and enhanced NaOCl solution. Enamel was sampled using a NewWave MicroMill to obtain approximately 10 mg of powdered tooth enamel (<0.25 mm). Samples were processed to remove any organic substances by reacting 5.6% NaOCl in 2 ml centrifuge tubes at room temperature with gentle agitation. After 24 hours, the sample solution was centrifuged, dissolved organic substances were removed, and the residue washed 4 to 5 times to neutrality with doubly distilled water. Humic substances were removed by adding 1 ml 0.15 M NaOH for 48 hours with gentle agitation. Samples were rinse 5 or more times for neutrality and to prevent the formation of salt during the acid dissolution. Dry apatite was dissolved in 2 ml HF for 24 hours at room temperature. The solution was centrifuged to separate CaF_2 and insoluble organic matter from the phosphate solution. The phosphate solution was pipetted into15 ml tubes and neutralized with 3 ml 2 M KOH. The remaining residue was rinsed with 2 ml of doubly distilled water and placed into beakers. Samples were dissolved in 3 ml of a buffered silver ammine solution (0.2 M $AgNO_3$; 1.16 M NH_4NO_3; 0.75 ml conc. NH_4OH) to precipitate Ag_3PO_4, and gradually warmed to 70°C for 3 hours, and slowly cooled to room temperature. When the samples were gently heated, the pH of the solution was about 10, and as the ammonia evolved the pH decreased, and Ag_3PO_4 began to precipitate. The reaction ends at a pH around 7.0 and the precipitation is quantitative. The crystals were filtered with a 0.2 μ filter, and washed several times with distilled water, then dried overnight at 50°C.

δD, $\delta^{18}O$, $\delta^{13}C$, and $\delta^{15}N$ Analyses

Stable isotopic compositions of all samples, except for those from the Maxwell Museum Documented Skeletal Collection and the Texas State University-San Marcos Forensic Research Facility, were analyzed in the Stable Isotope Laboratory in the Department of Earth and Planetary Sciences at UTK or the University of Alabama Tuscaloosa. Two Thermo-Electron isotope ratio mass spectrometers, including a Delta Plus and a Delta Plus XL, were used for these analyses. The Delta Plus is a dual inlet mass spectrometer, coupled with CarboFlo for carbonate analysis. The Delta Plus XL serves as a continuous flow mass spectrometer, coupled with the high Temperature Conversion/Element Analyzer (TC/EA) for analyzing δD, and $\delta^{18}O$ in hair and phospate, and Costech ECS4010 Elemental Analyzer (EA) for analyzing C%, N%, C/N ratio, $\delta^{13}C$ and $\delta^{15}N$ in collagen. $\delta^{13}C$ and $\delta^{15}N$ analysis of bone collagen was conducted with the Costec EA 4010-IRMS system. Approximately 1 mg of collagen was needed to generate C%, N%, C/N ratio, $\delta^{13}C$ and $\delta^{15}N$ data for each sample. The EA-IRMS system was equipped with a 50-position Zero-Blank autosampler. Four EA standards and six isotope standards were placed among the 50 samples. Quality control was implemented by using a two-endpoint correction algorithm.

$\delta^{18}O$ analysis of tooth phosphate was conducted with a Thermo-Electron TC/EA-IRMS system. About 200 μg of silver phosphate derived from tooth enamel phosphate was needed to generate enough signal for the $\delta^{18}O$ measurement for each sample. The TC/EA-IRMS system is equipped with a 50-position Zero-Blank autosampler. To implement quality control, a minimum of eight $\delta^{18}O$ standards including NIST 120C and IAEA 601 and 602 were placed in each carousal. The two-endpoint correction algorithm was performed for the raw data correction.

$\delta^{13}C$ and $\delta^{18}O$ analysis of apatite carbonate from bone was conducted on Finnigan CarboFlo Microvolume-Dual Inlet mass spectrometer. Approximately 70µg carbonate-equivalent of purified sample was needed for each analysis. Eight carbonate standards were included to insure quality control for each run.

$\delta^{2}H$ and $\delta^{18}O$ analysis of hair was conducted with the TC/EA-IRMS. Approximately 100 µg was needed from each sample. Non-exchangeable hydrogen and oxygen isotope standards including BWB, CFS and CHS were placed among the samples for quality control and calibration.

$^{87}Sr/^{86}Sr$ Analysis

Strontium isotope analyses were conducted at the R. Ken Williams Radiogenic Isotope Geosciences Laboratory at Texas A&M University, with all sample preparation conducted in a Class 100 clean laboratory environment. For the strontium isotope analysis, approximately 5 to 20 mg of powdered tooth enamel was dissolved in 15 mL Savillex PFA vials using 500 µl of 3N HNO3 and evaporated. The sample was then redissolved in 500 µl of 3N HNO3 and then purified through cation exchange columns filled with Sr exchange resin. The SrSpec resin was cleaned in the column with repeated washes of Milli-Q H2O and then conditioned with 3N HNO3. SrSpec resin was used once for sample elution and then discarded. The dissolved sample was loaded in the column and rinsed with five washes of 300 µL of 3N HNO3, and then Sr was eluted with 1 mL of H2O. After the purified samples were dried down, they were redissolved in 2 µl of 0.3N H3PO4 and 2 µl of TaCl5, and loaded on to degassed Re filaments for analysis by a Thermo Scientific Triton thermal ionization mass spectrometry (TIMS).

Trace Element Analysis

Laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) is a reliable method used in forensic science for determining trace elements. LA-ICP-MS provides faster analysis times and is virtually non-destructive when compared to the traditional TIMS method (Horstwood et al., 2008). Dentition from two of the donated collections were sampled from the WBDSC (n= 21) and TSUSM (n= 5). Sample preparation for the teeth was minimal due to the benefits of pre-ablation, which removes contaminates from the surface of the enamel and purges the chamber before the ablation process. The ICP-MS system used was an Elan DRC II coupled to a New Wave Research UP-213 laser ablation system (New Wave Research, Fremont, CA, USA) equipped with Nd:YAG laser emitting a nanosecond laser pulse in the fifth harmonic with a wavelength of 213 nm. ICP-MS was optimized daily with the Elan 6100 DRD set-up solution (Lot # 13-176GSL1). Tuning of the laser ablation unit was achieved using National Institute of Standards and Technology (NIST) standard reference materials SRM 610 and SRM 612. Another advantage of laser ablation is that quantitative analysis using a non-matrix matched calibration with internal standards is possible when no reference standards are available (Castro et al., 2010). Limited standards are available for teeth. NIST 1486 (bone meal) and NIST 1480 (bone ash) are used for bone samples and may be used for teeth, but were not used in this study. Instead optimization was achieved through the techniques mentioned above. Operating conditions for the optimized LA-ICP-MS system are given in table 4. Variable parameters include plasma power, argon gas flow, and lens voltage for the ion beam focusing for the mass spectrometer.

Enamel bioapatite provides a chronological record of changes in trace elements during the time of the tooth's formation (Balasse, 2002). By sampling enamel over the entire length of the tooth, changes in residential histories or certain biomarkers, such as medical treatments or environmental contaminates, can be observed in elevated REE's or trace metals. Since enamel matrix formation proceeds from the apex toward the cervix of the crown, the laser ablation sampling scheme was set to read trace element variations across the length of the tooth. Linear lines, approximately 400 μm in length, were placed towards the cervix of the crown, along the midline, and towards the apex, and ablated to a depth of 50μm. Intra-tooth sampling is beneficial when using known birth locations of the donated collections in order to determine if the variations are in fact caused by the known factors involved.

Table 4. LA-ICP-MS operating conditions.

Operating conditions for LA-ICP-MS	
RF power	1250 W
Plasma gas flow rate	15 L min ^{1}
Carrier gas	Ar
Carrier gas flow rate	1.15 L min ^{1}
Wavelength	213 nm
Sampling scheme	100 μm lines
Average fluence	20.31 J. cm ^{2}
Laser energy	50%
Scan mode	Peak hopping
Repetition frequency	20 Hz
Scan rate	30 μm s
Spot size	30 μm
Elements measured	Pb, Ba, Mg, Sr, Na, K, Fe, Rb, Sn, Zn, Li, Cu, Nd, Gd, La,, Ti, Cs, Sm, U, Y, As,, Th,Ce, Sc, Lu, Dy, Cd, Cr, V

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Results

Statement of Results

Multiple constituents including bone collagen, bioapatite (phosphate and carbonate), and hair keratin from 290 donations from WBDSC, UNMMM, and TSU-SM were prepared for $\delta^{13}C$, $\delta^{18}O$, $\delta^{15}N$, $^{87}Sr/^{86}Sr$, and $\delta^{2}H$ analysis using refined protocols. The protocols were enhanced by shortening the cycle of each sample preparation period for collagen extraction utilizing a filter-bag method assisted by an ultrasonic water bath, and modifying a Thermo TC/EA for improving analysis precision of phosphate $\delta^{18}O$. Dental enamel was sampled using a NewWave Micromill and analyzed for $\delta^{18}O$ of phosphate. The averaged $\delta^{18}O$ value for a select sample of the dental enamel was 16.91±2.21‰ VSMOW (n=215) (see Table 5). Our initial correlation analysis of the dental $\delta^{18}O$ values with meteoric water $\delta^{18}O$ at birth location (modeled) yielded the equation ($\delta^{18}O_{tooth}=0.62*\delta^{18}O_{water}+21.74$, r=0.63, n=45) (Figure 2) (Herrmann et al., 2010), which was similar to the equation ($\delta^{18}O_{bone}=0.64*\delta^{18}O_{water}+22.37$, r=0.98) generated by Longineli (1983). With the addition of the new samples from TSU-SM and UNMMM the correlation reduced significantly ($\delta^{18}O_{tooth}=0.349*\delta^{18}O_{water}+20.164$, r=0.36, n=120) and appears to vary by collection with TSU-SM and UNMMM showing poor relationships (Figure 3).

Non-exchangeable $\delta^{2}H$ of hair keratin was also analyzed using a Thermo TC/EA. The averaged $\delta^{2}H$ was -83.35± 6.36‰ VSMOW (n=14) (Table 6). The $\delta^{2}H$ values exhibit a positive correlation with the meteoric water $\delta^{18}O$ at death location (r=0.81) (Figure 4), and a negative correlation with altitude (r=-0.73) that is consistent with the isotope "Altitude Effect".

In addition, bioapatite carbonates samples (n=290) were analyzed for $\delta^{13}C$ and $\delta^{18}O$. The averaged value was -9.53±1.28‰ (VPDB) for $\delta^{13}C$, and -11.23± 4.00‰ (VPDB) for $\delta^{18}O$. These values vary by collection with marked differences between the TSU-SM samples as compared to both UTK and UNMMM for $\delta^{13}C$ and a significant difference between UTK as compared to both TSU-SM and UNMMM. These differences are evident, and are shown in the basic plot of the data shown in Figure 5. In addition, the samples show regional differences in the range of $\delta^{18}O$ values (Figure 6) with the UNMMM samples exhibiting a substantial range and the UTK range being far more limited. Several of the UNMMM samples' residential histories were limited to only the state for death locations, which resulted in several repeated latitudes and longitudes. Even with this generalizing effect the regional differences in oxygen values are evident in the bone bioapatite samples.

The relationship between bone bioapatite ($\delta^{18}O$ ‰, VPDB) and tooth enamel phosphate ($\delta^{18}O$ ‰, VSMOW) requires the conversion of the bioapatite value from VPDB to VSMOW (**http://www.cstl.nist.gov/div837/837.01/outputs/standards/algorithm/background.htm**). The bioapatite values were converted based on the published standards and compared (Figure 7). The tooth enamel phosphate $\delta^{18}O$ in relation to the bone bioapatite is enriched in ^{18}O by 6.25±1.63 (‰, VSMOW) (n=67) for UTK, -0.82±5.60 (‰, VSMOW) (n=18) for TSU-SM, 1.77±4.08 (‰, VSMOW) (n=86) for UNMMM. The low to inversed enrichment values for TSU-SM and UNMMM suggests a marked migration history for the skeletal collections in the western samples.

Bone collagen samples (n=215) were extracted for $\delta^{13}C$ and $\delta^{15}N$ analysis. In addition, N%, C%, N/C ratios were recorded for a subset of these samples (Figure 8). The averaged carbon content in human phalanx (both hand and foot) bone collagen was 32.93±6.87%,

11.31±3.32% for nitrogen content. The averaged C/N ratio was 3.133±1.04. The averaged $\delta^{13}C$ value was -16.32±1.25‰ (VPDB), and 11.24±0.53‰ (AIR) for $\delta^{15}N$. The latitude range of death locations for the collagen samples is between 29.424 and 44.840; the longitude range extends from -123.230 to -72.502. Significant correlations were observed between C and N isotopes and death locations (Table 10).

Powdered enamel samples (n=57) were collected for $^{87}Sr/^{86}Sr$ analysis. Sr results are available for 55 samples and were combined with the results presented by Regan (2006) for military personnel. The $^{87}Sr/^{86}Sr$ ratios were then converted to epsilon values (Beard and Johnson 2000) using the equation below:

$$\varepsilon^{87}\mathrm{Sr} = \left(\frac{\left(\frac{^{87}\mathrm{Sr}}{^{86}\mathrm{Sr}}\right)_{\mathrm{measured}}}{\left(\frac{^{87}\mathrm{Sr}}{^{86}\mathrm{Sr}}\right)_{\mathrm{bulkearth}}} - 1 \right) * 10000 .$$

The resulting epsilon values were compared to modeled bedrock (A) and modeled drainage and bedrock (B) epsilon values based on Beard and Johnson (2000) and Bataille and Bowen (2012), respectively. In addition, the values were plotted on the available GIS coverages for both models (Figure 9). Specific point values based on birth locations were extracted from the raster coverages of these two models and the two values were plotted to assess the match of the measured vs. location expected (or modeled) position (Figure 10). Both models provide poor fits to the modeled values. The data does appear to follow the pattern relative to birth location. The plot of ratios organized by value from low to high shows general patterning at the state level (Figure 11).

The LA-ICP-MS is included as preliminary and should be the focus of future studies with donated human skeletal collections. Figure 12 provides a breakdown of the ratio of lead (Pb_{208}) relative to Rubidium (Rb_{85}) to simply see if any individuals appear to have excessive Pb. There are at least two individuals that show excessive lead levels (UT37-07d and UT33-08D).

All of the assays and residential history information have been combined and added to an open database for researchers to use. The data is available in FIND and can be access from Mississippi State University (http://find.msstate.edu/fmi/webd).

Tables

Samples Analyzed

Table 5. PO_4 Enamel Samples prepared and processed.

IndividualID	SampleID	Tissue	Mass (mg)	d18O	Longitude	Latitude	Elevation
UT02-07D	UT02-07D_PO4	PO4 (Enamel)	0.340	18.2934	-92.28	34.74	102
UT05-08D	UT05-08D_PO4	PO4 (Enamel)	0.356	16.3030	-82.18	36.59	512
UT05-08D	UT05-08D_2_PO4	PO4 (Enamel)	0.212	18.1242	-82.18	36.59	512
UT07-07D	UT07-07D_PO4	PO4 (Enamel)	0.350	17.2554	-84.93	36.42	524
UT07-07D	UT07-07D_2_PO4	PO4 (Enamel)	0.348	17.6133	-84.93	36.42	524
UT08-07D	UT08-07D_PO4	PO4 (Enamel)	0.348	16.8212	-87.90	43.03	187
UT08-07D	UT08-07D_2_PO4	PO4 (Enamel)	0.196	17.0747	-87.90	43.03	187
UT101-06D	UT101-06D_PO4	PO4 (Enamel)	0.364	18.4304	-93.98	32.87	78
UT101-06D	UT101-06D_2_PO4	PO4 (Enamel)	0.209	18.7816	-93.98	32.87	78
UT102-06D	UT102-06D_PO4	PO4 (Enamel)	0.356	17.6684	-82.57	36.97	747
UT111-07D	UT111-07D_PO4	PO4 (Enamel)	0.358	21.4665	-98.49	29.42	198
UT112-07D	UT112-07D_PO4	PO4 (Enamel)	0.346	15.9584	-90.22	38.64	161
UT112-07D	UT112-07D_2_PO4	PO4 (Enamel)	0.205	17.8273	-90.22	38.64	161
UT116-07D	UT116-07D_PO4	PO4 (Enamel)	0.366	19.3644	-92.14	32.51	25
UT116-08D	UT116-08D_PO4	PO4 (Enamel)	0.191	20.0909	-72.55	42.85	67
UT17-08D	UT17-08D_PO4	PO4 (Enamel)	0.204	21.0288	-84.28	30.43	62
UT21-07D	UT21-07D_PO4	PO4 (Enamel)	0.352	17.1964	-79.94	37.27	285
UT21-07D	UT21-07D_2_PO4	PO4 (Enamel)	0.196	17.4759	-79.94	37.27	285
UT24-07D	UT24-07D_PO4	PO4 (Enamel)	0.358	16.6411	-87.90	43.03	187
UT24-08D	UT24-08D_PO4	PO4 (Enamel)	0.191	19.1719	-85.38	35.41	243
UT25-07D	UT25-07D_PO4	PO4 (Enamel)	0.358	18.6310	-87.38	36.07	245
UT26-07D	UT26-07D_PO4	PO4 (Enamel)	0.350	17.5509	-84.59	36.10	420
UT27-06D	UT27-06D_PO4	PO4 (Enamel)	0.198	17.3041	-86.58	35.51	218
UT30-07D	UT30-07D_PO4	PO4 (Enamel)	0.350	20.3018	-77.04	38.80	11
UT30-07D	UT30-07D_2_PO4	PO4 (Enamel)	0.201	17.1945	-77.04	38.80	11
UT32-06D	UT32-06D_PO4	PO4 (Enamel)	0.203	17.9961	-86.11	35.18	298
UT33-07D	UT33-07D_PO4	PO4 (Enamel)	0.360	19.3392	-83.92	35.96	276
UT37-07D	UT37-07D_PO4	PO4 (Enamel)	0.350	19.7776	-91.73	35.25	81
UT37-07D	UT37-07D_2_PO4	PO4 (Enamel)	0.193	18.2319	-91.73	35.25	81
UT38-07D	UT38-07D_PO4	PO4 (Enamel)	0.346	19.0090	-117.56	33.87	207
UT38-07D	UT38-07D_2_PO4	PO4 (Enamel)	0.185	17.1263	-117.56	33.87	207
UT39-06D	UT39-06D_PO4	PO4 (Enamel)	0.362	17.0584	-83.92	35.96	276
UT39-06D	UT39-06D_2_PO4	PO4 (Enamel)	0.354	17.0695	-83.92	35.96	276
UT41-07D	UT41-07D_PO4	PO4 (Enamel)	0.344	17.1949	-83.29	42.63	282
UT42-06D	UT42-06D_PO4	PO4 (Enamel)	0.346	16.8168	-82.56	36.54	369
UT42-06D	UT42-06D_2_PO4	PO4 (Enamel)	0.210	19.3234	-82.56	36.54	369
UT42-08D	UT42-08D_PO4	PO4 (Enamel)	0.368	15.9534	-80.41	38.47	445
UT44-06D	UT44-06D_PO4	PO4 (Enamel)	0.342	17.4644	-84.19	39.75	225
UT45-06D	UT45-06D_PO4	PO4 (Enamel)	0.334	17.5014	-90.04	35.14	78
UT45-06D	UT45-06D_2_PO4	PO4 (Enamel)	0.342	17.1961	-90.04	35.14	78
UT46-07D	UT46-07D_PO4	PO4 (Enamel)	0.352	18.5044	-90.07	29.95	0
UT46-07D	UT46-07D_2_PO4	PO4 (Enamel)	0.352	19.2228	-90.07	29.95	0
UT46-07D	UT46-07D_3_PO4	PO4 (Enamel)	0.204	18.1763	-90.07	29.95	0
UT47-07D	UT47-07D_PO4	PO4 (Enamel)	0.354	16.0415	-75.46	44.33	134
UT47-07D	UT47-07D_2_PO4	PO4 (Enamel)	0.183	14.5660	-75.46	44.33	134
UT48-06D	UT48-06D_PO4	PO4 (Enamel)	0.340	16.5264	-81.67	37.33	458
UT48-06D	UT48-06D_2_PO4	PO4 (Enamel)	0.338	16.5489	-81.67	37.33	458
UT48-07D	UT48-07D_PO4	PO4 (Enamel)	0.362	18.5154	-88.32	36.30	157
UT49-07D	UT49-07D_PO4	PO4 (Enamel)	0.356	16.1154	10.45	51.16	202

IndividualID	SampleID	Tissue	Mass (mg)	d18O	Longitude	Latitude	Elevation
UT49-07D	UT49-07D_2_PO4	PO4 (Enamel)	0.340	17.8271	10.45	51.16	202
UT49-07D	UT49-07D_3_PO4	PO4 (Enamel)	0.199	16.4001	10.45	51.16	202
UT49-08D	UT49-08D_PO4	PO4 (Enamel)	0.199	20.2497	-79.39	36.58	154
UT50-07D	UT50-07D_PO4	PO4 (Enamel)	0.364	15.8594	-76.61	39.29	11
UT50-07D	UT50-07D_2_PO4	PO4 (Enamel)	0.342	17.3764	-76.61	39.29	11
UT50-07D	UT50-07D_3_PO4	PO4 (Enamel)	0.201	18.1910	-76.61	39.29	11
UT53-06D	UT53-06D_PO4	PO4 (Enamel)	0.362	18.8284	-92.14	31.24	16
UT56-06D	UT56-06D_PO4	PO4 (Enamel)	0.366	17.0894	-79.39	36.58	154
UT56-06D	UT56-06D_2_PO4	PO4 (Enamel)	0.219	19.3978	-79.39	36.58	154
UT57-06D	UT57-06D_PO4	PO4 (Enamel)	0.360	16.9784	-96.76	35.98	285
UT57-06D	UT57-06D_2_PO4	PO4 (Enamel)	0.354	17.2997	-96.76	35.98	285
UT57-07D	UT57-07D_PO4	PO4 (Enamel)	0.350	17.7630	-83.92	35.96	276
UT58-07D	UT58-07D_PO4	PO4 (Enamel)	0.352	17.1364	-83.29	36.21	397
UT58-07D	UT58-07D_2_PO4	PO4 (Enamel)	0.342	18.7947	-83.29	36.21	397
UT58-07D	UT58-07D_3_PO4	PO4 (Enamel)	0.216	17.3732	-83.29	36.21	397
UT60-06D	UT60-06D_PO4	PO4 (Enamel)	0.368	18.4424	-70.66	42.61	16
UT60-06D	UT60-06D_2_PO4	PO4 (Enamel)	0.360	17.5390	-70.66	42.61	16
UT60-07D	UT60-07D_PO4	PO4 (Enamel)	0.358	16.5535	-73.96	40.78	35
UT61-07D	UT61-07D_PO4	PO4 (Enamel)	0.350	18.2070	-80.99	39.56	198
UT63-06D	UT63-06D_PO4	PO4 (Enamel)	0.362	17.6464	-82.18	36.59	512
UT63-06D	UT63-06D_2_PO4	PO4 (Enamel)	0.366	17.0298	-82.18	36.59	512
UT63-06D	UT63-06D_3_PO4	PO4 (Enamel)	0.211	17.4776	-82.18	36.59	512
UT64-08D	UT64-08D_PO4	PO4 (Enamel)	0.188	19.3822	-97.32	32.72	199
UT65-06D	UT65-06D_PO4	PO4 (Enamel)	0.370	18.3194			
UT65-06D	UT65-06D_2_PO4	PO4 (Enamel)	0.360	17.9186			
UT75-06D	UT75-06D_PO4	PO4 (Enamel)	0.348	18.1844	-90.04	35.14	78
UT75-06D	UT75-06D_2_PO4	PO4 (Enamel)	0.205	14.5139	-90.04	35.14	78
UT78-06D	UT78-06D_PO4	PO4 (Enamel)	0.362	17.8354	-99.73	32.44	524
UT79-07D	UT79-07D_PO4	PO4 (Enamel)	0.350	17.9355	-82.56	36.54	369
UT82-08D	UT82-08D_PO4	PO4 (Enamel)	0.195	18.0369	-89.40	43.07	266
UT85-06D	UT85-06D_PO4	PO4 (Enamel)	0.360	15.6364	-82.56	36.54	369
UT85-06D	UT85-06D_2_PO4	PO4 (Enamel)	0.334	18.4812	-82.56	36.54	369
UT85-06D	UT85-06D_3_PO4	PO4 (Enamel)	0.210	18.0325	-82.56	36.54	369
UT87-06D	UT87-06D_PO4	PO4 (Enamel)	0.354	15.9344	-121.27	38.13	15
UT87-06D	UT87-06D_2_PO4	PO4 (Enamel)	0.222	15.6789	-121.27	38.13	15
UT89-06D	UT89-06D_PO4	PO4 (Enamel)	0.346	18.0545	-83.92	35.96	276
UT89-07D	UT89-07D_PO4	PO4 (Enamel)	0.344	17.4490	-83.92	35.96	276
UT92-06D	UT92-06D_PO4	PO4 (Enamel)	0.350	16.1484	-81.77	41.70	174
UT93-06D	UT93-06D_PO4	PO4 (Enamel)	0.340	13.6684	-73.94	40.65	15
UT93-06D	UT93-06D_2_PO4	PO4 (Enamel)	0.340	16.7350	-73.94	40.65	15
UT95-06D	UT95-06D_PO4	PO4 (Enamel)	0.370	16.8494	-81.56	39.26	187
UT97-07D	UT97-07D_PO4	PO4 (Enamel)	0.210	18.5586	-82.65	34.50	240
D01-2009	D01-2009_PO4	PO4 (Enamel)	0.192	17.7698	-98.52	29.51	232
D02-2008	D02-2008_PO4	PO4 (Enamel)	0.192	21.0199	-100.92	32.72	707
D03-2008	D03-2008_PO4	PO4 (Enamel)	0.185	18.4227	-80.69	32.33	2
D03-2009	D03-2009_PO4	PO4 (Enamel)	0.210	18.2254	-122.08	37.67	31
D04-2009	D04-2009_PO4	PO4 (Enamel)	0.208	18.6351	-81.70	41.50	198
D04-2010	D04-2010_PO4	PO4 (Enamel)	0.197	18.5090	-95.77	34.93	223
D04-2011	D04-2011_PO4	PO4 (Enamel)	0.205	14.3516	-83.56	41.66	266
D05-2009	D05-2009_PO4	PO4 (Enamel)	0.201	20.0340	-97.40	27.80	1
D06-2009	D06-2009_PO4	PO4 (Enamel)	0.205	15.6900	-84.99	32.46	73
D07-2009	D07-2009_PO4	PO4 (Enamel)	0.205	21.3026	-87.63	41.88	181
D07-2010	D07-2010_PO4	PO4 (Enamel)	0.212	20.3334	-96.95	32.81	147
D08-2009	D08-2009_PO4	PO4 (Enamel)	0.202	19.0977	-83.00	39.96	237
D08-2010	D08-2010_PO4	PO4 (Enamel)	0.195	15.3942	-98.30	26.07	45
D09-2009	D09-2009_PO4	PO4 (Enamel)	0.188	16.1366	-77.57	40.60	150

IndividualID	SampleID	Tissue	Mass (mg)	d18O	Longitude	Latitude	Elevation
D09-2010	D09-2010_PO4	PO4 (Enamel)	0.209	19.9153	-118.24	34.05	86
D10-2010	D10-2010_PO4	PO4 (Enamel)	0.204	21.0623	-98.23	29.56	213
D11-2009	D11-2009_PO4	PO4 (Enamel)	0.198	20.1004	-84.89	39.83	298
D12-2010	D12-2010_PO4	PO4 (Enamel)	0.190	18.9662	-112.19	33.54	351
D14-2010	D14-2010_PO4	PO4 (Enamel)	0.214	19.3890	-95.33	29.80	14
D15-2011	D15-2011_PO4	PO4 (Enamel)	0.209	20.8802	-89.69	41.76	
UNMMM2000.24.1	UNMMM2000.24.1_PO4	PO4 (Enamel)	0.192	9.8609	-100.30	47.47	615
UNMMM2001.1.2	UNMMM2001.1.2_PO4	PO4 (Enamel)	0.213	18.6941	-89.50	39.74	177
UNMMM2001.1.3	UNMMM2001.1.3_PO4	PO4 (Enamel)	0.206	15.0344			
UNMMM2002.1.10	UNMMM2002.1.10_PO4	PO4 (Enamel)	0.199	16.5785	-92.44	38.26	186
UNMMM2002.1.13	UNMMM2002.1.13_PO4	PO4 (Enamel)	0.204	15.5203			
UNMMM2002.1.4	UNMMM2002.1.4_PO4	PO4 (Enamel)	0.206	16.9712			
UNMMM2002.1.5	UNMMM2002.1.5_PO4	PO4 (Enamel)	0.209	16.1024			
UNMMM2002.1.6	UNMMM2002.1.6_PO4	PO4 (Enamel)	0.237	16.2134			
UNMMM2002.1.7	UNMMM2002.1.7_PO4	PO4 (Enamel)	0.191	14.3187			
UNMMM2002.1.8	UNMMM2002.1.8_PO4	PO4 (Enamel)	0.212	19.3724			
UNMMM2003.6.2	UNMMM2003.6.2_PO4	PO4 (Enamel)	0.191	16.0224			
UNMMM2003.6.5	UNMMM2003.6.5_PO4	PO4 (Enamel)	0.215	16.3714			
UNMMM2004.3.3	UNMMM2004.3.3_PO4	PO4 (Enamel)	0.200	16.2155	-118.25	34.15	171
UNMMM2004.3.5	UNMMM2004.3.5_PO4	PO4 (Enamel)	0.202	17.3122	-95.69	30.39	91
UNMMM2004.3.6	UNMMM2004.3.6_PO4	PO4 (Enamel)	0.212	17.2706			
UNMMM2006.2.1	UNMMM2006.2.1_PO4	PO4 (Enamel)	0.189	15.8197	10.45	51.16	213
UNMMM2006.2.4	UNMMM2006.2.4_PO4	PO4 (Enamel)	0.199	15.6879	-99.68	41.50	811
UNMMM2006.2.5	UNMMM2006.2.5_PO4	PO4 (Enamel)	0.214	17.3941	-100.08	31.17	642
UNMMM2007.4.1	UNMMM2007.4.1_PO4	PO4 (Enamel)	0.210	16.4980	-85.17	42.32	255
UNMMM2008.9.1	UNMMM2008.9.1_PO4	PO4 (Enamel)	0.201	14.0085			
UNMMM2008.9.4	UNMMM2008.9.4_PO4	PO4 (Enamel)	0.201	15.9600	-117.39	33.95	252
UNMMM2008.9.6	UNMMM2008.9.6_PO4	PO4 (Enamel)	0.206	16.6443	-119.27	37.27	2440
UNMMM2010.30.3	UNMMM2010.30.3_PO4	PO4 (Enamel)	0.209	15.9872	-74.01	40.71	9
UNMMM2010.30.4	UNMMM2010.30.4_PO4	PO4 (Enamel)	0.194	17.5269			
UNMMM2011.11.1	UNMMM2011.11.1_PO4	PO4 (Enamel)	0.196	17.8069			
UNMMM2012.72.1	UNMMM2012.72.1_PO4	PO4 (Enamel)	0.208	13.7847			
UNMMM2012.72.2	UNMMM2012.72.2_PO4	PO4 (Enamel)	0.202	17.4768			
UNMMM78.23.12	UNMMM78.23.12_PO4	PO4 (Enamel)	0.131	13.0580			
UNMMM78.23.16	UNMMM78.23.16_PO4	PO4 (Enamel)	0.215	17.2139			
UNMMM78.23.17	UNMMM78.23.17_PO4	PO4 (Enamel)	0.196	16.6393	-74.01	40.71	9
UNMMM78.23.19	UNMMM78.23.19_PO4	PO4 (Enamel)	0.204	15.1223			
UNMMM78.23.21	UNMMM78.23.21_PO4	PO4 (Enamel)	0.196	16.4001			
UNMMM78.23.28	UNMMM78.23.28_PO4	PO4 (Enamel)	0.204	17.6121			
UNMMM78.23.31	UNMMM78.23.31_PO4	PO4 (Enamel)	0.210	-0.4404			
UNMMM78.23.42	UNMMM78.23.42_PO4	PO4 (Enamel)	0.200	17.0907			
UNMMM78.23.43	UNMMM78.23.43_PO4	PO4 (Enamel)	0.196	17.2038			
UNMMM78.23.44	UNMMM78.23.44_PO4	PO4 (Enamel)	0.199	12.7997			
UNMMM78.23.48	UNMMM78.23.48_PO4	PO4 (Enamel)	0.190	11.9057	-82.67	40.19	352
UNMMM78.23.49	UNMMM78.23.49_PO4	PO4 (Enamel)	0.189	13.5075			
UNMMM78.23.6	UNMMM78.23.6_PO4	PO4 (Enamel)	0.216	13.8083			
UNMMM78.23.7	UNMMM78.23.7_PO4	PO4 (Enamel)	0.183	16.5387			
UNMMM79.28.13	UNMMM79.28.13_PO4	PO4 (Enamel)	0.198	15.5496			
UNMMM79.28.19	UNMMM79.28.19_PO4	PO4 (Enamel)	0.194	14.3002			
UNMMM79.28.2	UNMMM79.28.2_PO4	PO4 (Enamel)	0.206	18.1198	-106.03	34.17	1890
UNMMM79.28.21	UNMMM79.28.21_PO4	PO4 (Enamel)	0.209	12.5004			
UNMMM79.28.23	UNMMM79.28.23_PO4	PO4 (Enamel)	0.204	17.0230			
UNMMM79.28.26	UNMMM79.28.26_PO4	PO4 (Enamel)	0.218	12.8425			
UNMMM79.28.3	UNMMM79.28.3_PO4	PO4 (Enamel)	0.197	16.8377			
UNMMM79.28.6	UNMMM79.28.6_PO4	PO4 (Enamel)	0.226	13.3130			
UNMMM80.7.22	UNMMM80.7.22_PO4	PO4 (Enamel)	0.188	13.5010			

IndividualID	SampleID	Tissue	Mass (mg)	d18O	Longitude	Latitude	Elevation
UNMMM80.7.22	UNMMM80.7.22_2_PO4	PO4 (Enamel)	0.170	14.3507			
UNMMM80.7.25	UNMMM80.7.25_PO4	PO4 (Enamel)	0.205	18.0938			
UNMMM80.7.28	UNMMM80.7.28_PO4	PO4 (Enamel)	0.218	16.1561			
UNMMM80.7.3	UNMMM80.7.3_PO4	PO4 (Enamel)	0.197	15.3370			
UNMMM80.7.32	UNMMM80.7.32_PO4	PO4 (Enamel)	0.189	15.5172			
UNMMM80.7.33	UNMMM80.7.33_PO4	PO4 (Enamel)	0.188	17.0464			
UNMMM80.7.34	UNMMM80.7.34_PO4	PO4 (Enamel)	0.200	16.4985			
UNMMM80.7.36	UNMMM80.7.36_PO4	PO4 (Enamel)	0.187	15.6238	-88.83	41.12	189
UNMMM80.7.36	UNMMM80.7.36_2_PO4	PO4 (Enamel)	0.205	16.5085	-88.83	41.12	189
UNMMM80.7.8	UNMMM80.7.8_PO4	PO4 (Enamel)	0.187	15.2005			
UNMMM81.59.3	UNMMM81.59.3_PO4	PO4 (Enamel)	0.173	15.7489			
UNMMM81.59.4	UNMMM81.59.4_PO4	PO4 (Enamel)	0.196	15.6576			
UNMMM81.59.8	UNMMM81.59.8_PO4	PO4 (Enamel)	0.168	18.0716	-87.35	36.52	144
UNMMM81.59.9	UNMMM81.59.9_PO4	PO4 (Enamel)	0.197	16.0488			
UNMMM83.8.10	UNMMM83.8.10_PO4	PO4 (Enamel)	0.194	16.3444			
UNMMM83.8.11	UNMMM83.8.11_PO4	PO4 (Enamel)	0.206	16.3331			
UNMMM83.8.16	UNMMM83.8.16_PO4	PO4 (Enamel)	0.180	16.5399			
UNMMM83.8.17	UNMMM83.8.17_PO4	PO4 (Enamel)	0.208	16.4208			
UNMMM83.8.7	UNMMM83.8.7_PO4	PO4 (Enamel)	0.178	18.2883			
UNMMM84.45.1	UNMMM84.45.1_PO4	PO4 (Enamel)	0.179	17.0054			
UNMMM86.16.5	UNMMM86.16.5_PO4	PO4 (Enamel)	0.212	16.5049			
UNMMM86.16.6	UNMMM86.16.6_PO4	PO4 (Enamel)	0.190	21.3961			
UNMMM86.16.7	UNMMM86.16.7_PO4	PO4 (Enamel)	0.217	16.4352			
UNMMM87.17.1	UNMMM87.17.1_PO4	PO4 (Enamel)	0.244	16.9925			
UNMMM87.17.2	UNMMM87.17.2_PO4	PO4 (Enamel)	0.208	15.2609			
UNMMM88.5.1	UNMMM88.5.1_PO4	PO4 (Enamel)	0.188	16.0316			
UNMMM88.5.2	UNMMM88.5.2_PO4	PO4 (Enamel)	0.199	11.5707			
UNMMM88.5.3	UNMMM88.5.3_PO4	PO4 (Enamel)	0.212	17.3933			
UNMMM88.5.5	UNMMM88.5.5_PO4	PO4 (Enamel)	0.209	18.3132			
UNMMM88.5.6	UNMMM88.5.6_PO4	PO4 (Enamel)	0.223	16.7229	-98.72	35.31	486
UNMMM88.5.7	UNMMM88.5.7_PO4	PO4 (Enamel)	0.186	16.9320			
UNMMM89.15.2	UNMMM89.15.2_PO4	PO4 (Enamel)	0.199	17.1715			
UNMMM89.15.3	UNMMM89.15.3_PO4	PO4 (Enamel)	0.207	15.4673			
UNMMM89.15.6	DOC 180-89.15.6_PO4	PO4 (Enamel)	0.185	*			
UNMMM89.15.7	UNMMM89.15.7_PO4	PO4 (Enamel)	0.216	17.4071			
UNMMM90.33.1	UNMMM90.33.1_PO4	PO4 (Enamel)	0.207	16.6109			
UNMMM90.33.5	UNMMM90.33.5_PO4	PO4 (Enamel)	0.215	16.1358			
UNMMM90.33.6	UNMMM90.33.6_PO4	PO4 (Enamel)	0.169	11.3570			
UNMMM91.20.2	UNMMM91.20.2_PO4	PO4 (Enamel)	0.210	13.6482			
UNMMM91.20.3	UNMMM91.20.3_PO4	PO4 (Enamel)	0.185	15.0677			
UNMMM91.20.4	UNMMM91.20.4_PO4	PO4 (Enamel)	0.194	16.2801			
UNMMM91.20.5	UNMMM91.20.5_PO4	PO4 (Enamel)	0.214	16.6718	-77.60	40.99	351
UNMMM92.13.1	UNMMM92.13.1_PO4	PO4 (Enamel)	0.191	17.3708			
UNMMM92.13.2	UNMMM92.13.2_PO4	PO4 (Enamel)	0.210	17.6525			
UNMMM92.13.3	UNMMM92.13.3_PO4	PO4 (Enamel)	0.211	16.7572			
UNMMM92.13.4	UNMMM92.13.4_PO4	PO4 (Enamel)	0.191	16.1662			
UNMMM93.39.1	UNMMM93.39.1_PO4	PO4 (Enamel)	0.223	16.0298			
UNMMM94.121.1	UNMMM94.121.1_PO4	PO4 (Enamel)	0.195	16.9143	-97.68	30.51	219
UNMMM94.121.2	UNMMM94.121.2_PO4	PO4 (Enamel)	0.191	16.2850			
UNMMM94.121.3	UNMMM94.121.3_PO4	PO4 (Enamel)	0.211	17.0517			
UNMMM94.121.4	UNMMM94.121.4_PO4	PO4 (Enamel)	0.209	16.4823			
UNMMM94.121.5	UNMMM94.121.5_PO4	PO4 (Enamel)	0.185	17.4601			
UNMMM95.42.1	UNMMM95.42.1_PO4	PO4 (Enamel)	0.204	16.9879	-78.48	43.21	157
UNMMM99.114.1	UNMMM99.114.1_PO4	PO4 (Enamel)	0.205	16.5002	-82.67	40.19	352
UNMMM99.114.2	UNMMM99.114.2_PO4	PO4 (Enamel)	0.212	16.6158			

* sample damaged during processing

Table 6. Hair samples prepared and processed.

IndividualID	SampleID	SampleID_2	Tissue	Mass (mg)	d2H
UT11-08	11-08	23394	Hair	0.102	-72.7677
UT82-08	82-08	23395	Hair	0.106	-87.3357
UT29-08	29-08	23396	Hair	0.092	-86.1753
UT21-08	21-08	23398	Hair	0.092	-83.2222
UT17-08	17-08	23399	Hair	0.102	-86.1230
UT64-08	64-08	23402	Hair	0.094	-77.2733
UT15-08	15-08	23403	Hair	0.100	-86.2161
UT116-08	116-08	23405	Hair	0.094	-84.2166
UT42-08	42-08	23406	Hair	0.102	-80.3098
UT05-08	05-08	23407	Hair	0.102	-97.1124
UT56-08	56-08	23410	Hair	0.106	-72.0598
UT49-08	49-08	23411	Hair	0.094	-85.0602
UT56-08	56-08D	23412	Hair	0.092	-72.0598
UT38-08	38-08	23413	Hair	0.090	-86.0547

Table 7. Apatite samples prepared and processed.

IndividualID	SampleID	Mass_mg	d13C	d18O	Longitude	Latitude	Elevation	Age
UT01-03D	C5-107-9/01-03-14A/LI/FENG	2.962	-9.0600	-6.7842	-86.58	35.51	218	47
UT01-03D	C5-111-3/01-03-14 A/LI/FENG	2.910	-9.0577	-6.9805	-86.58	35.51	218	47
UT05-08D	C5-111-12/05-08 A/LI/FENG	4.100	-7.5759	-5.9048	-82.18	36.59	511	53
UT07-07D	C5-105-11/07-07A/LI/FENG	2.636	-8.1535	-6.3353	-84.56	35.83	226	67
UT08-07D	C5-106-12/08-07A/LI/FENG	2.840	-9.5320	-7.2763	-84.14	35.89	278	57
UT100-06D	C5-105-9/100-06A/LI/FENG	2.944	-9.7344	-3.4679	-86.78	36.16	170	57
UT100-06D	C5-107-5/100-06 A/LI/FENG	3.240	-9.7439	-3.4617	-86.78	36.16	170	57
UT101-06D	C5-105-5/101-06A/LI/FENG	2.770	-9.0583	-5.2684	-83.56	35.86	275	60
UT102-06D	C5-105-10/102-06A/LI/FENG	2.563	-8.2866	-6.8632	-83.92	35.96	276	45
UT107-07D	C5-106-16/107-07-12A/LI/FENG	3.404	-7.8454	-8.0095	-82.49	34.52	275	46
UT108-07D	C5-099-3/108-07-3 A/LI/FENG	3.498	-12.1574	-8.0447	-123.23	44.84	62	69
UT11-08D	C5-099-5/11-08-8 A/LI/FENG	3.512	-11.3615	-7.5022	-85.30	35.04	206	79
UT113-07D	C5-099-4/113-07-30 A/LI/FENG	3.224	-9.6137	-7.2166	-84.50	35.88	233	75
UT116-07D	C5-106-19/116-07A/LI/FENG	2.648	-8.5362	-3.7088	-85.75	38.25	142	53
UT116-08D	C5-107-8/116-08-30 A/LI/FENG	3.704	-11.5534	-9.1832	-85.98	35.57	335	56
UT17-08D	C5-099-6/17-08-4 A/LI/FENG	3.236	-10.0039	-7.8048	-83.92	35.96	276	32
UT17-08D	C5-099-7/17-08-30 A/LI/FENG	3.204	-9.0095	-7.0993	-83.92	35.96	276	32
UT24-07D	C5-106-13/24-07A/LI/FENG	2.730	-10.3059	-7.2355	-86.61	36.30	147	58
UT24-07D	C5-111-4/24-07 A/LI/FENG	3.210	-10.1908	-7.2763	-86.61	36.30	147	58
UT24-08D	C5-099-8/24-08-19 A/LI/FENG	3.170	-8.6319	-7.8758	-86.29	36.20	161	66
UT25-06D	C5-108-11/25-06-30A/LI/FENG	2.960	-8.4771	-7.3326	-84.54	33.95	344	44
UT27-06D	C5-108-12/27-06-9A/LI/FENG	2.962	-9.5805	-7.3323	-85.02	35.94	565	86
UT29-08D	29-08A	2.500	-9.8440	-6.0077	-83.91	36.04	310	64
UT30-07D	C5-107-6/30-07 A/LI/FENG	3.380	-9.4293	-4.7422	-77.04	38.80	11	64
UT30-07D	C5-111-5/30-07A/LI/FENG	3.320	-9.3366	-4.6191	-77.04	38.80	11	64
UT32-06D	C5-108-13/32-06-3A/LI/FENG	2.916	-7.9093	-6.8559	-86.18	35.12	302	39
UT34-06D	C5-108-14/34-06-5A/LI/FENG	3.592	-7.8810	-8.4378	-86.62	36.19	148	56
UT36-06D	C5-108-15/36-06-14A/LI/FENG	3.008	-9.3234	-8.6325	-88.32	36.30	157	73
UT37-07D	C5-109-23/37-07 A/LI/FENG	4.000	-8.2335	-6.5625	-86.78	36.16	170	57
UT37-07D	C5-111-6/37-07 A/LI/FENG	2.110	-8.0839	-6.3365	-86.78	36.16	170	57
UT38-07D	C5-109-24/38-07A/LI/FENG	3.120	-9.0085	-6.2277	-86.51	35.98	166	53
UT38-07D	C5-111-7/38-07 A/LI/FENG	2.950	-8.8292	-6.0270	-86.51	35.98	166	53
UT38-08D	C5-099-10/38-08-9/LI/FENG	3.156	-9.6963	-7.3586	-86.78	36.16	170	69
UT41-07D	C5-109-26/41-07A/LI/FENG	3.040	-8.8591	-7.4813	-119.59	39.23	1340	37
UT41-07D	C5-111-8/41-07 A/LI/FENG	2.670	-8.8117	-7.7557	-119.59	39.23	1340	37
UT42-06D	42-06A	2.336	-9.5810	-6.2732	-82.71	36.52	371	56
UT42-08D	C5-106-20/42-08A/LI/FENG	2.978	-8.2243	-7.7049	-83.49	36.12	366	80

IndividualID	SampleID	Mass_mg	d13C	d18O	Longitude	Latitude	Elevation	Age
UT45-06D	45-06A	2.620	-8.2080	-6.7964	-88.24	35.22	135	33
UT45-06D	C5-106-24/45-06A/LI/FENG	2.308	-8.2481	-6.6326	-88.24	35.22	135	33
UT46-07D	C5-106-17/46-07A/LI/FENG	1.990	-8.6544	-6.2678	-83.92	35.96	276	59
UT47-07D	C5-109-27/47-07A/LI	3.550	-9.8669	-7.8653	-83.77	35.87	369	74
UT47-07D	C5-111-10/47-07 A/LI/FENG	3.720	-9.8069	-7.8884	-83.77	35.87	369	74
UT48-06D	48-06A	2.492	-8.3550	-7.9010	-83.92	35.96	276	60
UT49-07D	C5-106-18/49-07A/LI/FENG	3.400	-14.5144	-7.2100	-79.61	37.18	262	73
UT49-08D	C5-106-21/49-08A/LI/FENG	3.276	-8.0532	-6.0013	-83.92	35.95	282	51
UT53-06D	C5-106-23/53-06A/LI/FENG	3.128	-8.7578	-3.0488	-83.92	35.96	276	54
UT56-06D	56-06A	2.988	-9.5540	-6.8275	-79.39	36.58	154	58
UT56-07D	C5-108-20/56-07-3A/LI/FENG	3.126	-7.7969	-7.3726	-83.56	35.86	275	57
UT56-08D	56-08A	3.210	-8.9050	-6.0097	-83.92	35.96	276	57
UT56-08D	C5-112-13/56-08A/LI/FENG	2.750	-8.8846	-5.9822	-83.92	35.96	276	57
UT57-06D	57-06A	2.604	-9.8170	-7.4921	-84.26	36.01	259	60
UT57-07D	57-07A	3.080	-7.1790	-6.4758	-83.70	36.15	293	49
UT60-06D	60-06A	2.364	-9.1820	-6.4316	-117.35	33.15	16	89
UT60-07D	60-07A	2.260	-9.9870	-8.3902	-84.87	35.15	265	57
UT64-08D	C5-099-11/64-08-14 A/LI/FENG	3.714	-9.9903	-6.2683	-97.36	32.67	227	69
UT65-06D	65-06A	2.846	-8.5810	-6.6641	-87.49	31.02	87	31
UT73-06D	C5-108-16/73-06-19A/LI/FENG	3.066	-10.8957	-5.2401	-83.92	35.96	276	54
UT74-06D	74-06A	3.070	-9.0600	-7.0470	-89.82	34.96	118	42
UT75-06D	C5-107-25/75-06A/LI/FENG	3.694	-8.1935	-4.0618	-88.81	35.61	125	47
UT78-06D	C5-107-26/78-06A/LI/FENG	3.186	-10.3626	-4.2503	-83.92	35.96	276	49
UT79-07D	79-07A	3.370	-9.0910	-6.1169	-82.66	36.54	416	68
UT79-07D	C5-111-11/79-07 A/LI/FENG	3.800	-9.1211	-6.2407	-82.66	36.54	416	68
UT82-08D	C5-099-12/82-08-3 A1/LI/FENG	3.236	-12.6447	-8.9912	-83.18	35.78	587	26
UT82-08D	C5-107-7/82-08-3 A/LI/FENG	3.536	-12.1851	-8.7281	-83.18	35.78	587	26
UT83-06D	C5-108-19/83-06-22A/LI/FENG	2.942	-11.0364	-9.2478	-83.92	35.96	276	76
UT85-06D	C5-105-3/85-06A/LI/FENG	2.738	-8.6144	-7.7394	-86.78	36.16	170	50
UT87-06D	C5-107-3/87-06A/LI/FENG	4.150	-10.9687	-8.5419	-82.71	36.52	371	46
UT89-06D	89-06A	2.190	-8.0490	-6.4196	-83.56	35.86	275	50
UT89-06D	C5-112-14/89-06/07A/LI/FENG	2.340	-7.9069	-7.1064	-83.56	35.86	275	50
UT89-07D	89-06/07A	3.140	-7.9750	-7.2626	-83.92	35.96	276	43
UT92-06D	C5-105-6/92-06 A/LI/FENG	1.718	-10.3887	-6.9892	-84.11	36.38	327	48
UT93-06D	C5-105-4/93-06A/LI/FENG	3.170	-9.3437	-10.2705	-74.14	40.56	18	50
UT95-06D	C5-105-8/95-06A/LI/FENG	2.568	-8.2885	-7.2155	-83.92	35.96	276	54
UT95-06D	C5-107-4/95-06 A/LI/FENG	3.890	-8.3513	-7.5019	-83.92	35.96	276	54
UT96-07D	C5-108-21/96-07-14A/LI/FENG	2.960	-10.0935	-7.5373	-98.29	29.54	233	55
UT97-07D	C5-108-22/97-07-28A/LI/FENG	2.952	-9.5330	-8.0480	-83.97	35.75	285	66
D02-2008	D02-2008_ap_bone		-10.6612	-8.3256	-96.94	30.18	153	65
D03-2008	D03-2008_ap_bone		-10.3385	-16.5222	-98.41	29.59	271	75

IndividualID	SampleID	Mass_mg	d13C	d18O	Longitude	Latitude	Elevation	Age
D03-2009	D03-2009_ap_bone		-11.8684	-8.1876	-121.29	37.96	4	32
D04-2009	D04-2009_ap_bone		-11.7074	-17.8721	-97.74	30.27	148	87
D04-2010	D04-2010_ap_bone		-11.2683	-12.1112	-96.70	32.96	182	53
D04-2011	D04-2011_ap_bone		-11.2189	-9.9427	-83.89	40.89		68
D06-2009	D06-2009_ap_bone		-11.0995	-8.1993	-97.46	29.97	138	77
D07-2009	D07-2009_ap_bone		-12.3006	-17.5669	-87.96	42.17	207	66
D07-2010	D07-2010_ap_bone		-12.5904	-16.0366	-97.60	32.70	269	47
D08-2009	D08-2009_ap_bone		-11.8609	-18.9730	-72.50	44.20	194	53
D08-2010	D08-2010_ap_bone		-10.1459	-11.2775	-96.85	32.39	170	67
D09-2009	D09-2009_ap_bone		-12.0556	-8.3961	-77.57	40.60	150	58
D09-2010	D09-2010_ap_bone		-9.2662	-19.3915	-118.24	34.05	86	64
D10-2010	D10-2010_ap_bone		-10.6994	-16.7579	-98.49	29.42	197	34
D11-2009	D11-2009_ap_bone		-11.1493	-7.6527	-97.94	29.88	188	79
D12-2010	D12-2010_ap_bone		-11.1804	-13.2833	7.57	49.41	254	54
D14-2010	D14-2010_ap_bone		-10.3195	-7.6636	-95.33	29.80	14	63
D15-2011	D15-2011_ap_bone		-10.3954	-8.7465	-95.42	29.80		49
UNMMM2000.24.1	DOC215-2000.24.1		-10.4314	-13.2261	-106.58	35.07	1609	89
UNMMM2000.24.2	DOC215-2000.24.2		-10.6999	-11.9689				81
UNMMM2001.1.1	DOC216-2001.1.1		-10.2445	-14.2991	-106.51	35.06	1692	82
UNMMM2001.1.2	DOC217-2001.1.2		-9.3945	-12.4439	-106.37	35.10	2005	82
UNMMM2001.1.3	DOC218-2001.1.3		-10.2530	-12.8126				66
UNMMM2001.1.4	DOC220-2001.1.4		-10.6933	-18.1463				82
UNMMM2002.1.1	DOC224-2002.1.1		-10.5878	-17.1261	-106.69	34.85	1483	94
UNMMM2002.1.10	DOC231-2002.1.10		-10.7480	-16.1338	-92.44	38.26	186	93
UNMMM2002.1.11	DOC232-2002.1.11		-9.7928	-14.7108	-84.50	38.05	287	94
UNMMM2002.1.12	DOC233-2002.1.12		-9.9170	-13.1747	-104.52	33.39	1089	
UNMMM2002.1.13	DOC234-2002.1.13		-10.5182	-11.1204	-106.65	35.08	1511	90
UNMMM2002.1.3	DOC223-2002.1.3		-9.4695	-15.1304				
UNMMM2002.1.4	DOC230-2002.1.4		-10.0770	-17.8682				
UNMMM2002.1.5	DOC229-2002.1.5		-10.6097	-11.5258				
UNMMM2002.1.6	DOC226-2002.1.6		-9.2713	-9.6475				
UNMMM2002.1.7	DOC227-2002.1.7		-9.4242	-11.5208				
UNMMM2002.1.8	DOC228-2002.1.8		-9.4176	-13.8078				93
UNMMM2002.1.9	DOC225-2002.1.9		-10.0633	-14.3968	-106.78	32.31	1186	101
UNMMM2003.6.1	DOC221-2003.6.1		-9.3408	-9.6028	-118.36	34.15	183	102
UNMMM2003.6.2	DOC235-2003.6.2		-10.6252	-16.8921	-107.88	36.93	1783	92
UNMMM2003.6.3	DOC236-2003.6.3		-11.0230	-8.8235	-89.39	43.07	272	
UNMMM2003.6.4	DOC238-2003.6.4		-9.5546	-15.1700				59
UNMMM2003.6.5	DOC239-2003.6.5		-9.3661	-13.7393				
UNMMM2003.6.6	DOC237-2003.6.6		-10.7019	-12.6111	-106.65	35.08	1511	88
UNMMM2003.6.7	DOC240-2003.6.7		-9.0044	-13.4510	-106.57	35.17	1613	61

IndividualID	SampleID	Mass_mg	d13C	d18O	Longitude	Latitude	Elevation	Age
UNMMM2004.3.1	DOC241-2004.3.1		-9.6109	-14.9240	-106.61	35.07	1575	97
UNMMM2004.3.2	DOC178-2004.3.2		-10.2854	-14.4833	-106.57	35.06	1619	64
UNMMM2004.3.3	DOC243-2004.3.3		-10.2694	-19.2460	-106.64	35.07	1525	83
UNMMM2004.3.4	DOC244-2004.3.4		-10.8802	-9.1698	136.10	-31.93	121	53
UNMMM2004.3.5	DOC242-2004.3.5		-8.6189	-6.3866	-106.65	35.08	1511	79
UNMMM2004.3.6	DOC245-2004.3.6		-9.4095	-14.5108				
UNMMM2005.3.1	DOC246-2005.3.1		-10.4609	-10.9825	-106.58	35.10	1590	68
UNMMM2006.2.1	DOC251-2006.2.1		-12.1053	-18.3589	-94.06	31.96	71	61
UNMMM2006.2.2	DOC252-2006.2.2		-10.6178	-11.8657	-106.46	35.31	1732	95
UNMMM2006.2.3	DOC253-2006.2.3		-9.7300	-16.8961	-106.65	35.08	1510	91
UNMMM2006.2.4	DOC254-2006.2.4		-10.3360	-9.8747	-105.93	35.68	2132	77
UNMMM2006.2.5	DOC255-2006.2.5		-8.6467	-14.3015	-106.59	35.13	1579	61
UNMMM2007.4.1	DOC256-2007.4.1		-9.4560	-10.8473	-106.55	35.06	1643	52
UNMMM2008.9.1	DOC257-2008.9.1		-10.6694	-15.8423	-106.65	35.08	1510	86
UNMMM2008.9.2	DOC258-2008.9.2		-9.3227	-14.6314	-106.67	35.11	1513	46
UNMMM2008.9.3	DOC259-2008.9.3		-9.2418	-13.3552	-117.39	33.95	252	51
UNMMM2008.9.4	DOC260-2008.9.4		-9.3453	-15.8322	-117.39	33.95	252	85
UNMMM2008.9.5	DOC261-2008.9.5		-9.8779	-11.3648	-105.94	35.67	2135	88
UNMMM2008.9.6	DOC262-2008.9.6		-9.8409	-14.2370	-106.64	35.13	1516	94
UNMMM2008.9.7	DOC263-2008.9.7		-10.1675	-11.6433	-105.87	33.64	1656	
UNMMM2009.38.1	DOC264-2009.38.1		-10.1796	-9.3656	-106.74	32.32	1272	99
UNMMM2010.30.2	DOC266-2010.30.2		-9.9685	-13.2454	-88.24	40.11	224	79
UNMMM2010.30.3	DOC267-2010.30.3		-8.7121	-9.2791	-80.04	26.70	1	71
UNMMM2010.30.4	DOC268-2010.30.4		-10.0745	-18.9317				
UNMMM2011.11.1	DOC269-2011.11.1		-9.8500	-10.3152				
UNMMM2011.11.2	DOC270-2011.11.2		-10.3973	-15.6079				
UNMMM2012.72.1	DOC272-2012.72.1		-10.4324	-18.4179				
UNMMM2012.72.2	DOC274-2012.72.2		-10.1682	-19.0885				
UNMMM78.23.12	DOC12-78.23.12		-8.6701	-13.9530	-106.03	34.17	1890	13
UNMMM78.23.13	DOC13-78.23.13		-10.3663	-12.6760	-106.03	34.17	1890	67
UNMMM78.23.16	DOC16-78.23.16		-9.0010	-7.7081	-106.03	34.17	1890	60
UNMMM78.23.17	DOC17-78.23.17		-11.8232	-17.5324	-83.83	27.76		42
UNMMM78.23.19	DOC19-78.23.19		-10.9969	-18.8400	-110.75	33.38	1142	52
UNMMM78.23.20	DOC20-78.23.20		-10.5153	-10.7941				88
UNMMM78.23.21	DOC21-78.23.21		-8.4947	-12.8138	-106.03	34.17	1890	78
UNMMM78.23.28	DOC28-78.23.28		-8.8720	-18.7956	-106.03	34.17	1890	59
UNMMM78.23.29	DOC29-78.23.29		-9.2243	-10.6880	-106.03	34.17	1890	36
UNMMM78.23.3	DOC3-78.23.3		-9.9133	-15.8126	-106.65	35.08	1511	55
UNMMM78.23.31	DOC31-78.23.31		-10.2066	-11.2587	-106.65	35.08	1511	57
UNMMM78.23.32	DOC32-78.23.32		-10.1758	-11.4388	-110.98	29.09	200	73
UNMMM78.23.33	DOC33-78.23.33		-9.4110	-8.6064	-105.93	32.90	1366	67

IndividualID	SampleID	Mass_mg	d13C	d18O	Longitude	Latitude	Elevation	Age
UNMMM78.23.34	DOC34-78.23.34		-10.1105	-12.4592	-106.54	35.12	1676	71
UNMMM78.23.35	DOC35-78.23.35		-9.3766	-12.8608	-106.89	34.06	1402	69
UNMMM78.23.36	DOC36-78.23.36		-9.1108	-11.3950	-106.55	35.30	1540	77
UNMMM78.23.37	DOC37-78.23.37		-9.8689	-7.3695	-106.55	35.30	1540	88
UNMMM78.23.38	DOC38-78.23.38		-10.8275	-14.5285	-105.93	35.68	2138	87
UNMMM78.23.39	DOC39-78.23.39		-10.0538	-16.3659	-106.64	35.08	1511	1
UNMMM78.23.4	DOC4-78.23.4		-10.2600	-12.3285	-106.03	34.17	1890	52
UNMMM78.23.40	DOC40-78.23.40		-9.1239	-8.5374	-106.67	35.03	1503	69
UNMMM78.23.41	DOC41-78.23.41		-9.9163	-8.1870	-106.03	34.17	1890	78
UNMMM78.23.42	DOC42-78.23.42		-6.4442	-9.2071	-121.97	37.22	104	83
UNMMM78.23.43	DOC43-78.23.43		-9.0416	-14.1608	-106.03	34.17	1890	71
UNMMM78.23.44	DOC44-78.23.44		-9.8628	-11.4901	-106.03	34.17	1890	50
UNMMM78.23.45	DOC45-78.23.45		-8.9019	-8.5445	-106.03	34.17	1890	82
UNMMM78.23.46	DOC46-78.23.46		-10.4295	-10.7260	-106.03	34.17	1890	91
UNMMM78.23.47	DOC47-78.23.47		-10.7124	-9.2584	-106.78	34.65	1467	69
UNMMM78.23.48	DOC48-78.23.48		-9.3635	-11.4922	-106.56	35.06	1627	53
UNMMM78.23.49	DOC49-78.23.49		-9.1508	-8.7599	-106.03	34.17	1890	22
UNMMM78.23.5	DOC5-78.23.5		-9.7377	-6.7861	-106.03	34.17	1890	64
UNMMM78.23.6	DOC6-78.23.6		-9.2811	-9.0548	-106.03	34.17	1890	41
UNMMM78.23.7	DOC7-78.23.7		-10.0775	-15.0789	-106.03	34.17	1890	71
UNMMM79.28.1	DOC51-79.28.1		-10.2908	-12.6225	-106.03	34.17	1890	73
UNMMM79.28.11	DOC61-79.28.11		-10.2630	-12.9061	-106.65	35.10	1512	75
UNMMM79.28.12	DOC62-79.28.12		-8.9352	-9.5545	-106.03	34.17	1890	48
UNMMM79.28.13	DOC63-79.28.13		-9.4753	-10.0878	-106.81	34.70	1527	59
UNMMM79.28.15	DOC65-79.28.15		-10.2431	-18.1275	-106.65	35.08	1511	73
UNMMM79.28.16	DOC66-79.28.16		-11.2797	-13.4236	-106.03	34.17	1890	42
UNMMM79.28.18	DOC68-79.28.18		-9.5285	-9.4583	-106.03	34.17	1890	52
UNMMM79.28.19	DOC69-79.28.19		-7.1801	-13.7734	-106.03	34.17	1890	36
UNMMM79.28.2	DOC52-79.28.2		-10.7277	-9.1861	-106.03	34.17	1890	51
UNMMM79.28.2	DOC52-79.28.2A		-11.6750	-12.0905	-106.03	34.17	1890	51
UNMMM79.28.21	DOC71-79.28.21		-9.6134	-18.2638	-106.03	34.17	1890	16
UNMMM79.28.22	DOC72-79.28.22		-9.9902	-14.0740	-106.03	34.17	1890	47
UNMMM79.28.23	DOC75-79.28.23		-9.9811	-17.6991	-106.03	34.17	1890	
UNMMM79.28.26	DOC76-79.28.26		-12.3368	-8.8006				
UNMMM79.28.27	DOC77-79.28.27		-9.3708	-9.4128				59
UNMMM79.28.3	DOC53-79.28.3		-9.0158	-9.2768	-106.03	34.17	1890	51
UNMMM79.28.6	DOC56-79.28.6		-6.6400	-10.0973	-106.03	34.17	1890	76
UNMMM80.7.1	DOC79-80.7.1		-9.3854	-9.0315				26
UNMMM80.7.10	DOC88-80.7.10		-9.7800	-15.8507				
UNMMM80.7.11	DOC89-80.7.11		-7.6187	-10.4171	-106.03	34.17	1890	89
UNMMM80.7.15	DOC93-80.7.15		-9.6149	-13.6285	-105.22	35.61	1995	74

IndividualID	SampleID	Mass_mg	d13C	d18O	Longitude	Latitude	Elevation	Age
UNMMM80.7.16	DOC94-80.7.16		-8.9201	-12.6931	-106.76	32.31	1217	62
UNMMM80.7.17	DOC95-80.7.17		-9.5161	-12.0343	-106.78	32.32	1192	58
UNMMM80.7.2	DOC80-80.7.2		-10.4001	-15.4924	-108.54	35.46	2133	40
UNMMM80.7.22	DOC100-80.7.22		-10.2677	-16.7208	-106.03	34.17	1890	40
UNMMM80.7.22	DOC99-80.7.22		-10.8384	-9.0077	-106.03	34.17	1890	20
UNMMM80.7.24	DOC102-80.7.24		-6.7638	-15.4785	-106.03	34.17	1890	
UNMMM80.7.25	DOC103-80.7.25		-8.0938	-8.0337	-107.25	33.12	1294	31
UNMMM80.7.28	DOC106-80.7.28		-10.7580	-12.7975	-106.03	34.17	1890	26
UNMMM80.7.29	DOC107-80.7.29		-9.5505	-11.2707	-106.52	35.12	1713	73
UNMMM80.7.3	DOC81-80.7.3		-10.0576	-13.0284	-106.03	34.17	1890	83
UNMMM80.7.30	DOC108-80.7.30		-10.3837	-14.5756	-106.67	35.14	1516	35
UNMMM80.7.30	DOC108-80.7.30A		-10.5355	-13.7617	-106.67	35.14	1516	35
UNMMM80.7.32	DOC110-80.7.32		-9.8005	-15.7702	-105.93	35.68	2132	65
UNMMM80.7.33	DOC111-80.7.33		-8.5192	-13.2419	-106.65	35.08	151	32
UNMMM80.7.34	DOC112-80.7.34		-9.2077	-19.1684	-106.03	34.17	1890	68
UNMMM80.7.36	DOC113-80.7.36		-8.8719	-12.7754	-106.51	35.06	1691	68
UNMMM80.7.5	DOC83-80.7.5		-9.6606	-15.3076	-106.03	34.17	1890	24
UNMMM80.7.6	DOC84-80.7.6		-10.0457	-17.8606	-106.03	34.17	1890	59
UNMMM80.7.7	DOC85-80.7.7		-9.8133	-15.2804	-106.03	34.17	1890	80
UNMMM81.59.14	DOC128-81.59.14		-8.6627	-11.6418	-106.57	35.07	1612	74
UNMMM81.59.15	DOC127-81.59.15		-8.4230	-8.9390	-106.65	35.08	1510	56
UNMMM81.59.3	DOC117-81.59.3		-8.1887	-14.8361	-106.89	34.05	1403	64
UNMMM81.59.4	DOC118-81.59.4		-10.0095	-14.9309	-106.03	34.17	1890	72
UNMMM81.59.5	DOC119-81.59.5		-11.0701	-19.4217	-106.56	35.07	1624	72
UNMMM81.59.8	DOC122-81.59.8		-8.3009	-11.0391	-106.65	35.11	1513	66
UNMMM81.59.9	DOC123-81.59.9		-7.2184	-14.8510	-104.52	33.39	1089	30
UNMMM83.8.10	DOC140-83.8.10		-9.8155	-8.2659				63
UNMMM83.8.11	DOC141-83.8.11		-3.3766	-18.4293	-106.65	35.08	1510	31
UNMMM83.8.12	DOC142-83.8.12		-9.0966	-17.4124				56
UNMMM83.8.13	DOC143-83.8.13		-6.1416	-9.2609				66
UNMMM83.8.15	DOC145-83.8.15		-5.3781	-16.8424	-90.67	40.45	215	74
UNMMM83.8.17	DOC147-83.8.17		-5.1103	-16.9054	-105.93	35.68	2132	36
UNMMM83.8.3	DOC132-83.8.3		-9.7767	-7.4274	-106.65	35.09	1510	69
UNMMM83.8.4	DOC133-83.8.4		-8.0450	-13.1205	-107.25	33.12	1294	63
UNMMM83.8.7	DOC137-83.8.7		-9.5245	-18.6801	-106.65	35.08	1510	34
UNMMM84.45.1	DOC151-84.45.1		-8.4650	-9.4829	-106.95	36.02	2105	63
UNMMM84.45.2	DOC152-84.45.2		-9.6460	-14.1485	-106.65	35.08	1510	55
UNMMM85.26.2	DOC154-85.26.2		-8.5928	-9.6903	-105.96	32.89	1323	52
UNMMM86.16.1	DOC155-86.16.1		-8.5743	-16.3863	-106.65	35.08	1510	82
UNMMM86.16.2	DOC156-86.16.2		-7.5164	-18.6813	-106.63	35.08	1551	76
UNMMM86.16.3	DOC157-86.16.3		-9.4938	-10.1746	-106.65	35.08	1510	51

IndividualID	SampleID	Mass_mg	d13C	d18O	Longitude	Latitude	Elevation	Age
UNMMM86.16.4	DOC158-86.16.4		-7.0494	-10.6849	-106.73	34.80	1479	72
UNMMM86.16.5	DOC159-86.16.5		-6.2140	-18.7089	-106.65	35.08	1510	54
UNMMM86.16.7	DOC161-86.16.7		-6.4692	-19.3839	-106.55	35.30	1539	60
UNMMM87.17.1	DOC162-87.17.1		-8.4291	-11.1795	-105.93	35.68	2132	34
UNMMM87.17.2	DOC163-87.17.2		-6.0298	-10.1136	-106.30	35.88	2198	73
UNMMM87.17.3	DOC164-87.17.3		-9.7384	-8.0375	-105.22	35.59	1958	74
UNMMM88.5.1	DOC167-88.5.1		-8.7265	-13.8130	-103.72	35.17	1247	81
UNMMM88.5.2	DOC168-88.5.2		-9.0840	-12.0640	-106.64	35.12	1515	86
UNMMM88.5.3	DOC169-88.5.3		-9.5350	-14.4461	-108.01	36.82	1732	77
UNMMM88.5.4	DOC170-88.5.4		-9.0994	-8.7861	-106.65	35.24	1617	85
UNMMM88.5.5	DOC171-88.5.5		-8.3840	-17.3790				31
UNMMM88.5.6	DOC172-88.5.6		-9.3249	-8.0795	-108.21	36.72	1615	74
UNMMM88.5.7	DOC173-88.5.7		-9.3561	-16.8572	-104.52	33.42	1098	82
UNMMM89.15.1	DOC174-89.15.1		-7.9326	-8.2487	-106.77	32.29	1185	60
UNMMM89.15.2	DOC175-89.15.2		-9.4464	-10.6390	-106.65	35.08	151	67
UNMMM89.15.3	DOC176-89.15.3		-8.8587	-13.9292	-106.01	33.07	1373	90
UNMMM89.15.4	DOC177-89.15.4		-10.2271	-13.2535	-106.32	35.84	2249	77
UNMMM89.15.5	DOC179-89.15.5		-9.2254	-10.4000	-106.50	35.08	1727	78
UNMMM89.15.6	DOC182-89.15.6		-9.5418	-14.8054	-106.43	31.73	112	57
UNMMM89.15.7	DOC181-89.15.7		-8.5184	-8.1162	-106.60	35.05	1623	61
UNMMM90.33.1	DOC183-90.33.1		-9.8852	-13.0117	-83.30	39.68	277	
UNMMM90.33.3	DOC185-90.33.3		-10.5596	-10.4436	-106.61	35.16	1539	63
UNMMM90.33.4	DOC186-90.33.4		-9.2176	-14.1978	-103.33	34.17	1219	101
UNMMM90.33.5	DOC187-90.33.5		-9.9149	-12.1656	-106.65	35.08	151	81
UNMMM90.33.6	DOC188-90.33.6		-10.6702	-8.7021	-106.35	35.10	1996	56
UNMMM91.20.1	DOC189-91.20.1		-10.1492	-9.7626	-107.25	33.12	1294	69
UNMMM91.20.2	DOC190-91.20.2		-9.1709	-11.0346	-106.57	35.06	1619	62
UNMMM91.20.3	DOC191-91.20.3		-9.6533	-16.9236	-106.03	34.17	1890	62
UNMMM91.20.4	DOC192-91.20.4		-9.4689	-7.1980	-106.77	32.34	1236	73
UNMMM91.20.5	DOC193-91.20.5		-10.0236	-11.2852	-106.57	35.09	1606	73
UNMMM91.20.6	DOC194-91.20.6		-8.6592	-8.7542	-106.65	35.08	1511	68
UNMMM92.13.1	DOC195-92.13.1		-10.1310	-6.5880	-97.33	32.75	188	69
UNMMM92.13.2	DOC196-92.13.2		-9.6545	-12.3230	-106.65	35.08	1511	83
UNMMM92.13.3	DOC197-92.13.3		-8.4574	-15.1141	-105.57	36.43	2134	82
UNMMM92.13.4	DOC198-92.13.4		-9.4397	-8.1463	-105.57	36.43	2133	39
UNMMM93.39.1	DOC199-93.39.1		-9.0485	-7.2906	-106.89	34.05	1403	99
UNMMM94.121.1	DOC201-94.121.1		-8.7834	-8.7178	-106.65	35.08	1511	53
UNMMM94.121.2	DOC202-94.121.2		-9.7670	-7.7451				89
UNMMM94.121.3	DOC203-94.121.3		-10.2363	-14.0692	-106.77	34.75	1476	69
UNMMM94.121.4	DOC204-94.121.4		-8.9980	-17.7563	-106.52	35.13	1718	79
UNMMM94.121.6	DOC206-94.121.6		-8.4271	-13.3368	-106.59	35.11	1577	76

IndividualID	SampleID	Mass_mg	d13C	d18O	Longitude	Latitude	Elevation	Age
UNMMM94.121.7	DOC207-94.121.7		-9.7092	-8.0470	-106.65	35.08	1511	71
UNMMM95.42.1	DOC208-95.42.1		-10.2372	-11.6294	-106.59	35.10	1578	82
UNMMM96.42.1	DOC209-96.42.1		-9.5925	-14.7131				
UNMMM97.5.1	DOC210-97.5.1		-9.3027	-8.5801	-106.54	35.12	1674	
UNMMM97.5.2	DOC211-97.5.2		-9.7432	-12.2694				
UNMMM99.114.1	DOC212-99.114.1		-10.4003	-17.3408	-106.50	35.09	1725	68
UNMMM99.114.2	DOC213-99.114.2		-10.3845	-16.7673	-106.55	35.09	1626	83

Table 8. Bone collagen samples prepared and processed.

IndividualID	Tissue	Mass (mg)	δ13C	δ15N	C Percent	C/N Ratio	N Percent	Longitude	Latitude	Elevation	Age
UT01-03D	Collagen (Bone)	1.08	-15.360	10.837	35.022	2.709	12.926	-86.58	35.51	218	47
UT02-07D	Collagen (Bone)	0.77	-16.980	11.600	32.400	2.730	11.800	-84.50	35.88	233	80
UT05-08D	Collagen (Bone)	0.81	-14.800	10.980	40.100	2.780	14.500	-82.18	36.59	511	53
UT07-07D	Collagen (Bone)	0.85	-15.830	12.540	27.300	2.330	11.800	-84.56	35.83	226	67
UT08-07D	Collagen (Bone)	1.01	-16.210	11.230	29.200	2.860	10.200	-84.14	35.89	278	57
UT100-06D	Collagen (Bone)	0.88	-15.440	11.240	33.300	2.980	11.200	-86.78	36.16	170	57
UT101-06D	Collagen (Bone)	1.12	-15.720	11.700	37.000	2.800	13.200	-83.56	35.86	275	60
UT102-06D	Collagen (Bone)	0.80	-15.120	11.500	40.400	2.790	14.500	-83.92	35.96	276	45
UT107-07D	Collagen (Bone)	1.26	-14.135	10.929	32.100	2.712	11.835	-82.49	34.52	275	46
UT108-07D	Collagen (Bone)	1.06	-17.287	11.033	31.291	2.743	11.406	-123.23	44.84	62	69
UT11-08D	Collagen (Bone)	1.20	-17.996	11.095	26.837	2.820	9.515	-85.30	35.04	206	79
UT111-07D	Collagen (Bone)	0.89	-14.770	11.540	35.700	2.810	12.700	-85.39	35.37	217	50
UT112-07D	Collagen (Bone)	0.90	-18.600	12.720	19.300	4.220	4.600	-86.39	35.84	186	64
UT113-07D	Collagen (Bone)	1.16	-16.147	10.920	28.619	2.709	10.563	-84.50	35.88	233	75
UT116-07D	Collagen (Bone)	1.16	-15.770	10.820	38.800	2.770	14.000	-85.75	38.25	142	53
UT15-08D	Collagen (Bone)	1.05	-15.760	10.970	40.600	2.730	14.800	-83.92	35.96	276	39
UT17-08D	Collagen (Bone)	1.05	-17.226	10.092	33.749	2.690	12.548	-83.92	35.96	276	32
UT21-07D	Collagen (Bone)	1.09	-16.250	11.230	27.600	2.800	9.800	-82.83	36.16	463	54
UT21-08D	Collagen (Bone)	0.93	-16.260	11.030	38.100	2.730	14.000	-83.92	35.96	276	65
UT24-07D	Collagen (Bone)	0.74	-16.540	11.210	36.200	2.830	12.800	-86.61	36.30	147	58
UT24-08D	Collagen (Bone)	1.00	-14.477	11.373	34.105	2.689	12.682	-86.29	36.20	161	66
UT25-06D	Collagen (Bone)	0.94	-14.780	10.955	33.584	2.766	12.143	-84.54	33.95	344	44
UT25-07D	Collagen (Bone)	0.82	-15.320	11.400	23.700	2.840	8.300	-90.04	35.14	78	78
UT26-07D	Collagen (Bone)	0.78	-15.240	10.920	33.300	2.710	12.400	-84.68	35.86	272	72
UT27-06D	Collagen (Bone)	0.94	-16.480	10.480	30.664	2.793	10.978	-85.02	35.94	565	86
UT27-07D	Collagen (Bone)	0.75	-16.990	10.510	37.100	2.740	13.600	-84.03	36.19	295	45
UT29-08D	Collagen (Bone)	0.91	-15.680	10.800	27.100	2.510	10.800	-83.91	36.04	310	64
UT30-07D	Collagen (Bone)	1.05	-15.350	11.890	34.000	2.800	12.200	-77.04	38.80	11	64
UT32-06D	Collagen (Bone)	0.76	-15.829	11.138	30.433	2.770	10.989	-86.18	35.12	302	39
UT33-07D	Collagen (Bone)	1.03	-16.280	10.570	37.000	2.700	13.700	-83.92	35.96	276	70
UT34-06D	Collagen (Bone)	1.01	-15.144	11.689	31.373	2.738	11.459	-86.62	36.19	148	56
UT36-06D	Collagen (Bone)	1.08	-16.145	11.599	32.935	2.711	12.150	-88.32	36.30	157	73
UT37-07D	Collagen (Bone)	1.12	-15.760	11.680	34.900	2.660	13.100	-86.78	36.16	170	57
UT38-07D	Collagen (Bone)	0.84	-14.200	11.190	39.300	2.670	14.700	-86.51	35.98	166	53
UT38-08D	Collagen (Bone)	1.21	-14.959	10.887	31.073	2.758	11.268	-86.78	36.16	170	69
UT39-06D	Collagen (Bone)	0.80	-15.970	11.120	35.700	2.660	13.300	-83.92	35.96	276	85

IndividualID	Tissue	Mass (mg)	δ13C	δ15N	C Percent	C/N Ratio	N Percent	Longitude	Latitude	Elevation	Age
UT41-07D	Collagen (Bone)	0.80	-16.200	10.890	41.600	2.810	14.900	-119.59	39.23	1340	37
UT42-06D	Collagen (Bone)	1.09	-15.510	11.010	31.400	2.490	12.600	-82.71	36.52	371	56
UT42-08D	Collagen (Bone)	0.93	-17.080	10.650	31.900	2.890	11.000	-83.49	36.12	366	80
UT44-06D	Collagen (Bone)	1.00	-17.210	11.320	29.300	3.480	8.400	-86.29	36.20	161	65
UT45-06D	Collagen (Bone)	0.88	-14.630	10.790	40.100	2.700	14.900	-88.24	35.22	135	33
UT46-07D	Collagen (Bone)	0.93	-14.860	11.420	34.500	2.540	13.600	-83.92	35.96	276	59
UT47-07D	Collagen (Bone)	1.00	-15.740	11.360	37.000	2.720	13.600	-83.77	35.87	369	74
UT48-06D	Collagen (Bone)	0.83	-15.420	11.580	42.400	2.700	15.700	-83.92	35.96	276	60
UT48-07D	Collagen (Bone)	0.89	-15.600	11.060	32.100	2.750	11.700	-86.86	35.92	196	60
UT49-07D	Collagen (Bone)	1.17	-18.440	11.590	36.500	2.890	12.600	-79.61	37.18	262	73
UT49-08D	Collagen (Bone)	0.83	-15.220	12.000	20.000	2.520	7.900	-83.92	35.95	282	51.3
UT50-07D	Collagen (Bone)	1.13	-15.900	10.660	38.900	2.690	14.400	-83.05	36.62	371	38
UT53-06D	Collagen (Bone)	1.03	-14.890	11.430	37.500	2.810	13.300	-83.92	35.96	276	54
UT56-06D	Collagen (Bone)	0.81	-16.070	10.950	29.000	2.620	11.100	-79.39	36.58	154	58
UT56-07D	Collagen (Bone)	0.81	-14.992	11.122	28.105	2.800	10.038	-83.56	35.86	275	57
UT56-08D	Collagen (Bone)	0.93	-15.360	10.570	38.200	2.740	14.000	-83.92	35.96	276	57
UT57-06D	Collagen (Bone)	1.12	-15.320	11.090	36.500	2.720	13.400	-84.26	36.01	259	60
UT57-07D	Collagen (Bone)	0.80	-14.590	10.930	41.600	2.770	15.000	-83.70	36.15	293	49
UT58-07D	Collagen (Bone)	0.94	-15.330	11.090	39.900	2.700	14.700	-85.71	35.89	313	54
UT60-06D	Collagen (Bone)	0.87	-15.970	11.750	34.700	2.720	12.800	-117.35	33.15	16	89
UT60-07D	Collagen (Bone)	0.98	-15.380	10.770	41.900	2.820	14.900	-84.87	35.15	265	57
UT61-07D	Collagen (Bone)	0.83	-14.930	11.320	35.600	2.520	14.100	-88.09	42.47	239	81
UT63-06D	Collagen (Bone)	0.92	-14.380	10.900	40.000	2.540	15.700	-82.18	36.59	511	43
UT64-08D	Collagen (Bone)	1.17	-14.796	12.776	29.127	2.721	10.704	-97.36	32.67	227	69
UT65-06D	Collagen (Bone)	1.16	-15.710	10.770	37.800	2.740	13.800	-87.49	31.02	87	31
UT73-06D	Collagen (Bone)	1.07	-15.146	10.911	33.233	2.769	12.001	-83.92	35.96	276	54
UT74-06D	Collagen (Bone)	0.84	-14.770	10.990	42.300	2.720	15.500	-89.82	34.96	118	42
UT75-06D	Collagen (Bone)	0.96	-15.150	10.890	40.200	2.800	14.400	-88.81	35.61	125	47
UT78-06D	Collagen (Bone)	0.87	-16.230	10.080	40.300	2.810	14.400	-83.92	35.96	276	49
UT79-07D	Collagen (Bone)	1.14	-15.680	10.750	28.500	2.640	10.800	-82.66	36.54	416	68
UT82-08D	Collagen (Bone)	1.27	-15.324	10.137	30.461	2.664	11.433	-83.18	35.78	587	26
UT83-06D	Collagen (Bone)	0.75	-16.839	10.068	27.316	2.842	9.612	-83.92	35.96	276	76
UT85-06D	Collagen (Bone)	0.91	-15.470	11.190	39.200	2.780	14.100	-86.78	36.16	170	50
UT87-06D	Collagen (Bone)	0.95	-16.930	10.810	39.200	2.770	14.200	-82.71	36.52	371	46
UT89-06D	Collagen (Bone)	0.91	-15.810	10.820	38.400	2.800	13.800	-83.56	35.86	275	50
UT89-07D	Collagen (Bone)	0.87	-15.720	10.790	35.100	2.620	13.400	-83.92	35.96	276	43
UT92-06D	Collagen (Bone)	1.06	-15.790	11.320	40.800	2.760	14.800	-84.11	36.38	327	48
UT93-06D	Collagen (Bone)	0.98	-14.900	10.870	41.300	2.770	14.900	-74.14	40.56	18	50
UT95-06D	Collagen (Bone)	1.02	-15.020	10.750	40.900	2.730	15.000	-83.92	35.96	276	54
UT96-07D	Collagen (Bone)	1.14	-15.568	11.734	36.723	2.728	13.463	-98.29	29.54	233	55

IndividualID	Tissue	Mass (mg)	δ13C	δ15N	C Percent	C/N Ratio	N Percent	Longitude	Latitude	Elevation	Age
UT97-07D	Collagen (Bone)	0.74	-16.024	10.795	31.201	2.784	11.208	-83.97	35.75	285	66
D02-2008	Collagen (Bone)	1.41	-15.431	10.079	43.449	2.975	14.605	-96.94	30.18	153	65
D03-2008	Collagen (Bone)	1.45	-16.812	11.911	34.294	3.047	11.254	-98.41	29.59	271	75
D03-2009	Collagen (Bone)	1.38	-16.476	10.720				-121.29	37.96	4	32
D04-2009	Collagen (Bone)	1.46	-18.088	10.933	16.443	4.687	3.508	-97.74	30.27	148	87
D04-2010	Collagen (Bone)	1.46	-15.655	10.991				-96.70	32.96	182	53
D04-2011	Collagen (Bone)	1.27	-16.094	11.030				-83.94	40.93	626	68
D07-2009	Collagen (Bone)	1.47	-16.115	10.523				-87.97	42.16	207	66
D07-2010	Collagen (Bone)	1.57	-15.855	10.704							46
D08-2009	Collagen (Bone)	1.54	-15.751	10.808				-72.50	44.20	194	53
D08-2010	Collagen (Bone)	1.50	-14.565	11.323				-96.85	32.39	170	67
D09-2009	Collagen (Bone)	1.44	-16.893	10.857	27.598	3.067	8.997	-77.57	40.60	150	58
D09-2010	Collagen (Bone)	1.45	-16.895	10.981							64
D10-2010	Collagen (Bone)	1.45	-16.178	10.774	35.609	3.093	11.512	-98.49	29.42	197	34
D11-2009	Collagen (Bone)	1.47	-16.999	11.503	27.225	5.030	5.412	-97.94	29.88	188	79
D12-2010	Collagen (Bone)	1.34	-15.631	10.911	43.430	3.037	14.301	-98.49	29.42	197	54
D14-2010	Collagen (Bone)	1.87	-15.382	10.387				-95.33	29.80	14	63
D15-2011	Collagen (Bone)	1.27	-15.643	10.538	21.624	3.108	6.958	-96.50	33.18	197	49
UNMMM2000.24.2	Collagen (Bone)	1.46	-16.632	11.399							69
UNMMM2001.1.2	Collagen (Bone)	1.47	-16.912	11.550				-106.37	35.10	2005	82
UNMMM2001.1.3	Collagen (Bone)	1.27	-17.445	10.566	28.902	3.259	8.868				66
UNMMM2001.1.4	Collagen (Bone)	1.49	-17.016	11.069	35.019	3.160	11.082				
UNMMM2002.1.1	Collagen (Bone)	1.35	-15.710	12.198				-106.69	34.85	1483	82
UNMMM2002.1.1	Collagen (Bone)	1.35	-17.166	11.156	29.119	3.083	9.445	-106.69	34.85	1483	82
UNMMM2002.1.12	Collagen (Bone)	1.47	-15.601	11.590	37.123	3.017	12.306	-104.52	33.39	1089	
UNMMM2002.1.13	Collagen (Bone)	1.39	-17.174	11.185				-106.65	35.08	1511	90
UNMMM2002.1.2	Collagen (Bone)	1.42	-15.555	10.808							
UNMMM2002.1.5	Collagen (Bone)	1.35	-16.426	11.820							
UNMMM2002.1.6	Collagen (Bone)	1.43	-15.464	10.905							
UNMMM2002.1.7	Collagen (Bone)	1.32	-16.415	10.831							
UNMMM2002.1.8	Collagen (Bone)	1.35	-16.961	11.031							
UNMMM2002.1.9	Collagen (Bone)	1.56	-15.891	11.126				-106.69	34.85	1483	93
UNMMM2002.1.3	Collagen (Bone)	1.30	-15.509	11.808	35.231	3.190	11.044				
UNMMM2003.6.1	Collagen (Bone)	1.35	-17.539	11.216	15.287	3.445	4.438	-118.36	34.15	183	101
UNMMM2003.6.2	Collagen (Bone)	1.36	-17.555	11.001				-107.88	36.93	1783	32
UNMMM2003.6.4	Collagen (Bone)	1.42	-16.109	11.071							59
UNMMM2003.6.5	Collagen (Bone)	1.52	-16.276	10.718							
UNMMM2003.6.7	Collagen (Bone)	1.33	-15.201	11.638				-106.57	35.17	1613	61
UNMMM2004.3.1	Collagen (Bone)	1.41	-17.033	11.103				-106.61	35.07	1575	61
UNMMM2004.3.3	Collagen (Bone)	1.38	-17.593	10.837				-106.64	35.07	1525	64

IndividualID	Tissue	Mass (mg)	δ13C	δ15N	C Percent	C/N Ratio	N Percent	Longitude	Latitude	Elevation	Age
UNMMM2004.3.5	Collagen (Bone)	1.46	-15.086	11.928				-106.65	35.08	1511	53
UNMMM2004.3.6	Collagen (Bone)	1.40	-15.927	10.927							
UNMMM2004.3.4	Collagen (Bone)	1.06	-17.730	11.542				-106.65	35.08	1511	83
UNMMM2005.3.1	Collagen (Bone)	1.37	-16.253	11.562				-106.58	35.10	1590	79
UNMMM2006.2.1	Collagen (Bone)	1.44	-18.469	11.465				-94.06	31.96	71	68
UNMMM2006.2.2	Collagen (Bone)	0.13	-21.676	10.331				-106.46	35.31	1732	61
UNMMM2009.38.1	Collagen (Bone)	1.31	-17.399	10.269				-106.74	32.32	1272	99
UNMMM2007.4.1	Collagen (Bone)	1.45	-16.977	10.768				-106.55	35.06	1643	61
UNMMM2008.9.1	Collagen (Bone)	1.40	-16.453	11.343				-106.65	35.08	151	52
UNMMM2008.9.4	Collagen (Bone)	1.56	-17.709	10.742				-106.56	35.06	1629	46
UNMMM2008.9.6	Collagen (Bone)	1.36	-17.136	10.781				-106.64	35.13	1516	88
UNMMM2008.9.7	Collagen (Bone)	1.51	-17.278	10.199				-105.87	33.64	1656	94
UNMMM2010.30.2	Collagen (Bone)	0.64	-16.459	11.661				-106.57	35.06	1616	79
UNMMM2010.30.4	Collagen (Bone)	1.39	-15.912	10.819							
UNMMM2011.11.1	Collagen (Bone)	1.34	-16.264	10.915							
UNMMM2011.11.2	Collagen (Bone)	1.50	-17.679	10.312	15.978	4.043	3.952				
UNMMM2012.72.2	Collagen (Bone)	1.28	-15.918	10.920							
UNMMM78.23.12	Collagen (Bone)	1.45	-17.377	10.715				-106.03	34.17	1890	13
UNMMM78.23.16	Collagen (Bone)	1.47	-14.887	10.946				-106.03	34.17	1890	60
UNMMM78.23.17	Collagen (Bone)	1.30	-17.719	11.310				-106.55	35.30	1540	42
UNMMM78.23.19	Collagen (Bone)	1.39	-15.668	11.440				-110.75	33.38	1142	52
UNMMM78.23.20	Collagen (Bone)	1.17	-17.177	11.449							88
UNMMM78.23.21	Collagen (Bone)	1.41	-14.274	11.404				-106.03	34.17	1890	78
UNMMM78.23.31	Collagen (Bone)	1.39	-16.532	11.878				-106.65	35.08	1511	57
UNMMM78.23.33	Collagen (Bone)	1.37	-17.015	12.282	14.614	6.133	2.383	-105.93	32.90	1366	67
UNMMM78.23.35	Collagen (Bone)	1.32	-15.028	12.167	18.987	3.107	6.112	-106.89	34.06	1402	69
UNMMM78.23.36	Collagen (Bone)	1.39	-16.458	12.363				-106.55	35.30	1540	77
UNMMM78.23.37	Collagen (Bone)	1.41	-17.622	12.112	25.606	6.249	4.098	-106.55	35.30	1540	88
UNMMM78.23.4	Collagen (Bone)	1.33	-15.994	11.954				-106.03	34.17	1890	52
UNMMM78.23.40	Collagen (Bone)	1.25	-15.443	12.256				-106.67	35.03	1503	69
UNMMM78.23.42	Collagen (Bone)	1.38	-13.001	10.960				-103.75	34.93	1308	83
UNMMM78.23.44	Collagen (Bone)	1.33	-16.770	11.353				-106.03	34.17	1890	50
UNMMM78.23.47	Collagen (Bone)	1.46	-17.656	12.031	34.002	4.629	7.346	-106.78	34.65	1467	69
UNMMM78.23.48	Collagen (Bone)	0.83	-16.956	11.689				-106.56	35.06	1627	53
UNMMM78.23.49	Collagen (Bone)	1.29	-16.867	11.940				-106.03	34.17	1890	22
UNMMM78.23.5	Collagen (Bone)	0.75	-17.012	11.995				-106.03	34.17	1890	64
UNMMM78.23.6	Collagen (Bone)	1.39	-15.785	11.636				-106.03	34.17	1890	41
UNMMM78.28.1	Collagen (Bone)	1.44	-15.957	12.726	26.655	9.015	2.957	-106.03	34.17	1890	72
UNMMM78.23.3	Collagen (Bone)	1.48	-16.168	11.200				-106.65	35.08	1511	56
UNMMM79.28.11	Collagen (Bone)	1.44	-17.253	12.127	24.398	7.710	3.164	-106.65	35.10	1512	75

IndividualID	Tissue	Mass (mg)	δ13C	δ15N	C Percent	C/N Ratio	N Percent	Longitude	Latitude	Elevation	Age
UNMMM79.28.12	Collagen (Bone)	1.24	-15.975	11.403				-106.03	34.17	1890	47
UNMMM79.28.13	Collagen (Bone)	1.31	-15.721	11.567				-106.81	34.70	1527	59
UNMMM79.28.16	Collagen (Bone)	1.38	-18.513	11.681				-106.03	34.17	1890	42
UNMMM79.28.18	Collagen (Bone)	1.84	-15.976	12.004				-106.03	34.17	1890	52
UNMMM79.28.19	Collagen (Bone)	1.42	-14.615	10.606				-106.03	34.17	1890	36
UNMMM79.28.2	Collagen (Bone)	1.45	-17.470	10.710				-106.03	34.17	1890	51
UNMMM79.28.21	Collagen (Bone)	1.54	-16.269	10.741				-106.03	34.17	1890	16
UNMMM79.28.22	Collagen (Bone)	1.33	-16.406	11.446				-106.03	34.17	1890	60
UNMMM79.28.26	Collagen (Bone)	1.49	-18.305	10.682							
UNMMM79.28.27	Collagen (Bone)	1.48	-17.215	11.035	32.926	3.533	9.319				
UNMMM79.28.3	Collagen (Bone)	1.43	-14.767	12.071				-106.03	34.17	1890	59
UNMMM79.28.6	Collagen (Bone)	1.40	-12.378	11.091				-106.03	34.17	1890	51
UNMMM80.7.1	Collagen (Bone)	1.10	-16.079	11.004				-106.03	34.17	1890	76
UNMMM80.7.10	Collagen (Bone)	1.50	-15.249	11.671							
UNMMM80.7.11	Collagen (Bone)	1.31	-14.488	11.843				-106.03	34.17	1890	26
UNMMM80.7.15	Collagen (Bone)	1.34	-16.320	11.707	37.729	3.335	11.312	-105.22	35.61	1995	89
UNMMM80.7.16	Collagen (Bone)	1.05	-18.943	11.650				-106.76	32.31	1217	74
UNMMM80.7.16	Collagen (Bone)	1.39	-16.694	11.690	17.750	3.246	5.468	-106.76	32.31	1217	74
UNMMM80.7.2	Collagen (Bone)	1.33	-15.552	12.030				-108.54	35.47	2118	58
UNMMM80.7.22	Collagen (Bone)	1.32	-17.683	11.214				-106.03	34.17	1890	40
UNMMM80.7.22	Collagen (Bone)	1.45	-17.732	12.170				-106.03	34.17	1890	40
UNMMM80.7.24	Collagen (Bone)	1.47	-13.272	11.791				-106.03	34.17	1890	
UNMMM80.7.25	Collagen (Bone)	1.38	-14.734	10.930				-107.25	33.12	1294	20
UNMMM80.7.28	Collagen (Bone)	1.50	-17.504	10.837				-106.03	34.17	1890	31
UNMMM80.7.29	Collagen (Bone)	1.25	-16.871	10.978	16.364	3.420	4.785	-106.53	35.13	1711	26
UNMMM80.7.3	Collagen (Bone)	1.45	-16.751	11.726				-106.03	34.17	1890	73
UNMMM80.7.30	Collagen (Bone)	0.49	-17.703	11.666				-106.67	35.14	1516	83
UNMMM80.7.32	Collagen (Bone)	1.52	-15.946	11.459				-105.93	35.68	2132	35
UNMMM80.7.34	Collagen (Bone)	1.48	-16.725	10.939				-106.03	34.17	1890	32
UNMMM80.7.36	Collagen (Bone)	1.47	-17.721	11.391				-106.51	35.06	1691	68
UNMMM80.7.5	Collagen (Bone)	1.02	-16.633	10.993				-106.03	34.17	1890	24
UNMMM80.7.6	Collagen (Bone)	1.44	-16.509	11.484				-106.03	34.17	1890	68
UNMMM80.7.9	Collagen (Bone)	0.66	-17.763	12.025				-107.26	33.11	1298	73
UNMMM81.59.3	Collagen (Bone)	1.43	-17.152	11.430				-106.89	34.05	1403	56
UNMMM81.59.4	Collagen (Bone)	1.42	-16.621	11.460				-106.03	34.17	1890	64
UNMMM83.8.3	Collagen (Bone)	1.30	-16.464	11.845				-106.65	35.09	1510	70
UNMMM84.45.1	Collagen (Bone)	1.36	-15.487	11.042				-106.95	36.02	2105	34
UNMMM84.45.2	Collagen (Bone)	1.39	-16.750	11.634				-106.65	35.08	1516	55
UNMMM86.16.7	Collagen (Bone)	1.26	-15.414	12.335				-106.55	35.30	1539	60
UNMMM87.17.1	Collagen (Bone)	1.23	-17.036	11.692				-105.93	35.68	2132	54

IndividualID	Tissue	Mass (mg)	δ13C	δ15N	C Percent	C/N Ratio	N Percent	Longitude	Latitude	Elevation	Age
UNMMM87.17.2	Collagen (Bone)	1.21	-16.507	11.457				-106.30	35.88	2198	34
UNMMM88.5.1	Collagen (Bone)	1.50	-17.241	11.204				-103.72	35.17	1247	74
UNMMM88.5.3	Collagen (Bone)	1.38	-16.629	11.849	35.919	3.253	11.041	-108.01	36.82	1732	77
UNMMM88.5.4	Collagen (Bone)	1.40	-17.792	11.013				-106.65	35.24	1617	82
UNMMM88.5.5	Collagen (Bone)	1.45	-17.776	10.046							31
UNMMM89.15.1	Collagen (Bone)	1.46	-20.591	11.385				-106.77	32.29	1185	82
UNMMM89.15.4	Collagen (Bone)	1.44	-18.824	11.837	38.249	4.496	8.507	-106.32	35.84	2249	90
UNMMM89.15.5	Collagen (Bone)	1.45	-16.315	11.742				-106.50	35.08	1727	77
UNMMM91.20.1	Collagen (Bone)	1.44	-21.843	11.061				-107.25	33.12	1294	69
UNMMM91.20.2	Collagen (Bone)	1.35	-16.421	12.068				-106.57	35.06	1619	62
UNMMM91.20.3	Collagen (Bone)	1.33	-16.448	10.724				-106.03	34.17	1890	62
UNMMM91.20.4	Collagen (Bone)	1.22	-18.807	11.427	23.382	6.976	3.352	-106.77	32.34	1236	73
UNMMM91.20.6	Collagen (Bone)	1.44	-16.707	11.710				-106.65	35.08	1511	68
UNMMM92.13.4	Collagen (Bone)	1.39	-16.987	11.403				-105.57	36.43	2133	39
UNMMM94.121.1	Collagen (Bone)	1.23	-16.712	11.898				-106.65	35.08	1511	53
UNMMM94.121.2	Collagen (Bone)	1.38	-16.905	11.466	30.840	3.334	9.251				89
UNMMM94.121.3	Collagen (Bone)	1.34	-16.791	10.837	39.005	3.087	12.636	-106.77	34.75	1476	69
UNMMM94.121.4	Collagen (Bone)	1.34	-16.710	11.470				-106.52	35.13	1718	79
UNMMM94.121.6	Collagen (Bone)	1.48	-16.901	11.553				-106.59	35.11	1577	76
UNMMM90.33.6	Collagen (Bone)	1.24	-17.596	11.510				-106.35	35.10	1996	56
UNMMM96.42.1	Collagen (Bone)	1.53	-15.840	11.428				-106.59	35.10	1578	82
UNMMM97.5.2	Collagen (Bone)	1.39	-16.889	10.859							56
UNMMM78.23.33	Collagen (Bone)	1.26	-18.205	11.148				-105.93	32.90	1366	67
UNMMM99.114.1	Collagen (Bone)	1.45	-17.459	11.185				-106.50	35.09	1725	68
UNMMM99.114.2	Collagen (Bone)	0.52	-19.214	10.224				-106.55	35.09	1626	83

Table 8. Strontium samples analyzed by Texas A&M University Geochemistry Laboratory (n=55).

IndividualID	SampleID	Tissue	Mass (mg)	$^{87}Sr/^{86}Sr$	Standard Error (absolute)
UT02-07D	UT02-07D_Sr	Sr (Enamel)	8.80	0.71031989	0.00000403
UT05-08D	UT05-08D_Sr	Sr (Enamel)	19.95	0.71043734	0.00000716
UT08-07D	UT08-07D_Sr	Sr (Enamel)	7.69	0.70989126	0.00000424
UT101-06D	UT101-06D_Sr	Sr (Enamel)	14.33	0.70922675	0.00000425
UT11-08D	UT11-08D_Sr	Sr (Enamel)	12.40	0.71048441	0.00000432
UT116-08D	UT116-08D_Sr	Sr (Enamel)	14.75	0.71092476	0.00000423
UT17-08D	UT17-08D_Sr	Sr (Enamel)	12.93	0.70896122	0.00000481
UT17-08D	UT17-08D_2_Sr	Sr (Enamel)	14.06	0.70812051	0.00000450
UT21-07D	UT21-07D_Sr	Sr (Enamel)	11.02	0.71069497	0.00000492
UT24-08D	UT24-08D_Sr	Sr (Enamel)	24.26	0.71003972	0.00000473
UT27-06D	UT27-06D_Sr	Sr (Enamel)	11.27	0.71324364	0.00000451
UT27-07D	UT27-07D_Sr	Sr (Enamel)	12.18	0.71100672	0.00000524
UT30-07D	UT30-07D_Sr	Sr (Enamel)	31.78	0.70971211	0.00000462
UT32-06D	UT32-06D_Sr	Sr (Enamel)	14.98	0.71017972	0.00000396
UT37-07D	UT37-07D_Sr	Sr (Enamel)	8.70	0.71053001	0.00000423
UT38-07D	UT38-07D_Sr	Sr (Enamel)	13.75	0.70909953	0.00000331
UT38-08D	UT38-08D_Sr	Sr (Enamel)	12.92	0.70998907	0.00000414
UT42-06D	UT42-06D_Sr	Sr (Enamel)	12.71	0.71083883	0.00000481
UT44-06D	UT44-06D_Sr	Sr (Enamel)	12.27	0.70890656	0.00000508
UT46-07D	UT46-07D_Sr	Sr (Enamel)	8.39	0.71048536	0.00000394
UT47-07D	UT47-07D_Sr	Sr (Enamel)	26.13	0.71008229	0.00000435
UT49-07D	UT49-07D_Sr	Sr (Enamel)	13.94	0.71013570	0.00000430
UT49-08D	UT49-08D_Sr	Sr (Enamel)	9.21	0.71022266	0.00000404
UT50-07D	UT50-07D_Sr	Sr (Enamel)	22.66	0.71070878	0.00000506
UT56-06D	UT56-06D_Sr	Sr (Enamel)	11.56	0.71068445	0.00000469
UT58-07D	UT58-07D_Sr	Sr (Enamel)	11.35	0.71015219	0.00000435
UT60-07D	UT60-07D_Sr	Sr (Enamel)	10.70	0.71079133	0.00000741
UT63-06D	UT63-06D_Sr	Sr (Enamel)	6.98	0.71100904	0.00000574
UT64-08D	UT64-08D_Sr	Sr (Enamel)	15.61	0.70902809	0.00000392
UT75-06D	UT75-06D_Sr	Sr (Enamel)	7.43	0.70968166	0.00000498
UT82-08D	UT82-08D_Sr	Sr (Enamel)	11.68	0.7093286	0.00000424
UT83-06D	UT83-06D_Sr	Sr (Enamel)	7.64	0.71147362	0.00000390
UT85-06D	UT85-06D_Sr	Sr (Enamel)	12.41	0.70986451	0.00000426
UT87-06D	UT87-06D_Sr	Sr (Enamel)	11.14	0.70749273	0.00000498
UT97-07D	UT97-07D_Sr	Sr (Enamel)	13.13	0.71100617	0.00000438
D01-2009	D01-2009_Sr	Sr (Enamel)	12.58	0.70850675	0.00000408
D02-2008	D02-2008_Sr	Sr (Enamel)	7.00	0.70899857	0.00000484
D03-2008	D03-2008_Sr	Sr (Enamel)	10.34	0.70951283	0.00000420
D03-2009	D03-2009_Sr	Sr (Enamel)	5.69	0.70834679	0.00000456
D04-2009	D04-2009_Sr	Sr (Enamel)	8.51	0.71023092	0.00000533
D04-2010	D04-2010_Sr	Sr (Enamel)	12.51	0.71027814	0.00000463
D04-2011	D04-2011_Sr	Sr (Enamel)	5.36	0.70912928	0.00000395
D05-2009	D05-2009_Sr	Sr (Enamel)	8.88	0.70909649	0.00000511
D06-2009	D06-2009_Sr	Sr (Enamel)	22.66	0.71177275	0.00000461
D07-2009	D07-2009_Sr	Sr (Enamel)	8.35	0.7092628	
D07-2010	D07-2010_Sr	Sr (Enamel)	9.84	0.70918991	0.00000519

IndividualID	SampleID	Tissue	Mass (mg)	$^{87}Sr/^{86}Sr$	Standard Error (absolute)
D08-2009	D08-2009_Sr	Sr (Enamel)	12.27	0.70989207	0.00000417
D08-2010	D08-2010_Sr	Sr (Enamel)	19.08	0.70754483	0.00000377
D09-2009	D09-2009_Sr	Sr (Enamel)	7.46	0.7111313	0.00000466
D09-2010	D09-2010_Sr	Sr (Enamel)	6.04	0.70887371	0.00001272
D10-2010	D10-2010_Sr	Sr (Enamel)	13.96	0.70814215	0.00000515
D11-2009	D11-2009_Sr	Sr (Enamel)	16.60	0.70935723	0.00000554
D12-2010	D12-2010_Sr	Sr (Enamel)	8.19	0.70993167	0.00000386
D14-2010	D14-2010_Sr	Sr (Enamel)	11.43	0.71029067	0.00000418
D15-2011	D15-2011_Sr	Sr (Enamel)	12.04	0.70940474	0.00000419

Figures

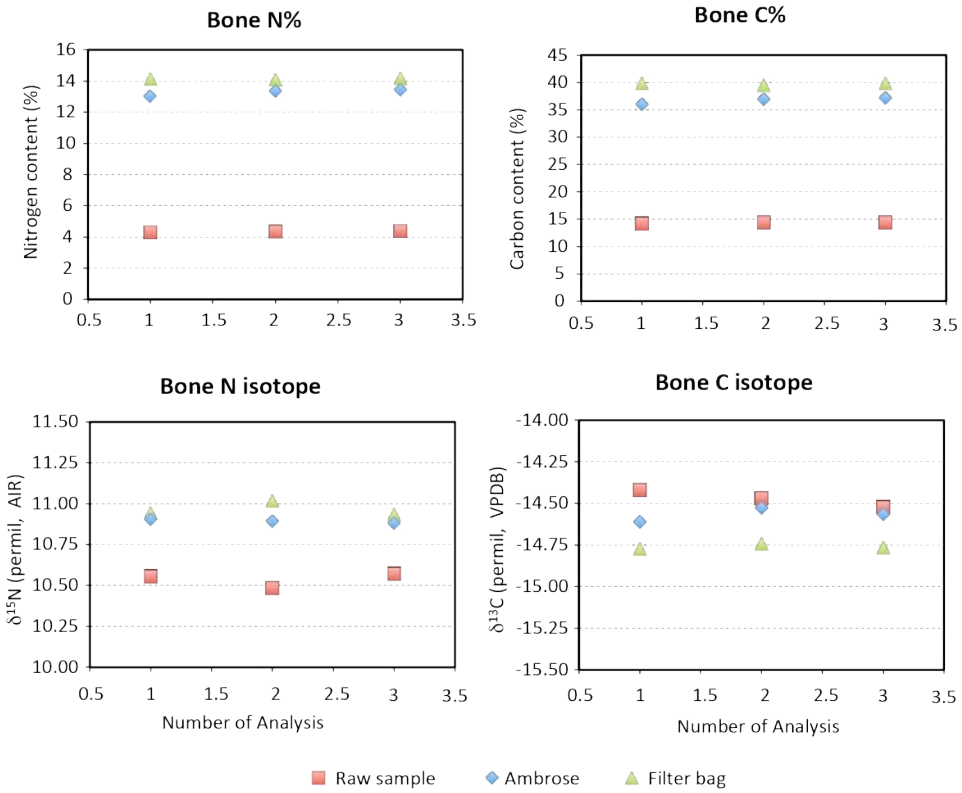


Figure 1. Filter bag experiment for bone collagen extraction: The distinct advantage of the Filter-Bag method is the limited time required to perform the chemical extraction portion of the procedure, and allows more samples to be processed simultaneously. The red squares represent data from raw bone samples; the blue diamonds are the results from Ambrose method (Ambrose et al., 1990). The triangles are the results from the Filter-Bag method.

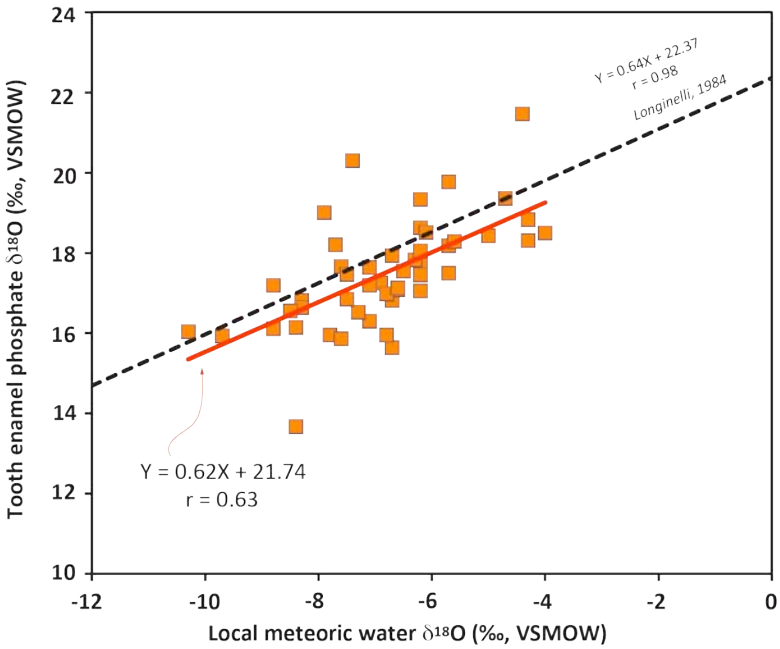


Figure 2. Preliminary $\delta^{18}O$ relationship between tooth enamel PO_4^{3-} and local meteoric water at birth location. The local meteoric water $\delta^{18}O$ values were derived from Bowen, 2006, Earth and Atmospheric Sciences, Purdue University. The yellow dash line represents bone PO_4^{3-} $\delta^{18}O$ values from Longinelli, 1984.

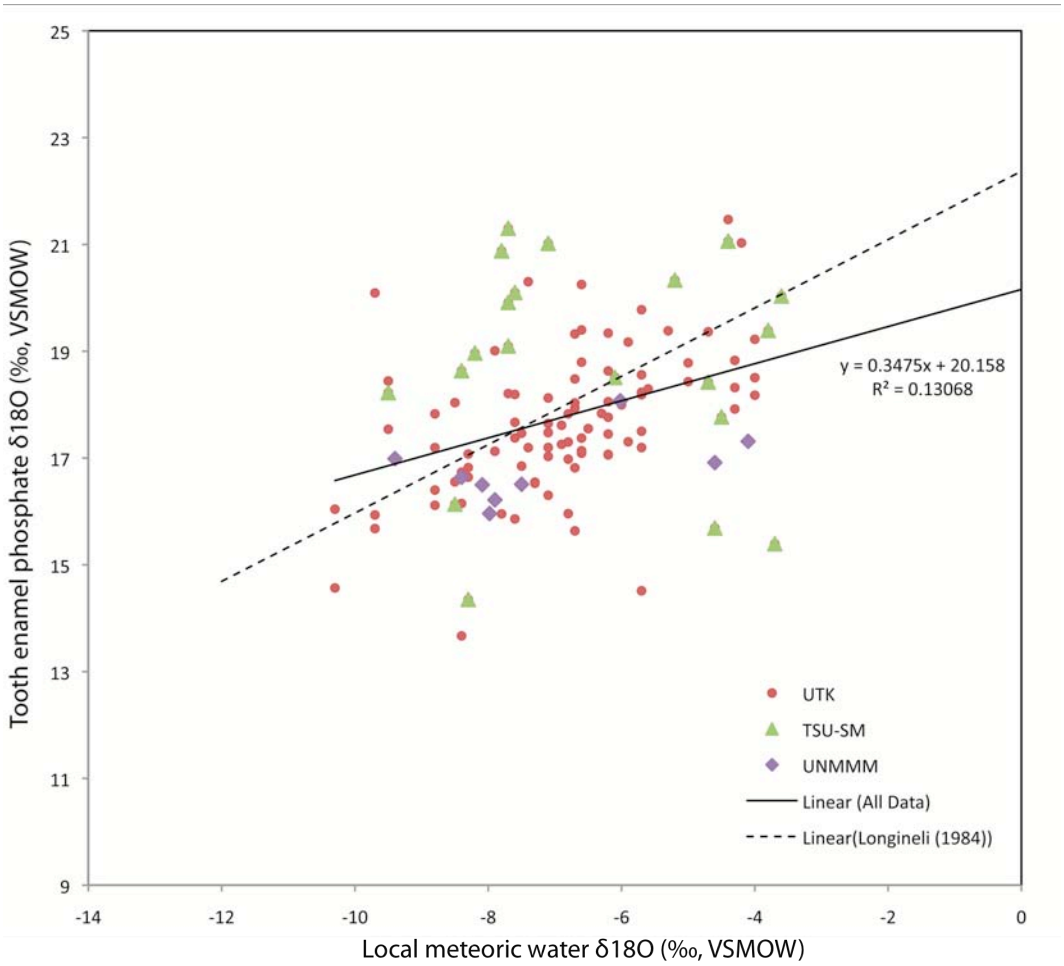


Figure 3. Final $\delta^{18}O$ relationship between tooth enamel PO_4^{3-} and local meteoric water at birth location. The local meteoric water $\delta^{18}O$ values were derived from Bowen, 2006, Earth and Atmospheric Sciences, Purdue University. The dash line represents bone PO_4^{3-} $\delta^{18}O$ values from Longinelli, 1984. The three samples are depicted as different symbols.

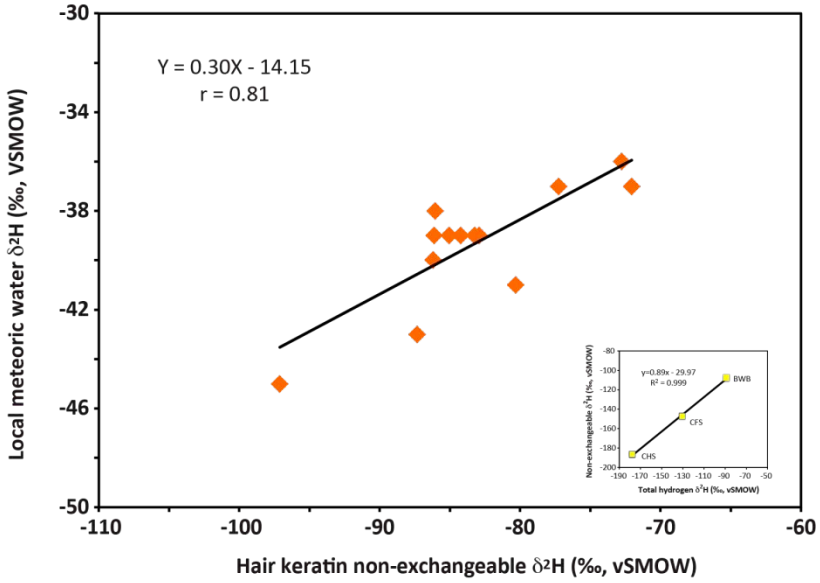


Figure 4. δ^2H relationship between hair keratin non-exchangeable hydrogen isotope and local meteoric water at death location. The local meteoric water d2H values were derived from Bowen, 2006, Earth and Atmospheric Sciences, Purdue University. Non-exchangeable δ^2H values were calculated by analyzing BWB, CFS and CHS samples (Wassenaar et al, 2003) (see the insert).

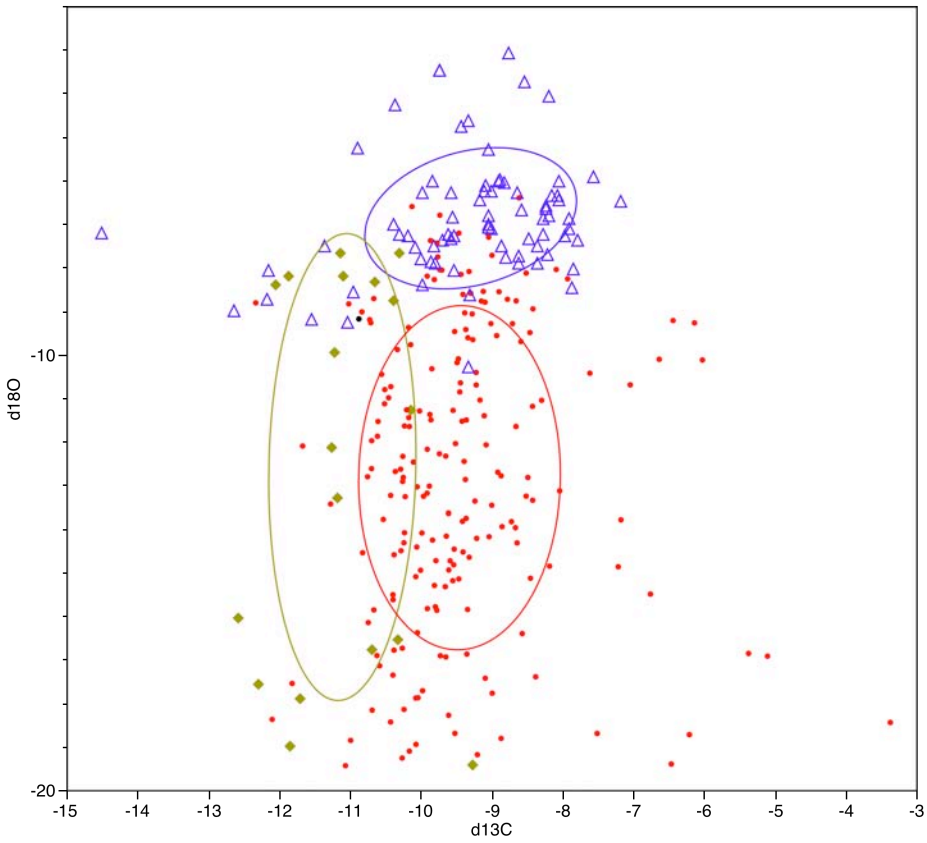


Figure 5. Bone apatite $\delta^{13}C$ values plotted by $\delta^{18}O$ values with 50% density ellipses for each sample (UTK=blue triangles; TSU-SM=green diamonds; UNMMM=small red circles). The relationship exhibits distinct distributions for the three collections with the UTK sample distinguished from TSU-SM and UNMMM along the $\delta^{18}O$ axis and the TSU-SM collection distinguished from UTK and UNMMM along the $\delta^{13}C$ axis.

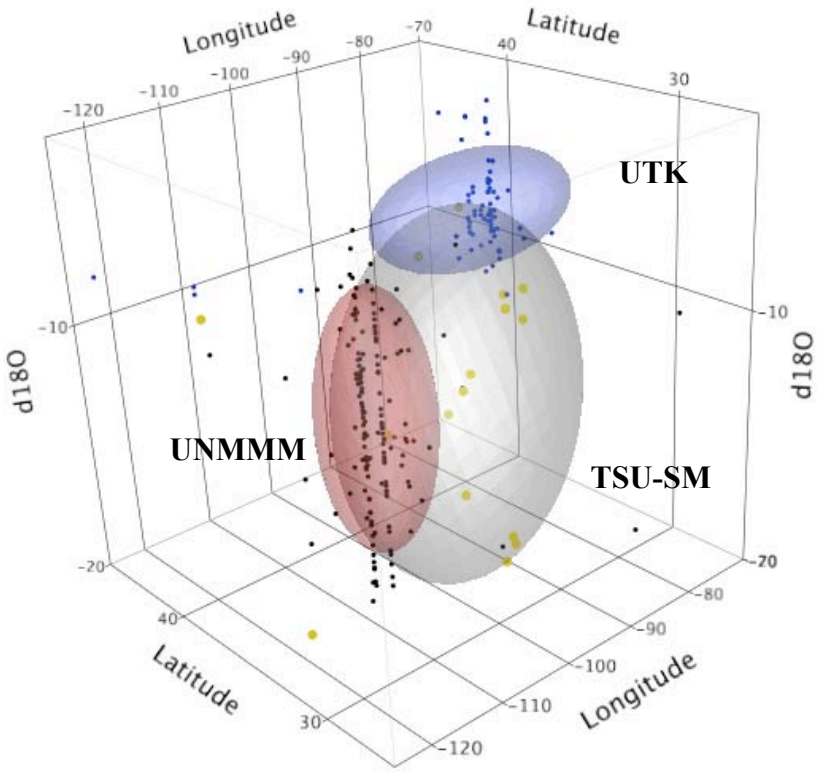


Figure 6. Bone apatite $\delta^{18}O$ values plotted by latitude and longitude with 50% density spheres for each sample (UTK=blue dot; TSU-SM=green dots; UNMMM=black dots). The relationship exhibits distinct distributions for the three collections. The UTK sample exhibits the highest $\delta^{18}O$ values. The TSU-SM and UNMMM exhibit similar $\delta^{18}O$ distributions but the death locations are distinct.

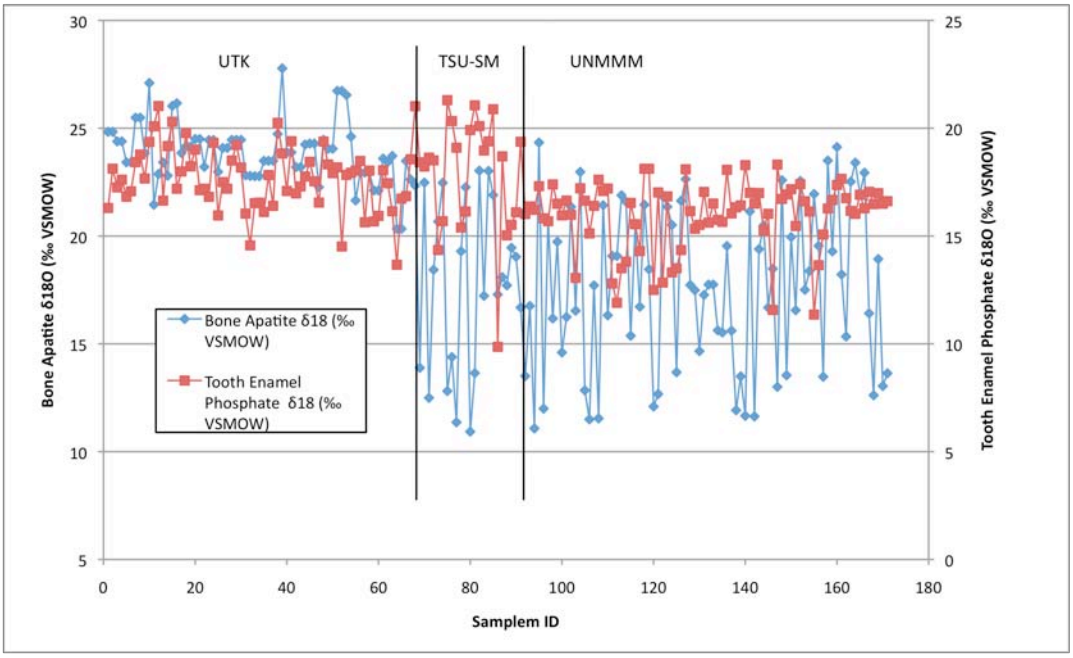


Figure 7. $\delta^{18}O$ relationship between bone apatite (blue line) and tooth enamel phosphate (red line) with divisions by collection. Compared to the tooth enamel phosphate $\delta^{18}O$, the bone apatite is enriched in ^{18}O by 6.25±1.63 (‰, VSMOW) (n=67) for UTK, -0.82±5.60 (‰, VSMOW) (n=18) for TSU-SM, 1.77±4.08 (‰, VSMOW) (n=86) for UNMMM. The low to inversed enrichment values for TSU-SM and UNMMM suggesting marked migration into the western samples.

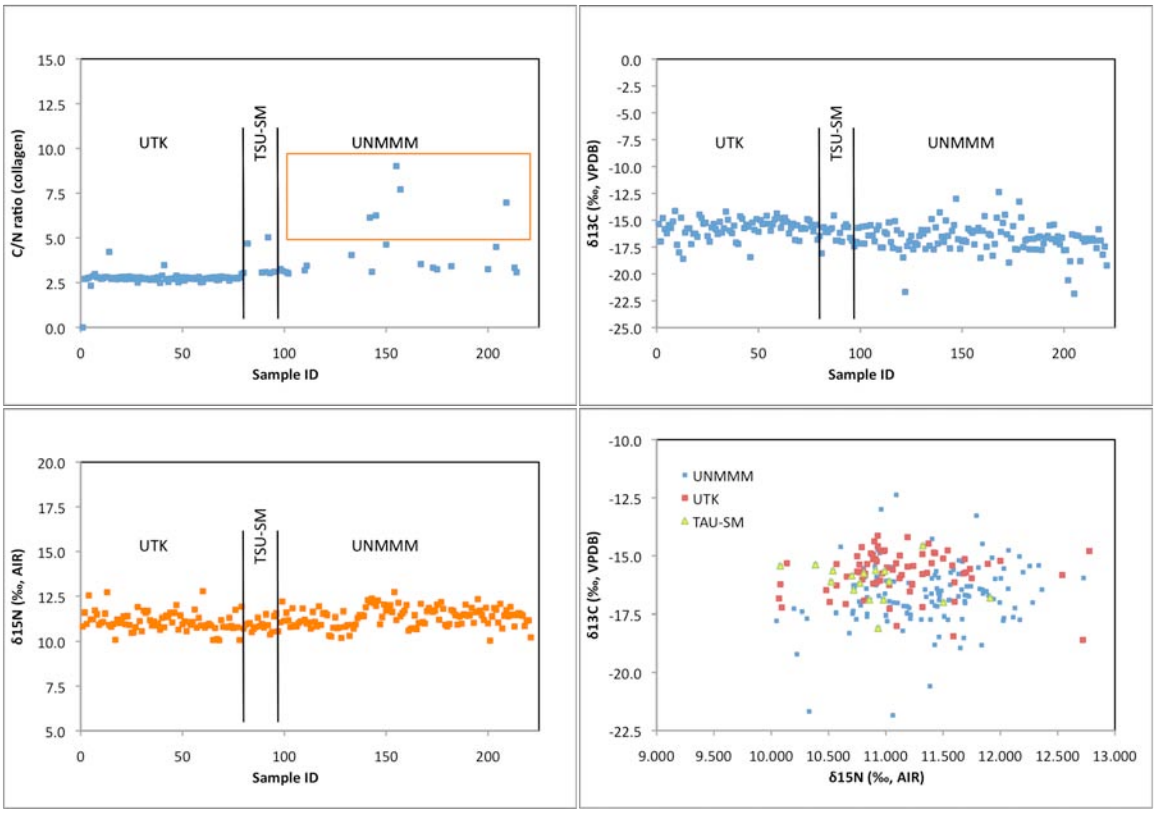
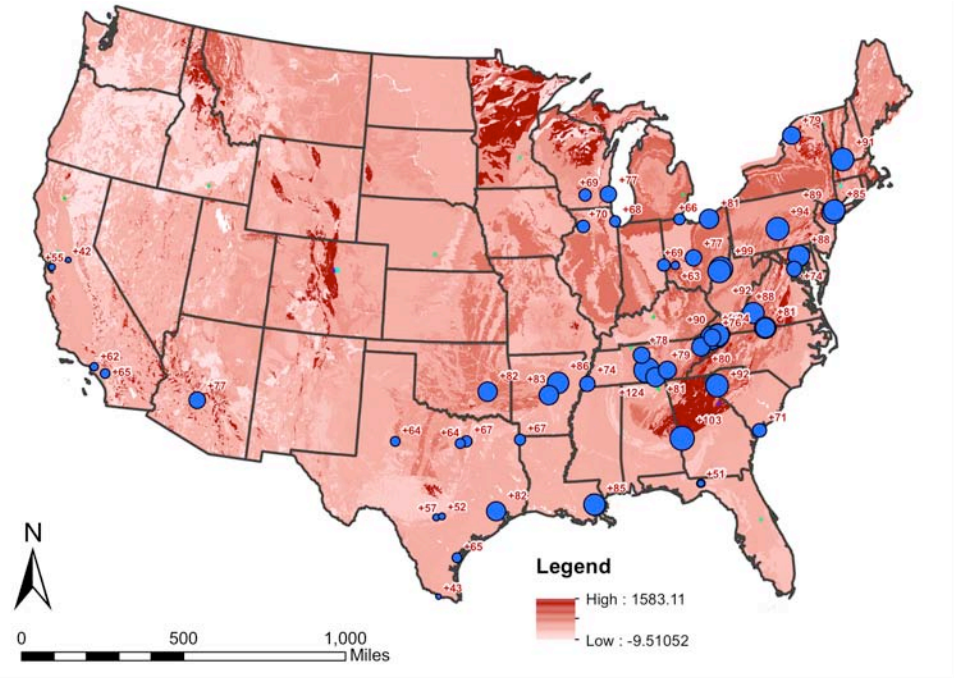


Figure 8. Bone collagen C/N ratio (A), $\delta^{13}C$ values (B), $\delta^{15}N$ values (C), and relationship between C and N isotopes (D). The C/N ratio averages 3.133±1.04 and the ratios exhibit a nearly constant value for the UTK and TSU-SM collections with considerable variation in the UNMMM collection. This variation may be related to the fact that the UNMMM samples were derived from foot phalanges, which produced low collagen yields. The averaged $\delta^{13}C$ = -16.32 ± 1.250‰. The averaged d15N =11.24 ± 0.53‰. The latitude range of death locations for these samples is between 29.424 and 44.840; -123.230 and -72.502 for longitude range. Significant correlations were observed between C and N isotopes and death locations.

Table 1. Correlation matrix of bone collagen results with longitude (death), latitude (death), elevation (death), and age. The results show significant correlations ($p<0.05$, *shaded*) with nearly all values except latitude.

	d13C	d15N	C.Percent	C.N.Ratio	N.Percent	Long	Lat	Ele	Age
d13C	NA	0.683	0.000	0.000	0.000	0.000	0.085	0.000	0.001
d15N	0.028	NA	0.005	0.000	0.000	0.000	0.097	0.000	0.002
C.Percent	0.425	-0.271	NA	0.000	0.000	0.002	0.092	0.026	0.000
C.N.Ratio	-0.472	0.420	-0.414	NA	0.000	0.000	0.008	0.000	0.001
N.Percent	0.596	-0.380	0.898	-0.727	NA	0.000	0.005	0.000	0.000
Longitude	0.346	-0.304	0.306	-0.481	0.493	NA	0.000	0.000	0.094
Latitude	0.123	-0.119	0.168	-0.261	0.275	0.341	NA	0.006	0.533
Elevation	-0.285	0.300	-0.222	0.586	-0.478	-0.772	-0.194	NA	0.891
Age	-0.241	0.219	-0.358	0.316	-0.448	-0.120	-0.045	-0.010	NA

A



B

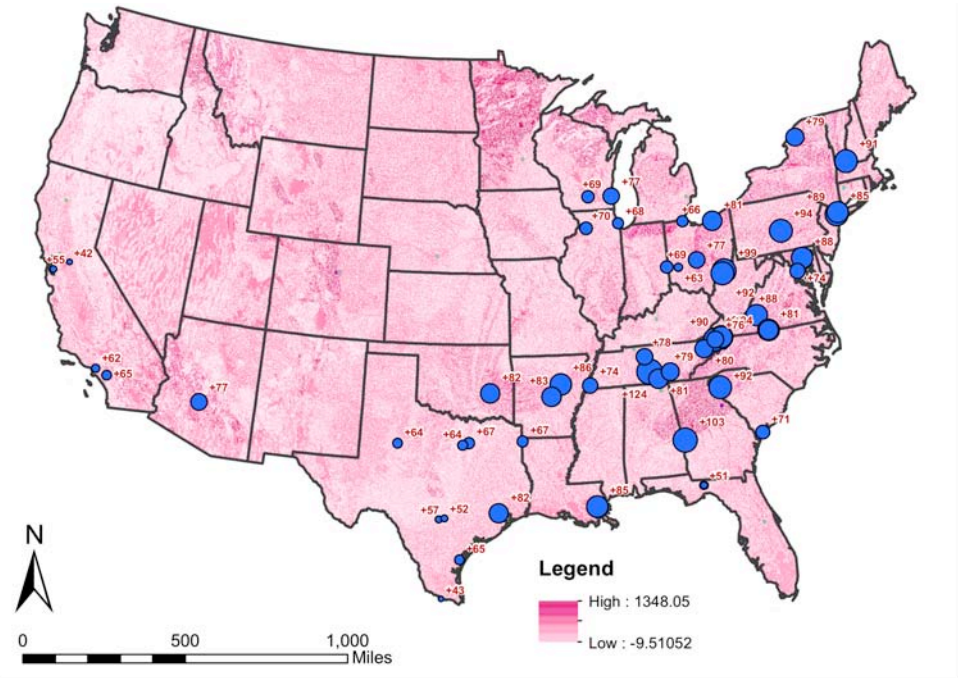
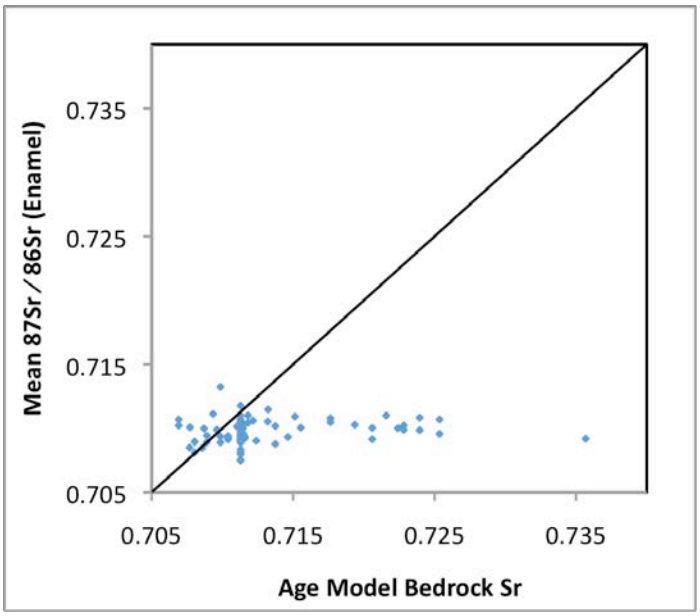


Figure 9. Enamel Sr ($^{87}Sr/^{86}Sr$) epsilon values plotted on the modeled bedrock (A) and modeled drainage and bedrock (B) epsilon values based on Beard and Johnson (2000) and Bataille and Bowen (2012), respectively. Blue dots represent birth locations of UTK or TSU-SM samples.

A



B

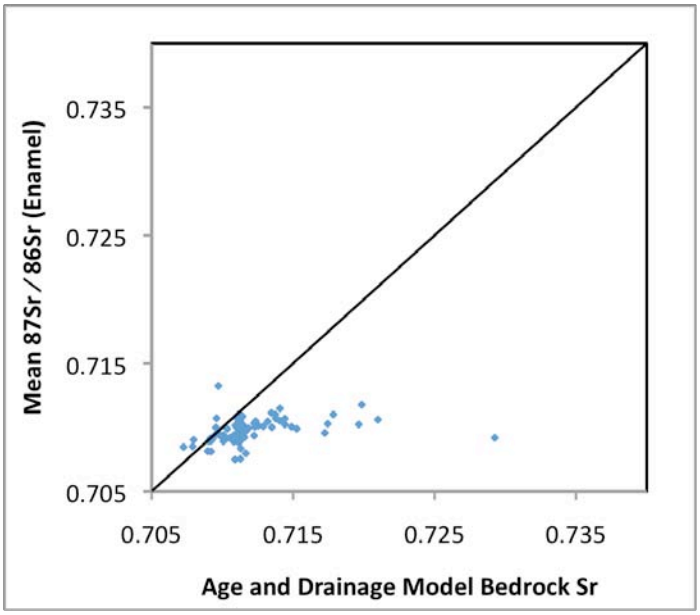


Figure 10. Enamel Sr ($^{87}Sr/^{86}Sr$) ratio values plotted by modeled bedrock (A) and modeled drainage and bedrock (B) ratio values based on Beard and Johnson (2000) and Bataille and Bowen (2012), respectively. Dots represent birth locations of UTK or TSU-SM samples and the diagonal line is a one-to-one relationship. The age and drainage model appears to conform to the mean $^{87}Sr/^{86}Sr$ values but fall off as the ratios increase.

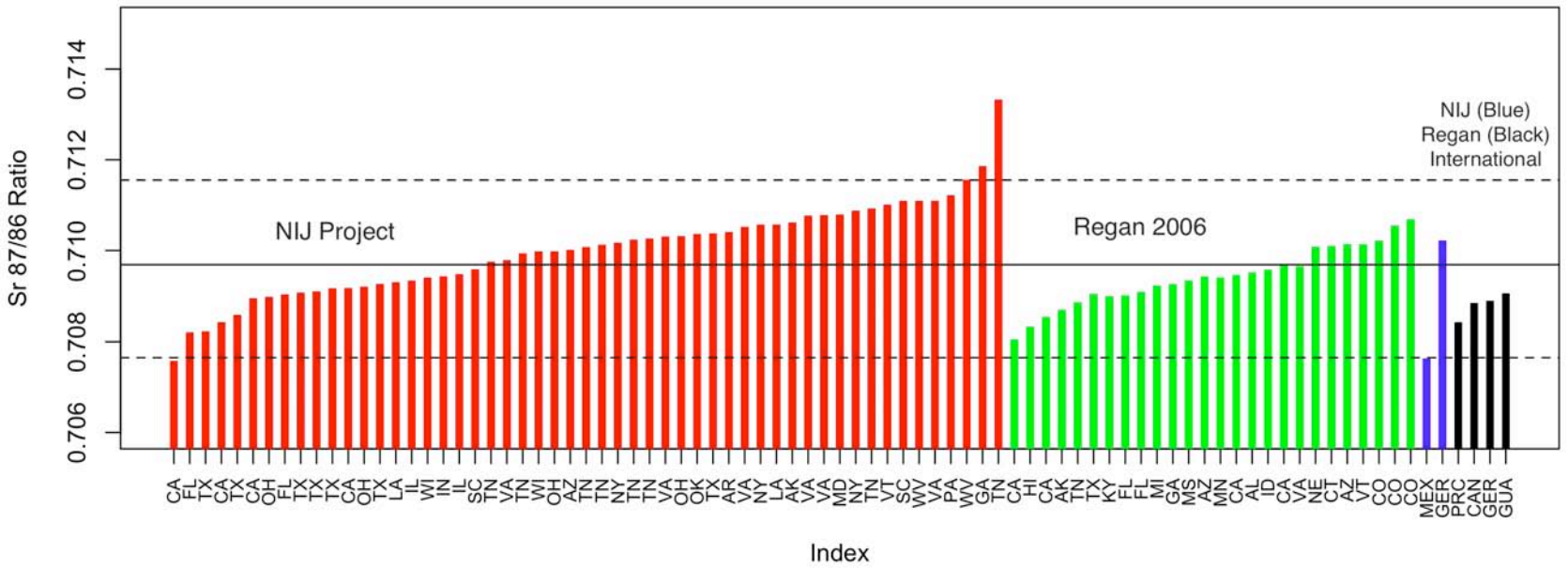


Figure 11. Enamel Sr ($^{87}Sr/^{86}Sr$) ratio values plotted in ascending order by project (Red and Blue – current NIJ project; Green and Black – Regan (2006) study). Regan's data for military personnel is included for comparative purposes in the plot. In general, there is some degree of clustering of values by state.

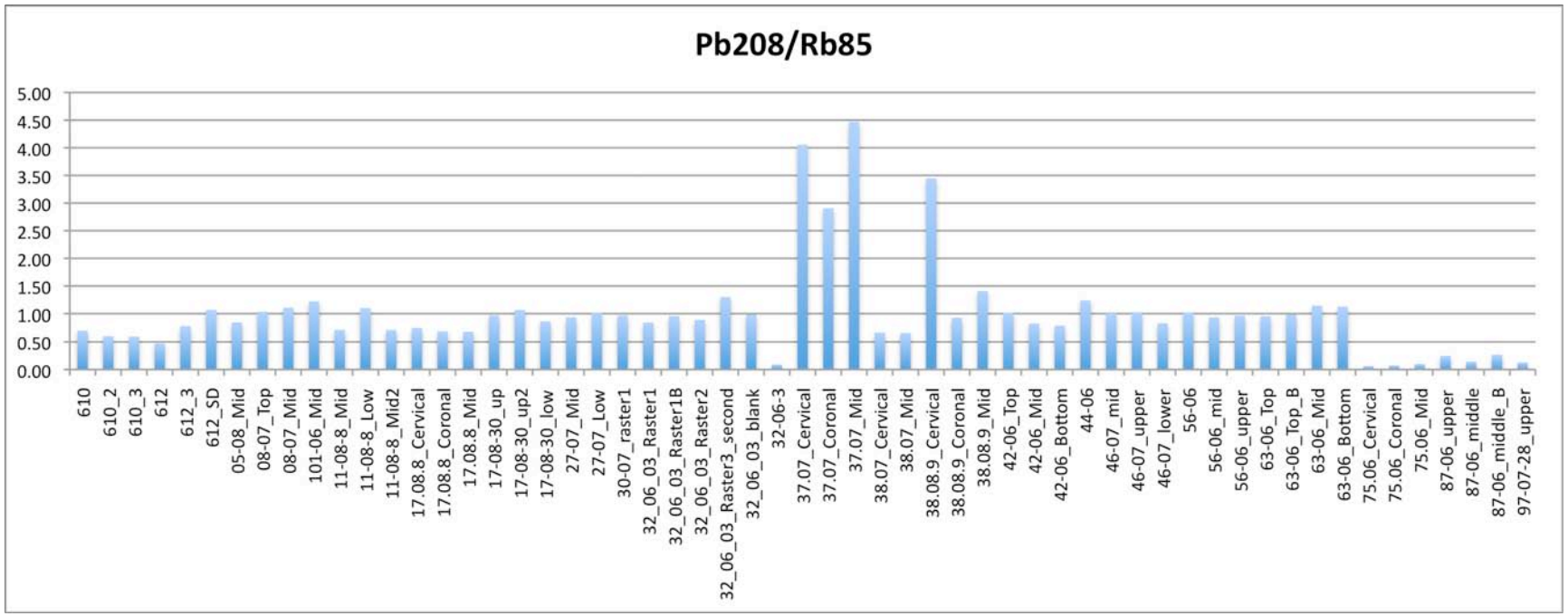


Figure 12. Preliminary LA-ICP-MS results based on counts per second (cps). The plot depicts Pb208 cps scaled by Rb85 cps. Overall, the values are consistent with the standard (610 or 612) except UT37-07D and UT38-08D.

Conclusions

Discussion of findings

Our study indicates that the dental enamel $\delta^{18}O$ values from the WBSC collections are overall reflective of the individual's birth location, whereas hair keratin $\delta^{2}H$ values are influenced by the individual's death location, which is consistent with several other isotopic studies of forensically derived human samples and suggests that the application of the dual isotopes (O, H) could provide better constrain on the residential history by pinpointing the beginning (tooth) and the ending (hair) of the individual life journey. Although the correlation coefficient of the dental $\delta^{18}O$ with local water is not as high as reported by several other researchers, the relationship however does follow the trend of Longinelli (1984). This could result from the potential influence of isotopic pattern of tap water as compared to meteoric precipitation, especially with the inclusion of the samples from Texas and New Mexico. It is also suspected that the WBDSC does not represent a geographically heterogeneous sample and it is likely that self- or family-reported residential histories, as is the practice at the UTK FAC, are more variable.

Implications for policy and practice

This study has implications for law enforcement and practicing forensic geochemists and forensic anthropologists interested in isotope and trace element research. This study has provided a large isotopic dataset from three donated human skeletal collections currently used as reference samples for active forensic anthropologists. These data enhance our understanding of the isotopic variation in modern humans, specifically modern US residents. The isotopic variation we see in these samples is greater than typically observed in more controlled laboratory studies, but the results do conform to current isotopic models, specifically for $\delta^{18}O$, and is therefore useful for estimating residential histories. Future isotopic work with unidentified decedents could be linked to their NamUs record and used to provide potential matches within the system based on geographic histories.

Broad impacts of the study relate to the Forensic Isotopic National Database (FIND). The data generated by this study will be made available to researchers through FIND and researchers can also submit their own results from forensic casework and modern donated collections. FIND will serve as a repository of forensic isotope data for human skeletal, dental, and hair studies. The study has also contributed to the training and laboratory experiences of both graduate and undergraduate students at the University of Tennessee- Knoxville, Mississippi State University, University of Alabama-Huntsville, University of New Mexico, and Texas State University-San Marcos.

The PIs on the project have also reached out to the medicolegal community to provide these services for a nominal fee during the process of the grant. Dr. Li has processed several bone and enamel samples for $\delta^{18}O$ as well as carbon and nitrogen. Isotopic analysis is now viewed as an important step in the analysis of unidentified decedents in some agencies.

Implications for further research

As the donated collections at UTK, UNM, and TSSU as well as several new body donation programs across the country grow, it is essential that reliable residential histories be collection from the donors and that isotopic data be collected (specifically adequate hair samples for research requests). These expanding collections combined with recent forensic isotope surveys being conducted and recently published will provide a much better picture of the isotopic and trace element variation across the United States. It is anticipated that this study will provide a foundation for future research with these collections.

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Dissemination of Research Findings

Websites:

http://find.msstate.edu (currently http://find.msstate.edu/fmi/webd) An example screen capture is provided. Access is available with username FINDUser and password FINDUser.

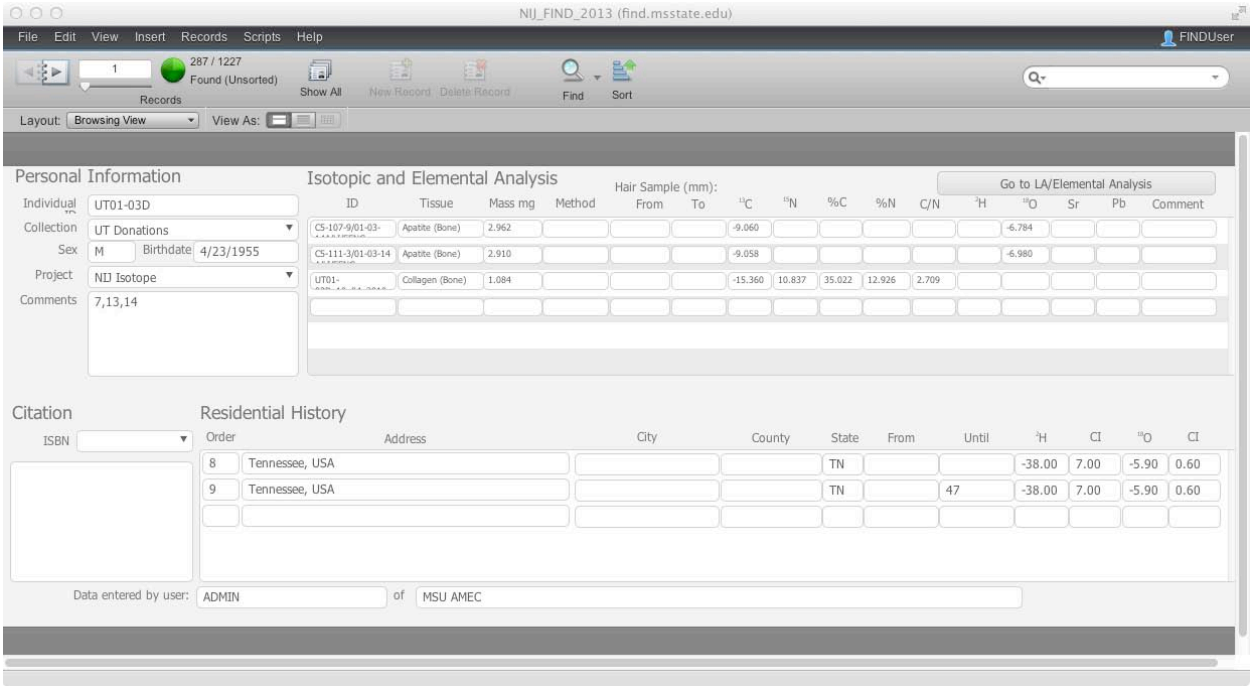

Figure 13. Screen capture from FIND.

Publications:

2010 Herrmann NP, Li Z-H, and Soto M.
Isotopic evaluation of modern human remains from the University of Tennessee William M. Bass Donated Collection. *American Journal of Physical Anthropology* Supplement 50:127-127.

Papers/Posters Presented:

2013 Li Z-H, Herrmann NP, Jantz RL, and Soto ME
Isotope Forensic Evaluation of Modern Human Remains From the University of Tennessee William M. Bass Donated Skeletal Collection. Poster presented at the Sixty-fifth Annual Meeting of the American Academy of Forensic Sciences, Washington D.C.

2013 Warner MM, Herrmann NP, Trask W, Li Z-H, and Li Y
Strontium Variation in the William M. Bass and Texas State University Donated Skeletal Collections: A Preliminary Assessment. Paper presented at the Mountain, Swamp, and Beach Regional Forensic Conference, Starkville, MS.

2011 Herrmann NP, Li Z-H, Weinand D, and Soto M

Isotopic and Elemental Analysis of the William Bass Donated Skeletal Collection and Other Modern Donated Collections. "Did Colonel Mustard Really Kill Miss Scarlet in the Library with the Lead Pipe?" Identifying Clues Through NIJ Research. Grantee symposium organized by the National Institute of Justice, Chicago, Illinois. February.

2010 Herrmann NP

Isotopes and Databases: Tools For the Identification of Unknown Forensic Cases. Invited lecture to the Department of Anthropology, Texas State University, San Marcos. February.

2009 Herrmann NP, Li Z-H, Weinand DC, Jantz RL, and Soto ME

Isotopic And Elemental Analysis of the William Bass Donated Skeletal Collection and Other Modern Donated Collections. Invited paper presentation at the National Institute of Justice Forensic Science Research and Development Forensic Anthropology Working Group, Alexandria, Virginia. December.

2009 Herrmann NP

Forensic Anthropology, NamUs and Isotopes. Lecture presented at the Mississippi MS State ME Training Course, Jackson, MS. December.

2009 Herrmann NP

Archaeology, Bones, and People: Forensic Anthropology of the Past. Lecture presented as part of Mississippi Archaeology Month at Plymouth Bluff Center, Columbus, MS. October.