Multiregional Pb Isotopic Linear Patterns and Diagenesis: Isotopes from Ancient Animal Enamel Show Native American "Foreign War Trophies" Are Local Ancestors

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Abstract

Skull burials are found all over the world and often are interpreted to be foreigners, sacrifices, or victims of warfare. The cause of ancient Native American skull deposits often leads to disagreement among scholars torn between warfare and ancestor veneration. Most previous research suggested a Caddo skull-and-mandible deposit (consisting of clusters of skulls and clusters of isolated mandibles) in southwest Arkansas, USA contained foreign victims of interregional warfare, representing at least 352 people (1253-1399 CE). While Sr isotopes are commonly used in archaeology to investigate such issues, they did not provide a conclusive answer to the geographic origin of the remains. This study advances the biologically available Pb method by constructing a large-scale multiregional Pb isotopic background with ancient animal tooth enamel and uses their associated linear patterns to evaluate human geographic origins. Evaluation of Pb contamination through diagenesis in human tooth enamel is evaluated *and advanced using correlation analysis of trace elemental data from teeth and burial soil. A total of 180 animal teeth were processed from 28 ancient sites in the southcentral USA. Combining Pb isotopic linear patterning analysis with the Sr isoscape, allows us to establish that the skulls and mandibles are local to southwest Arkansas and indicate or strongly suggest they are non-local to all other tested regions. This illustrates the importance of Pb isotopes in studies of human geographic origins. It also provides one cautionary tale that interpretations about violence related to detached skulls should be evaluated with appropriate methods and evidence and with a critical eye for other explanations. This study was conducted in collaboration with the Caddo Nation of Oklahoma and provided both the descendant community and researchers with answers to the questions surrounding the remains, serving as one example of how stakeholders can come together and produce positive outcomes.*

Keywords: Pb, diagenesis, violence, isotopes, Caddo

1. Introduction

When deposits of severed heads and mandibles are discovered at an archaeological site, warfare may first come to mind. Skull deposits are a worldwide phenomenon, the origins of which are often contested by scholars (Barrett and Scherer 2005; Hodder 2009; Kuijt 2009; Milner 1999; Schulting 2013; Testart 2008). Isotopic studies of skull deposits in ancient Mesoamerica and South America often conclude they are foreign victims of warfare or sacrifices (Moreiras Reynaga et al. 2021; Scaffidi et al. 2021). However, this is not necessarily applicable to the treatment of the dead by ancient Native North Americans. One such large deposit containing at least 352 skulls and mandibles at the Crenshaw site (3MI6) in southwest Arkansas, USA led researchers to investigate the prevalence and extent of warfare at the intersection between the Eastern Woodlands and the Southern Plains, ca. 1200 and 1500 CE, shortly before European contact (Akridge 2014; Samuelsen 2014, 2016; Samuelsen and Potra 2020; Schambach et al. 2011; Zabecki 2011). A new approach became necessary when strontium (Sr) isotopes failed to regionally differentiate the skulls and mandibles (Samuelsen 2016; Samuelsen and Potra 2020). A large-scale, multiregional lead (Pb) and Sr isotopic background was constructed using ancient non-migratory animal tooth enamel for comparison to the skull-and-mandible deposits at Crenshaw (Fig. 1).

This study has three objectives. 1) It advances and exemplifies the biologically available Pb method (Samuelsen and Potra 2020) by constructing a large-scale, multiregional Pb isotopic backgrounds using ancient animal tooth enamel (180 animal teeth from 28 ancient sites), illustrating regional differentiability and the ability of linear patterning analysis of Pb isotopes to evaluate ancient human geographic origins. The application of Pb isotope geochemistry for evaluating ancient human geographic origins is relatively new and underutilized compared to the widely used Sr isotope technique, but it is becoming clear that Pb isotopes can be highly sensitive to regional differences when Sr is not (Samuelsen and Potra 2020). This works because ancient animal tooth enamel provides a preserved record of pre-anthropogenic Pb isotopes within regions, mitigating the impact of modern Pb pollution. Including the 73 ancient human teeth tested, 253 ancient tooth enamel samples have been processed for Pb and Sr isotopes. Previous work includes comparisons to 99 Pb isotopes from whole rocks, rock leachates, and soil from southwest Arkansas (Samuelsen and Potra 2020). This represents a large Pb isotope dataset with enamel-to-enamel comparisons, providing future researchers with a replicable method and model. 2) It evaluates the effectiveness of trace elemental methods (Kamenov et al. 2018) in detecting Pb contamination in ancient human tooth enamel through correlation analysis. Pb isotope geochemistry is still underutilized because some of the basic underpinnings of the methods are still being developed and because there are significant challenges with obtaining uncontaminated, good quality Pb isotope data from ancient remains (King et al. 2020; Samuelsen and Potra 2020). Methods to confidently detect contamination are needed, as are studies that demonstrate these methods are effective (Dudás et al. 2016; Kamenov et al. 2018; Simonetti et al. 2021). Clearly and confidently identifying Pb contamination (or the lack thereof) in ancient tooth enamel is critical for advancement of studies of ancient human and animal geographic origins. The interpretations of Pb isotopic results (including in this study) are only as trustworthy as the evidence that the tooth enamel is uncontaminated. 3) It combines the Pb and Sr isotopic backgrounds with data from an ancient Caddo skull-and-mandible cemetery to evaluate their geographic origins and determines if they reflect war trophies from other regions or a local burial practice for revered ancestors.

1.1. Ancient Human Geographic Origins and Isotopes

Assessing the geographic origins of ancient human remains with geologically sensitive isotopes (e.g. Sr and Pb) requires comparisons to some type of background value (Bentley 2006; Price et al. 2002). Obtaining an isotopic value from human remains does not reveal their geographic origin without first establishing the isotopic values that define the geographic areas of investigation. The resultant data from large-area studies that construct these background values in multiple geographic areas are often described as "isoscapes" (Bowen 2010). In studies of ancient human geographic origins, the isotope ratios of individuals are compared to the isotope ratios of a locality or region, as defined by the background. If the isotope ratios of the individuals fall outside of the isotope ratios defined by the area of investigation, the individuals are considered non-local to that area. This works because humans and animals deposit elements like Sr and Pb in their tooth enamel as the teeth are formed. These elements are locked into the enamel and reflect the Sr and Pb isotopes in the surrounding geology. Depending on the element and pollution levels, the isotopes reflect the ingestion or inhalation of the food, soil, or dust where the people grew up (Bentley 2006; Price et al. 2002; Samuelsen and Potra 2020; Scaffidi et al. 2021). For ancient populations in the US, like the Caddo, this is most likely to reflect the food and soil since anthropogenic Pb aerosol is not expected to be significant in this time and place (Samuelsen and Potra 2020).

Studies of ancient humans using Pb isotopes have been greatly expanding in the last few years (Beherec et al. 2016; Dudás et al. 2016; Eshel et al. 2020; Jones et al. 2017; King et al. 2020; Price et al. 2021; Samuelsen and Potra 2020; Scaffidi et al. 2021; Sharpe et al. 2016; Simonetti et al. 2021; Tschetsch et al. 2020; Turner 2021). While many previous studies have constructed Sr isoscapes (Hedman et al. 2018), no study has yet created a Pb isotopic background at this scale from ancient animal tooth enamel. This study builds on previous work by including multiple regions while creating backgrounds and by focusing on biological samples rather than backgrounds created using rocks or ores (Jones et al. 2017; Price et al. 2021; Scaffidi et al. 2021; Sharpe et al. 2016; Turner et al. 2009; Valentine et al. 2015). One recent study adds to the literature by producing a large number of animal bone samples (not enamel) processed for Pb and Sr isotopes in one region (Tschetsch et al. 2020). Another study outlined the biologically available Pb method using ancient animal tooth enamel in a single region (Samuelsen and Potra 2020). The present study builds on these by utilizing the biologically available Pb method to create multiregional backgrounds from animal Pb isotopes (180 animal teeth from 28 ancient sites) and by validating the use of linear patterning analysis to robustly assess ancient human geographic origins in multiple regions.

The multivariate and linear nature of Pb isotopes necessitate multiple samples from each site and many sites to be sampled per region to construct a robust background signature (Samuelsen and Potra 2020). It is not the number of samples itself that is important, but larger sample sizes of animal tooth enamel allow regionally defined linear patterns in Pb isotopes to be used as a fingerprint to assess ancient human geographic origins. In most research, Sr isotope analysis focuses only on the range of single isotope ratio, $^{87}Sr/^{86}Sr$. With Pb, a similar approach may be appropriate for certain types of background samples (e.g., rock samples). Some Pb isotope analyses use a range of Pb isotope ratios in a similar way to how Sr is analyzed or limit the comparisons to only a subset of Pb isotope ratios. That type of Pb isotope analysis is common for studies analyzing individuals exposed to Pb through metallurgy or pollution and when using rocks to assess human geographic origins (Beherec et al. 2016; Scaffidi et al. 2021; Sharpe et al. 2016). However, ancient animal tooth enamel is directly comparable to ancient human tooth enamel and enables linear patterning analysis using multiple Pb isotope ratios through enamel-to-enamel comparisons (Samuelsen and Potra 2020). The linear patterning of Pb isotopes from human tooth enamel and non-migratory, ancient animal tooth enamel must match all in 15 unique bivariate comparisons using all six Pb isotope ratios ($^{208}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$, $^{206}Pb/^{204}Pb$, $^{208}Pb/^{206}Pb$, $^{207}Pb/^{206}Pb$, and $^{208}Pb/^{207}Pb$) for the humans to be considered local. Humans that do not match the animals in all 15 bivariate graphs are considered non-local. It is in this linear patterning comparison that Pb isotopes are most robust in detecting ancient human geographic origins. Sr isotopes have no linear patterning and therefore do not necessarily require such large sample sizes for backgrounds, but they may not provide as much clarity about geographic origins if used alone.

There are two major factors preventing wide-spread adoption of Pb isotopes in studies of ancient human geographic origins (Samuelsen and Potra 2020). 1) Obtaining high-quality Pb isotope data from tooth enamel is challenging because it is difficult to get enough Pb from tooth enamel, unless the individual was exposed to a large amount of Pb during their formative years. This can restrict studies by only enabling analysis of those individuals with high Pb concentrations. To mitigate this issue, some research does not include the lowest abundance isotope (^{204}Pb), but this can severely reduce the usefulness of the data and the significance of the conclusions since this limits comparisons to only three Pb isotope ratios (Gulson et al. 2018). This process is destructive and therefor lesser amounts of Pb in the tooth enamel requires either more tooth enamel, better methods for extracting, and/or more expensive, sensitive, and accurate instrumentation. By contrast, there is much more Sr in tooth enamel, so this is generally not an issue for that element. 2) Pb in tooth enamel is much more likely to have issues with contamination. Tooth enamel is generally thought to be more resistant to post-burial contamination than bone, but this is mostly based on Sr research (Bentley 2006). There are dueling potential problems with Pb isotope contamination (Samuelsen and Potra 2020). First, large amounts of anthropogenic Pb have been deposited in soils due to modern pollution and can affect buried remains and materials. Second, even if there is no issue with anthropogenic Pb, the elements naturally in soil can attach to or penetrate the surfaces of tooth enamel (Weber et al. 2021). Only recently have there been methods published to help assess this contamination with

Pb isotopes in mind (Dudás et al. 2016; Kamenov et al. 2018; Samuelsen and Potra 2020). Relatedly, since Pb concentrations in human tooth enamel are often below 200 ppb, labs need to be extremely clean to prevent laboratory contamination of samples from ambient Pb in the environment and from reagents used in chemical processing and column chemistry.

1.2. Pb Isotopes and Soil Contamination

Pb concentrations in human tooth enamel are typically much lower than Sr concentrations and Pb concentrations in soil can often be relatively high. Studies have repeatedly shown evidence that Sr isotopes in tooth enamel are resistant to post-burial contamination (Bentley 2006; Pacheco-Forés et al. 2021). Pb contamination of tooth enamel is more common (Kamenov et al. 2018; King et al. 2020; Simonetti et al. 2021). This makes post-burial contamination of human tooth enamel a major issue for Pb isotope studies as it increases the likelihood of anthropogenic or soil Pb contamination of the teeth (Kamenov et al. 2018; Samuelsen and Potra 2020). Therefore, assessing soil contamination of ancient human teeth is a critical element of studies utilizing Pb isotopes. Not doing so could lead to heavily contaminated samples being unknowingly presented as valid data. In cases where the contamination was due to anthropogenic Pb, it could overestimate the number of non-locals since the non-local Pb isotopic signature of anthropogenic Pb could overwhelm the ancient Pb in the sample. If the contamination is due to soil Pb, then it could overestimate the number of locals by overwhelming the ancient Pb with locally derived Pb isotope ratios.

The large number of remains placed in the same soil context and the lack of anthropogenic Pb contamination (Samuelsen and Potra 2020) makes the Crenshaw skull-and-mandible cemetery particularly well-suited for understanding soil contamination of ancient human tooth enamel since it allows comparisons between ancient teeth without significantly different burial soils affecting the analysis. This study follows the trace element analysis method (Kamenov et al. 2018) that utilizes Maximum Threshold Concentrations (MTCs) for ancient human tooth enamel. The method is robust because it detects excessive elemental concentrations in ancient human tooth enamel using elements that have low concentrations in uncontaminated modern human tooth enamel. Evidence of higher-than-expected concentrations of these elements in ancient human tooth enamel suggests that soil or other contaminants were attached to or penetrated the enamel, contaminating the Pb by proxy.

Three tests of the method are considered. 1) For particular elements to be confidently used to detect Pb contamination, they should have a correlation between higher concentrations of these elements and higher concentrations of Pb. Trace element data, Pb concentration data, and Pb isotope data are analyzed for correlations to detect evidence of relationships between particular elemental concentrations and Pb contamination. Pb isotopic data from tooth enamel and soil leachates allow for a validation of these results. 2) MTCs are based on modern human tooth enamel, so potential differences between modern and ancient indigenous peoples' exposure to some elements may not be incorporated in the defined thresholds. While it is recognized that modern humans have greater exposure to some elements like Pb, ancient indigenous people may have greater exposure to other elements. For example, dietary difference can also affect the concentrations of these elements, such as trophic level (Kohn et al. 2013). Correlations between elemental concentrations are analyzed to detect hypothesized differences between *in-vivo* concentrations in ancient human tooth enamel (deposited in teeth prior to death) and high elemental concentrations related to direct soil addition. 3) The concentrations of some elements in human tooth enamel may be different in other regions based on the natural concentrations of these elements in the soil. Correlated elemental concentrations in ancient human tooth enamel and soil from Crenshaw are compared to established MTCs to test if there is evidence that higher concentrations of some elements may be related to *in-vivo* exposure instead of post-burial contamination.

1.3. Skull Deposits and Late Pre-Contact Warfare in the Southcentral US

One thing is clear about skull deposits: the head or skull has special significance to Native Americans, just as it does for many people all over the world (Bonogofsky 2011; Brown 1971; Charles and Buikstra 1983; Pluckhahn 2003; Schulting 2013). Whatever the context or region, discoveries of skull deposits often result in significant disagreement among scholars, who are torn between competing arguments of warfare and ancestor veneration (Barrett and Scherer 2005; Eerkens et al. 2016; Hodder 2009; McAnany 1998; Milner 1999; Pluckhahn 2003; Schulting 2013; Schwitalla et al. 2014; Sears 1956; Seeman 1988, 2008; Webb and Snow 1945). Some argue that ancient Native American cultures practiced warfare resulting in skull deposits (Schambach et al. 2011; Schwitalla et al. 2014; Sears 1956; Seeman 1988, 2008). Others proposed that such skulls represent locals, perhaps kept for the purposes of venerating and honoring deceased ancestors (Brown 1971; Eerkens et al. 2016; McAnany 1998; Pluckhahn 2003; Samuelsen 2016; Webb and Snow 1945). To this point, many Native American tribes carried their family's disarticulated remains over long distances for burial at places of significance, sometimes with accompanying rituals affirming community identity (Brown 2012; Charles and Buikstra 1983; Milner 2004; Pluckhahn 2003).

It is no surprise to archaeologists and bioarchaeologists studying ancient warfare and peace that distinguishing between the two using archaeological data can be a struggle with current methods (Chacon and Mendoza 2007; Dye 2009; Kintigh et al. 2014; Milner 1995, 1999). Archaeologists typically use a few key datasets to assess if warfare was affecting the lives of ancient Native Americans; these include biological trauma, burned villages, fortifications, and nucleated settlement patterns. Some researchers (Dye 2009; Milner 1995, 1999) have argued that the best evidence for ancient violence can be found through skeletal trauma, burned villages, and in the use of fortifications. Indirect evidence for peace and cooperation include community rituals, exchange networks, dispersed settlement patterns, and political organization (Dye 2009). Some (Chacon and Mendoza 2007) argue that warfare in ancient North America was ubiquitous and that others view ancient Native Americans through a peacefully idealized lens. While it is true that ancient warfare was ubiquitous, it is also clear that there are times and places where war dominates and other times and places that are relatively peaceful. Each time and place should be independently evaluated for the prevalence and extent of ancient warfare using the available archaeological and bioarchaeological evidence.

1.3.1. Warfare in the Southern Plains and the Central and Lower Mississippi Valleys

While there is little evidence before 950 CE, beginning around 1200 CE the Plains see a great increase in the evidence of warfare (Bovee and Owsley 1994; Brooks 1994; Lambert 2007; Owsley et al. 1994). Warfare in the Southern Plains is characterized as consisting of small-scale raids and intertribal warfare, relatively light compared to the Northern Plains (Lambert 2007). The evidence for large-scale warfare in the Southern Plains is lacking compared to the strong evidence seen in the Northern Plains, where hundreds of people were killed, mutilated, and buried in the Crow Creek massacre (Lambert 2007). Several areas in the Southern Plains are typified by some sort of fortification (Brooks 1994). There are many sites in Texas and Oklahoma that have some potential evidence of violence including embedded projectile points in bone, isolated skulls, and fortification (Baugh and Blaine 2017; Bovee and Owsley 1994; Brooks 1994; Huff and Biggs 1963; Owsley et al. 1989; Owsley and Jantz 1989; Perttula 2001; Pillaert 1963; Potter 2005; Prewitt 2012; Reinhard et al. 1990; Rose, D. Gentry, et al. 1999; Ross-Stallings 2008; Story et al. 1990). One site, the Nagle site (34OK4), has some evidence of interregional warfare between the Caddo and the Wichita of the Southern Plains. Despite its location in central Oklahoma, one study (Brooks and Cox 2011) argues that Nagle was occupied by a group of Caddo people around 1200 CE. One individual buried there had evidence of scalping and four Harrell and Wichita points in the thoracic cavity. The location of this site, well outside of the typical delineation of the Caddo Area, and the evidence of violence does provide some basis for the hypothesis that there may have been interregional warfare during this time.

The bioarchaeological record of the Lower Mississippi Valley seems to indicate that the prevalence of warfare was different in the northern and southern portions. The bioarchaeology of the Plaquemine culture in Arkansas and Louisiana remains relatively unknown due to a lack of excavations and analyses (Harmon and Rose 1989). Limited bioarchaeological data is available from Mississippi, although recent studies have begun to document what remains are available (Danforth 2012; Davis 2015; Listi 2011). There is little evidence of fortification with the exception of Lake George (22YZ557) in west Mississippi where one burned bundle burial was missing a skull (Kidder 1998; Ross-Stallings 2008; Williams and Brian 1983). One study (Kidder 1998) casts doubt on the idea that the earthworks at sites like Lake George reflect a concern about warfare, instead it suggests they have functional or ceremonial significance. It also notes that the dispersed settlement patterns in the southern portion of the area could preclude the use of palisades given the lack of population nucleation. The more nucleated settlement patterns in the northern portions, like the Yazoo Basin, could suggest some concern for violence, but these sites still lack evidence for fortifications.

Evidence of violence is present in the Central Mississippi Valley and the northern portion of the Lower Mississippi Valley. In Mississippi, one burial at the Austin site (22TU549) showed evidence of being decapitated before burial (Ross-Stallings 2008). This site is located near a double burial at Bonds Village which contained two individuals buried without their skulls (Brookes 1999; Ross-Stallings 2008). Nucleation and fortification are common in the Central Mississippi Valley and include sites like Zebree (3MS20), Old Town Ridge (3CG41), Nodena (3MS3/4), and Parkin (3CS29) in northeast Arkansas; Kincaid in south Illinois; and Powers Fort (23BU10), Snodgrass (23BU21B), and Towosahgy B (23MI2) in southeast Missouri (Krus 2016; Milner 1999; Morse and Morse 1983; O'Brien 2001). One of the better examples of violence is the Norris Farms #36 cemetery in west-central Illinois where one individual had a point lodged in a bone and 11 individuals at the site were missing their skulls (Milner 1995; Milner et al. 1991).

1.3.2. The Crenshaw Skulls and Mandibles and Caddo Burial Practices

The Crenshaw site, located along the Great Bend of the Red River in southwest Arkansas, was a multiple-mound Caddo ceremonial center occupied between at least 900 and 1400 CE and had clear ritual significance to the ancient Caddo (Samuelsen 2009, 2014; Schambach 2014). The skull-and-mandible cemetery has great importance as a baseline dataset for studying ancient conflict and cooperation because the large number of people represented would imply a substantial degree of interregional warfare was being practiced in the area prior to European contact. Salvage excavations recovered these skulls and mandibles in two small areas (Samuelsen 2016:Figure 3), the West Skull Area (WSA) and North Skull Area (NSA). Collectors had previously collected other skulls nearby, some of which were donated to the Arkansas Archeological Survey (ARAS). These remains were deposited in clusters of complete skulls or clusters of isolated mandibles, with a couple of exceptions. The skull clusters generally contained from one to several people while the mandible clusters contained as many as 100 people (Zabecki 2011). The Caddo Nation of Oklahoma and researchers alike questioned if the remains were Caddo ancestors or perhaps their former rivals. A collaborative project with the Caddo Nation and the ARAS was developed to provide an evidence-based answer to these questions and aid repatriation. While a large massacre may seem to be a possibility, direct dating of the remains showed that the practice occurred over time between 1253 and 1399 CE, ruling out single event interpretations (Samuelsen 2014). Similarly, local warfare is very unlikely to be the cause of these deposits. If local warfare were causing such large-scale acts of violence, it would be expected to have great impacts on the rest of the cultural system (e.g. fortification/nucleation). This does not occur among the ancient Caddo in southwest Arkansas and neither does any strong evidence of violent trauma. The possibility that migrants translocated their ancestor’s remains is also rejected. Archaeological and bioarchaeological data have consistently shown a lack of evidence for any large-scale migration in the Caddo Area (Rose et al. 1998).

There are two plausible explanations for this deposit offered by previous studies (Samuelsen 2016; Schambach et al. 2011). First, these individuals represent victims of warfare from other regions. If the victims were from distant communities, the Caddo may not have suffered reprisals, needed fortifications, or needed to change their settlement patterns. Most studies examining these remains infer identities of extra-local victims of warfare from places such as the Southern Plains or Central and Lower Mississippi Valleys, suggesting the Caddo participated in large-scale interregional warfare (Akridge 2014; Brookes 1999; Milner 1995:232; Powell 1977; Schambach 2014; Schambach et al. 2011; Zabecki 2011). Analyses of osteological and fortification data show that at the same time the skulls and mandibles appear at Crenshaw there is increased evidence for warfare in the Plains and Central and Lower Mississippi Valleys (see Supplementary Text). Radiocarbon analysis of palisades in the Eastern Woodlands (Krus 2016) and bioarchaeological evidence (Lambert 2007) illustrates that the skulls and mandibles at Crenshaw appeared at the same time that palisades were becoming common across the Eastern Woodlands (ca. 1200-1400 CE) and violence was occurring in the Plains. The historic record is an important source of information about warfare. The Caddo are one of only a few tribes that can be directly traced from the present into ancient times, making possible the cautious (Belfer-Cohen and Goring-Morris 2009; Milner 1999) application of the direct historical approach. Although internally peaceful, the historic Caddo were under threat of violence from other tribes including the Wichita, Choctaw, Chickasaw, Osage, Tonkawan, and Apache (Barr 2007; John 1975; Smith 1994). Records indicate the Hasinai Caddo of northeast Texas took heads as war trophies during historic times (Swanton 1942).

Second, the deposit reflects a Caddo ritual signifying Crenshaw as a place of regional ritual significance through the deposition of ancestors' remains from outlying sites. A hasty interpretation of the skull-and-mandible cemetery might be trophy taking as a result of interregional warfare, but there is little archaeological evidence of warfare among the ancient Caddo. There is also little evidence of violent trauma among the ancient Caddo and the antecedent Woodland period Fourche Maline (Rose, Burnett, et al. 1999; Rose, D. Gentry, et al. 1999; Rose and Harmon 1999). However, a recent bioarchaeological analysis at the Akers site (34LF32) in eastern Oklahoma shows that this was not universally the case (Rowe 2017). In the rest of the Caddo Area, researchers have seen a lack of evidence for violence (Burnett 1990; Rose, Burnett, et al. 1999; Rose, D. Gentry, et al. 1999; Rose et al. 1998; Rose and Harmon 1999). Outside of the Crenshaw skulls and mandibles, the few interpretations of ancient violence in the Caddo Area mainly come from the presence of isolated skulls, which often lack any justification for the interpretation they are trophy skulls (Harris 1953; Perino 1983; Story 1990). No evidence of fortification has been found at Crenshaw (Samuelsen 2010) and the Caddo are not known for having fortified, nucleated villages after 1200 CE (Perttula and Walker 2012). The lack of nucleated, fortified settlements in the Caddo Area suggests that their settlement patterns may have been more influenced by food procurement strategies than violence. The Caddo adopted maize as a staple during between 1200 and 1500 CE, which may have been more productive with a dispersed settlement pattern (Wilson and Perttula 2013). In sum, the available information from archaeological and bioarchaeological sources outside of Crenshaw generally show a lack of evidence for warfare. While it is clear from the historic accounts that warfare was not foreign to the Caddo after European contact (John 1975; Smith 1994:199; Swanton 1942), 1200-1500 CE may have been a time when the Caddo lacked a motivation to be involved in violent conflicts with neighboring regions.

Caddo burial practices in the Southern Caddo Area are commonly defined by shaft burials dug into mounds, often containing large numbers of associated objects. However, burials in separate cemetery areas and in fields around mounds were also common. All of these can be seen at Crenshaw (Samuelsen 2009). Skull or mandible burials were generally not recognized as a major form of burial among the Caddo until the Crenshaw remains were uncovered. However, it is clear that it was practiced at other sites in southwest Arkansas, including Battle, Haley, Miller’s Crossing, and Mineral Springs, as well as in northeast Texas (Harris 1953; Samuelsen 2016). Headless bodes have been found at Haley and Hardman in southwest Arkansas and there are copious examples of remains in different stages of disarticulation in mound burials at Crenshaw. One example even includes a cluster of skulls buried next to a large number of disarticulated postcranial bones (Samuelsen 2020). There are not many excavated cremations from this time, but there are examples at Crenshaw and at Mineral Springs.

Ancestor veneration by the Caddo could be reflected in the care and complex suite of burial practices and rituals that they performed. A finding that the skulls and mandibles represent local ancestors would have important implications about Caddo burial rituals and practices given the great expansion of this preexisting burial practice. For example, in the Northern Caddo Area, the comingling of disarticulated burials, such as those in the Craig mound at Spiro, have led to interpretations that such burial events represent expressions of collective or corporate identity (Brown 2012). The large collection of individuals at Crenshaw could represent a similar collective or corporate identity. However, there is biological trait and dietary reasons to suggest that the clusters of skulls could represent family groupings while the mandibles represent a collection of other individuals (Samuelsen 2020). The possible family groupings and the associated potential for the collection and display of family members for a period of time prior to burial could reflect strong ties to particular family lineages and the veneration of these ancestors. The adoption of maize as a staple and the potential dispersal of the population or incorporation of surrounding sites in its ritual sphere of influence could provide another explanation for the expansion of this practice. Incorporating larger numbers of people from greater distances would create a functional challenge in the need to move large numbers of bodies over long distances. Severing the skull or mandible would allow for burial at Crenshaw without the need to transport entire bodies.

2. Materials and Methods

2.1. Sample Selection

Human teeth were selected from a cross section of skull and mandible clusters from both the WSA and NSA, 50 m north-northeast of the WSA, on the southern edge of the site. This included samples from WSA Clusters 1, 2, 5, 6, 17 and 25 and NSA Clusters 1, 2, and 8. Some skull clusters were sampled because there was inter-observer error related to evidence of violent trauma, with the most recent analysis (Zabecki 2011) unable to verify evidence of violent trauma. These skull clusters were WSA Clusters 6, 17, and 25 and NSA Cluster 1, although WSA Cluster 17 also included an isolated mandible. Some skull clusters were also sampled because they had evidence of cranial modeling (modification of the shape of the skull during childhood growth). Although cranial modeling was practiced by the Caddo, specific types of cranial modeling were previously hypothesized to be a culturally foreign trait (Schambach et al.

2011), so evaluating these were a priority (see Samuelsen 2020). These skull clusters were WSA Clusters 5 and 6 and NSA Clusters 1 and 2, although NSA Cluster 2 also contained an isolated mandible. WSA Cluster 2 contained 112 mandibles and was sampled to investigate if mandibles might be coming from different locations than skulls. WSA Cluster 1 and NSA Cluster 8 were also sampled to provide a test of skull clusters that had been previously tested for Sr, carbon, and nitrogen isotopes (Akridge 2014; Samuelsen 2016) and to provide a test of skulls that had no suggested evidence of violence or cranial modeling. One duplicate sample from the Rayburn Cluster previously analyzed by (Samuelsen and Potra 2020) was reanalyzed for trace element concentrations and isotopes. Only Sr isotopes were taken from some human teeth from the Rayburn Cluster, WSA Cluster 15 (mandibles), and WSA Cluster 18 (skulls). Trace element analysis was only performed on samples analyzed for both Pb and Sr isotopes. Soil leachates are all from previously processed cores from Crenshaw and from the soil surrounding the burials themselves (Samuelsen and Potra 2020). These were all located greater than or equal to 25 cm below the surface, with some as deep as 1.25 m. This previous research showed the lack of evidence for anthropogenic Pb contamination at these depths.

Animal tooth samples were selected from key sites with evidence of violence from ca. 1200-1500 CE (Bovee and Owsley 1994; Brookes 1999; Brooks 1994; Brooks and Cox 2011; Early 1993; Harmon and Rose 1989; Harris 1953; Huff and Biggs 1963; Krus 2016; Owsley et al. 1989, 1994; Owsley and Jantz 1989; Pillaert 1963; Potter 2005; Prewitt 2012; Reinhard et al. 1990; Rose, D. Gentry, et al. 1999; Ross-Stallings 2008; Story 1990). While efforts were made to sample specific sites with potential evidence of violence, sometimes ancient animal teeth were of limited availability. In those cases, samples were obtained from nearby sites to provide an idea of the regional isotopic signature. Samples from the Southern Plains were collected from sites in central and west Oklahoma and in east Texas. Samples from the Central Mississippi Valley and the upper portion of the Lower Mississippi Valley were sampled from south Illinois, southeast Missouri, northeast Arkansas, and northwest Mississippi. To provide a test if a more proximal area could be distinguished with Pb isotopes and to test the range of Crenshaw's ritual influence, sites in northwest Louisiana were also sampled. Samples previously (Samuelsen and Potra 2020) processed for Pb isotopes by were selected for Sr isotope analysis, further establishing the Sr isotopic values in southwest Arkansas, northwest Louisiana, and northwest Mississippi. Animals sampled included deer, rabbit/cottontail, opossum, squirrel, pocket gopher, raccoon, beaver, ground hog, black bear, grey fox, skunk, dog, rat, and other small rodents.

Contamination of ancient animal tooth enamel is also potentially an issue, but it is unclear if the trace element methods and MTCs created for human tooth enamel are applicable to animal tooth enamel since animals may have biological or dietary differences (e.g. soil ingestion) that result in different elemental concentrations in their tooth enamel, which may be different depending on the species (Kohn et al. 2013; Samuelsen and Potra 2020). While developing such a method for animal tooth enamel is viewed as important for future research, it is considered beyond the scope of the present study. Some research (Giovas et al. 2016) has suggested Pb isotopes could be problematic from some animals, such as smaller animals. However, as noted previously (Samuelsen and Potra 2020), most of the samples with issues in that study were modern animal teeth or snails, which are more likely to be contaminated with modern anthropogenic Pb. This present study utilized only ancient animal tooth enamel to avoid these issues and utilized acid leaching to clean the enamel.

Animal teeth were generally selected from ancient contexts greater than 20 cm below the surface to limit the impact of anthropogenic Pb, which did not affect ancient animals in the US and typically stays close to the surface (Samuelsen and Potra 2020). To avoid anthropogenic Pb, animal teeth were selected from these deeper contexts. There are exceptions, particularly two samples (AN174 and AN175) at Bonds Village site (22TU530) which are surface collections. This was necessary due to the lack of collections of buried faunal material at the site. Sampling this site was a top priority for this research since headless burials at the site had been previously suggested to be victims of Caddo raids from Crenshaw (Brookes 1999). Including these samples did not contradict the linear patterning defined by the other samples in northwest Mississippi. If the animal teeth are contaminated by soil Pb, but not anthropogenic Pb, then their Pb isotope values would still be an appropriate comparison to the human remains. If it is not impacted by anthropogenic Pb, the labile portion of soil is considered a viable source of biologically available Pb ratios for the geographic area under study (Eshel et al. 2020; Samuelsen and Potra 2020). However, uncontaminated ancient animal teeth are the preferred comparison.

2.2. Lab Methods

2.2.1. Tooth Drilling and Pre-treatment

The Caddo Nation of Oklahoma gave permission for destructive analysis on the human teeth tested in this study. Each tooth was cleaned through sonication in ultra-pure water for 30 minutes and dried overnight (Samuelsen and Potra 2020). A microscope was used for high accuracy drilling of the teeth and aided in the removal of dentin from enamel. The surface of the human tooth enamel was entirely removed (animal teeth surfaces were abraded (Turner et al. 2009) with a drill bit to clean and remove any potential contaminants. Any areas of discoloration were also entirely removed. A diamond wheel bit was used to cut approximately 50 mg of enamel from each animal tooth. Any cracks in the enamel were physically broken and both sides of the enamel along the cracks were removed with a drill bit. Small animal teeth often did not have 50 mg of enamel present, so amounts closer to 20 mg were used for these samples. Human enamel samples used smaller amounts of enamel (about 20 mg). Dentin was clearly removed from all human, deer, beaver, and bear samples. Every effort was made to remove all dentin from all samples, but in order to maximize enamel recovery, some small animal teeth may include small amounts of dentin. As an additional precautionary step, the enamel was sonicated for 60 minutes in ultra-pure water, sonicated for 30 minutes in 0.1 M high-purity acetic acid, sonicated in fresh acetic acid a second time for 5 minutes, and rinsed to a neutral pH with ultra-pure water. Samples were generally processed in batches of 25 teeth with multiple blanks.

2.2.2. Column Chemistry

Column chemistry (ion chromatography) was executed in a class 100 clean room at the University of Arkansas Radiogenic Isotope Laboratory. The samples were digested in 1 N HBr in acid-cleaned Teflon beakers. A portion of the sample was then removed for trace element analysis. The columns, containing 80 µl of Dowex 1X-8 Pb resin, were cleaned with 2 ml of 0.5 N HNO_3, followed by 2 ml of ultra-pure water. The columns were then conditioned with 2 ml of 6 N HCl. Each enamel sample was loaded and then the columns were washed three times with 1 ml of 1 N HBr. The Pb fraction from the sample was then eluted into a Teflon beaker using 2 ml of 20% HNO_3 and subsequently dried down on a hot plate inside a class 10 laminar flow hood for isotope analysis. The loaded sample and wash from the Pb column processing were collected in a separate Teflon beaker. The liquid in these beakers was dried down at 80°C on a hotplate and redigested in 1 ml of 3.5 N HNO_3 three times. Following the final digestion in 1 ml of 3.5 N HNO_3, the sample was used for Sr column chemistry. This included the leftover portions of samples previously processed for Pb isotopes (Samuelsen and Potra 2020), providing Sr samples from southwest Arkansas humans (HU1-HU36) and southwest Arkansas, Louisiana, and Mississippi animals (AN1-AN72 and AN149-AN156). The columns, containing 0.1 ml of Eichrom Sr resin, were cleaned with 2 ml of ultra-pure water. They were then conditioned with 1 ml of 3.5 N HNO_3 before being loaded with the sample digested in 1 ml of 3.5 N HNO_3. The sample was then washed with four 100 µl aliquots of 3.5 N HNO_3, followed by 1 ml of the same acid. Finally, the Sr fraction was eluted into an acid-cleaned vial using 1.8 ml of ultra-pure water. An additional 0.2 ml of 20% HNO_3 was added to make the Sr fraction solution 2% HNO_3. The sample and wash that passed through the column prior to elution was collected in a separate acid-cleaned vial. The samples were generally processed in batches of 25 samples with both blanks from the acid pretreatment step and column blanks for both Pb and Sr. Blanks from the acid pretreatment went through all the same processes as the samples (post-drilling).

2.2.3. Trace Element Analysis

Trace element analysis was performed on tooth enamel (including one modern tooth enamel sample) by taking portions from the pre-column solutions, placing them in a vial, and adding 2% HNO_3 until they were diluted 10,000 times. Trace element analysis focused on Pb and the elements identified by in previous research (Kamenov et al. 2018) as useful for assessing post-burial contamination: V, Mn, Fe, La, Ce, Nd, Dy, Yb, Th, and U. However, additional elements (Li, B, Al, Cr, Co, Ni, Cu, Zn, Y, Mo, Ag, Cd, Ba, Pr, Sm, Eu, Gd, Tb, Ho, Er, Tm, and Lu) were obtained (data S1). The trace element analysis was carried out on a Thermo Scientific iCAP quadrupole inductively-coupled plasma mass spectrometer (Q ICP-MS) and corrected to multiple concentrations of elemental standard ICP-MS-68A and corrected for drift using a standard bracketing method for each element (drift peak was assigned based on peak Ca concentrations within the samples). Replicate animal tooth enamel samples (n=3) tested reproducibility for each element. Certain elements provided more reliable results, similar to previous studies showing some elements in tooth enamel are more reproducible than others (Kamenov et al. 2018; Kohn et al. 2013). Some had deviations of less than 10% of the average concentration (V, Mn, Ni, Zn, Y, Ba, La, Pr, Ho, Yb, Pb, U), others were less than 15% (Ce, Nd, Sm, Gd, Er), others were less than 25% (B, Fe, Co, Cu, Eu, Tb, Dy), others were less than 36% (Al, Ag, Cd, and Tm), and the most unreliable (>36%) were Li, Cr, Mo, Lu, and Th (see data S1). Th had variable concentrations in the first two animal enamel replicates which is likely related to a known Th washout issue with the Q ICP-MS. This issue was fixed before the human tooth enamel and the other replicate sample were run, so it is suspected that Th was more reliable in the human enamel than suggested by this measure. Samples HU40, HU41, and HU43 were excluded from analysis since the trace element portion of these samples was clearly lab contaminated. The source (pipette) and timing (during trace element dilution) of this contamination was obvious and did not affect the isotopic portion of the samples as it occurred after the trace element portions were removed. HU42 was processed at a different time and therefore was not contaminated. Additional trace elements on soil leachates from previous work (Samuelsen and Potra 2020) are also included. Despite the lab contamination of the trace element samples, the Nd concentrations of HU40, HU41, and HU43 were above the Nd MTC but below three times the Nd MTC and are therefore included in the above MTC group for Pb isotope analysis.

2.2.4. Pb and Sr Isotope Ratio Analysis

The Pb fraction was analyzed on a Nu Plasma MC-ICP-MS using a desolvating system at the University of Arkansas' Trace Element and Radiogenic Isotope Laboratory (TRAIL). The dried down Pb samples were redissolved in 2% HNO_3 spiked with a thallium (Tl) standard created just before analysis (Kamenov et al. 2004). The Pb isotopes were corrected to NBS 981 Pb standard (Todt et al. 1996) values ($^{208}Pb/^{204}Pb = 36.7006$, $^{207}Pb/^{204}Pb = 15.4891$, $^{206}Pb/^{204}Pb = 16.9356$) using a time-based bracketing method. A standard was run after every fourth sample. All standard and sample Pb data were normalized to $^{205}Tl/^{203}Tl = 2.38750$ (Kamenov et al. 2004). All standards used for correcting data throughout different runs had higher standard deviation ($^{208}Pb/^{204}Pb = 36.667\pm0.012\ 2\sigma$, $^{207}Pb/^{204}Pb = 15.482\pm0.003\ 2\sigma$, $^{206}Pb/^{204}Pb = 16.929\pm0.003\ 2\sigma$). Samples were corrected to standards within runs and the standard deviation was lower within runs (average, $^{208}Pb/^{204}Pb \pm0.007\ 2\sigma$, $^{207}Pb/^{204}Pb \pm0.002\ 2\sigma$, $^{206}Pb/^{204}Pb \pm0.002\ 2\sigma$). Given the small amount of Pb in many teeth, aiming to a consistent concentration in solution for all samples is generally not possible. Samples with the lowest concentrations were analyzed using time-resolved analysis. Given that for human teeth the entire surface of the tooth enamel wedge was removed and a lower amount of enamel was used, some samples had very low concentrations (data S1). The effect of lower concentrations was investigated on the Nu Plasma by repeatedly running multiple concentrations (80 ppb, 8 ppb, and 0.8 ppb) of the Pb standards as samples bracketed by 80 ppb Pb standard concentrations after every fourth sample. The Pb standards run as samples were corrected to the 80 ppb Pb standard using a time-based bracketing method.

The Sr fraction was similarly analyzed at TRAIL for all human and most animal samples AN1-AN24 and AN57-AN180. Samples AN25-AN56 were analyzed at the University of Illinois Urbana-Champaign also using a Nu Plasma HR (data S1). The analysis program used at both locations corrected for any detected interference from Rb, Kr, and BaAr. The Sr isotopes were corrected to SRM 987 standard value ($^{87}Sr/^{86}Sr = 0.71025$) using a time-based linear bracketing method. All standard and sample Sr data were normalized to a ratio of $^{86}Sr/^{88}Sr = 0.1194$. Samples were diluted in 2% HNO_3 until they matched the standard concentrations, which were run at around 15v on ^{88}Sr. Blanks processed through all procedures and column blanks had Pb concentrations that were less than 5‰ of human enamel samples (7.5‰ animal) used in linear patterning analysis and less than 1‰ for all Sr samples.

2.3. Selection of Low Pb Concentration Thresholds for Isotope Analysis

Multiple concentration Pb standard runs showed that there were no significant problems in accuracy or precision with the 80 ppb (~0.450 v on ^{204}Pb) and 8 ppb (~0.045 v on ^{204}Pb) standards. However, the 0.8 ppb (~0.0045 v on ^{204}Pb) standard showed a dramatic decrease in accuracy and precision (**Fig. S1**). This made it clear that low concentration samples would cause local individuals to appear non-local in a patterned way. The pattern consisted of a trend that directly affects linear pattering analysis because it is nearly perpendicular to the linear patterning represented by the animals in southwest Arkansas (**Fig. S1**b). This would have great effects on the human data, pushing otherwise local samples outside of the local range. In one bivariate comparison (**Fig. S1**b), it would most likely result in samples appearing below the southwest

Arkansas animals, causing them to appear non-local and as though they originated from another region. While the accuracy could potentially be corrected for, the great lack of precision would undermine the reliability of any comparisons. It became apparent that human samples under about 0.025v on ^{204}Pb had significantly decreased accuracy and precision. Given the potential for incorrect interpretations during linear patterning analysis, a strict threshold of 0.025v on ^{204}Pb was used for the humans. This was determined to be less of a factor for the animal teeth since the increased variability would not affect interpretations, so a threshold of 0.015v on ^{204}Pb was used for these samples. Few animals (n=13) fell below the thresholds because of the greater amount of enamel used compared to human samples. Animal teeth between 0.025v and 0.015v did not contradict the general patterns whereas some humans in that range did due to the patterned way accuracy and precision were affected.

3. Results

3.1. Linear Patterning Analysis of Pb and Sr Isotopes

The results show that the skulls and mandibles are consistent with the local Pb isotope fingerprint defined by the southwest Arkansas animal tooth enamel. Linear patterning analysis of Pb isotopes (Fig. 2) from the skulls and mandibles (both above and below the Nd MTC) and southwest Arkansas animals show that they are consistent with animals from surrounding sites in all 15 bivariate graphs (**Fig. S2**), but generally not consistent with local Crenshaw humans and animals. The fact that the skulls and mandibles mostly match the animals from surrounding sites rather than the animals and articulated humans at Crenshaw is consistent with a dispersed settlement pattern. This suggests the burial practice may reflect the ritual treatment of surrounding populations' remains in a regional cemetery. The fact that the skulls and mandibles don't match Crenshaw as well as surrounding sites also supports the conclusion that the Pb in the ancient human tooth enamel is uncontaminated. One sample (HU62) is slightly outside the range defined by the animals in one graph (Fig. 2), but this sample is at the lower end of the voltage threshold (0.0273v on ^{204}Pb) and deviates the same way the lowest concentration standards do for that ratio comparison. The difference is within two times the standard error of the sample, making the difference insignificant. It is worth noting that no significant difference was seen between the skulls and mandibles below the MTC and those up to 4.34 times the Nd MTC. The samples below the MTC tended to have lower ratios, but this is an artifact of the higher voltage threshold (0.025v). When a lower voltage threshold (e.g. 0.010v) is used, both samples above and below the MTC have higher ratios. This suggests those samples have not been significantly modified by contaminant Pb.

The results also show that the skulls and mandibles are definitively not from most other tested regions. Comparisons between the skulls and mandibles and south Illinois animals show that the skulls and mandibles are non-local to south Illinois (Fig. 3a). The linear patterning of animal teeth from south Illinois is clearly different from the skulls and mandibles. Sampling in southeast Missouri was limited to a single site (Powers Fort), so interpretations are limited. However, the animals from southeast Missouri are separated from the skulls and mandibles and show a much greater perpendicular range, suggesting the skulls and mandibles are non-local to this area (Fig. 3b). Comparing the skulls and mandibles to Oklahoma animals very clearly shows that the animals are extremely different from the skulls and mandibles (Fig. 3c). This indicates the skulls and mandibles are non-local to Oklahoma and do not come from this portion of the Southern Plains. Northwest Louisiana animals are also distinguished from the skulls and mandibles except for a few samples that are close to each other (Fig. 3d). The differences, however, are very strong and indicate the skulls and mandibles are not coming from northwest Louisiana.

The results from other regions are sometimes less definitive, but the vast majority of skulls and mandibles are inconsistent with their Pb isotope fingerprint. Northwest Mississippi animals have a linear pattern that is close to the skulls and mandibles but is still differentiable (Fig. 4a). One of these sites (Bonds Village) included headless burials that were previously interpreted as possibly being victims of raids from Crenshaw (Brookes 1999). The Pb isotopes strongly suggest they are not coming from this area. As might be expected given their very similar geology, northeast Arkansas is similar to northwest Mississippi but does have some overlap with the skulls and mandibles in some places (Fig. 4b). However, the linear patterning shows the lower values are not represented in the skulls and mandibles suggesting they are not coming from this area. This is further supported by the narrow range of the Sr isotope data. Animal teeth from Texas show a different linear pattern than the skulls and mandibles and have many Pb isotope ratios that are inconsistent with them (Fig. 4c). There is a significant area of overlap. However, it is considered very unlikely that the skulls and mandibles were coming from Texas since none of them have the lower isotope ratios represented among the Texas animals. Still, this Pb data alone cannot conclusively show that at least some of the skulls and mandibles were not coming from Texas. The addition of Sr data was very helpful in this case.

The Sr isotopic background developed in this study shows that the Sr isotope ratios in Mississippi, northeast Arkansas, Oklahoma, and especially Texas (with many ratios below 0.708) are generally too low for most of the skulls and mandibles (Fig. 5). The Sr isotopes from

Illinois, Louisiana, and Missouri by contrast are too similar to distinguish these areas. Fortunately, the Pb isotopes clearly distinguished the skulls and mandibles from these regions. The southwest Arkansas animals clearly match the skulls and mandibles but have a slightly higher range. This might be expected as humans have a broader diet that may lead to less extreme ratios. It could also be because some of the sampled sites were too far away from Crenshaw to be within its sphere of influence. Sr isotopes from previous research (Esker et al. 2019; Hedman et al. 2018) confirm these results where sampled areas overlap.

Combining the Pb and Sr isotopes of the animal tooth enamel suggests the skulls and mandibles are not from any of these other regions. This provides a more definitive conclusion for regions where Pb isotopes alone were less clear. A direct comparison of the skulls and mandibles with Texas animals using both Sr isotopes and $^{208}Pb/^{204}Pb$ shows that they are clearly differentiable using this method (Fig. 4d). Since this comparison does not require as high accuracy and precision as the Pb isotope linear patterning analysis, it enabled many more skulls and mandibles to be compared (those with thresholds above 0.010v). This allowed for most of the skulls and mandibles (n=41) to be compared to Texas animals (also excluding the four highest concentrated Nd samples). Similar comparisons with northwest Mississippi and northeast Arkansas indicate the vast majority of the skulls and mandibles are non-local to those areas, but a few individuals could not be definitively distinguished.

3.2. Analysis of Soil Contamination

Previous work (Samuelsen and Potra 2020) showed that anthropogenic Pb contamination at Crenshaw is not a significant factor. However, soil Pb contamination still needs to be considered for each sample. This study focuses on Nd for two reasons. Nd had the strongest correlations with the most elements and Nd had the highest concentration (C) relative to the MTC, or C/MTC, (besides V) for almost every sample. The trace element concentrations of the human tooth enamel samples ordered by Nd concentration show that about half of the samples fall below all thresholds with the exception of V (Fig. 6a). The correlation analysis of trace elemental concentrations suggests that most enamel samples were not impacted by Pb contamination. Excluding the four samples with the highest Nd concentrations greatly decreased or removed any correlation with Pb concentrations. Therefore, they are interpreted to be the most likely samples to have been contaminated by the soil.

While the thresholds outlined in previous research (Kamenov et al. 2018) were useful, it became apparent that certain elements correlated with each other and that when stricter MTCs for Fe (60 ppm), Yb (0.005 ppm), and Th (0.005 ppm) were used, this correlation became more visually apparent (Fig. 6b). Some figures use modified MTCs, but these are always lower than previously established MTCs, are only used for display purposes, and the MTCs used are noted in the captions. Some elements clearly correlated with each other while others did not. Three groups of correlated elements are defined here because they more closely correlated with each other in the human tooth enamel: V and U; Fe, Mn, and Th; and the rare earth elements (REE) Nd, La, Ce, Dy, and Yb. While this grouping and analysis may prove to be useful elsewhere, it is important to note that other locations may not follow these same patterns with more complex chemical compositions and contaminants or where diagenesis is caused by particular chemical reactions. In this case, Pb correlated with every other element in the soil leachates except Ag and Mo (R^2<0.2), although some more than others (data S1). Some elements may be more or less likely to penetrate enamel during diagenesis, so lack of correlation could be caused by elemental differences. However, we saw little evidence of this with most elements in this study as they generally correlated with Pb in the contaminated samples. The elements that did not strongly correlate with Pb in those samples (R^2<0.5) are Li, B, Al, V, Co, Ni, Cu, Zn, Ag, Ba, and Th.

3.2.1. V and U

The first correlation group is V and U (**Fig. S3**). V correlated better with U than with any other element (R^2=0.33) and vice versa when the four highest concentrated Nd enamel samples (HU44, HU49, HU38, and HU45) were excluded. The results indicate that a V MTC of 0.11 ppm was not useful for detecting diagenesis in tooth enamel. V does not seem to have any relation to the other elements (Fig. 6). In addition, V and U seem to have little to no relation to Pb concentrations. When the four highest concentrated Nd samples are excluded, there is no correlation with U (R^2=0.00) or V (R^2=0.00).

3.2.2. Fe, Mn, and Th

The second correlation group is Fe, Mn, and Th. Fe moderately correlated with Mn and Th, although Mn and Th did not correlate well (Fig. 7). This is also visible when comparing them on an MTC graph where they increase at similar rates (**Fig. S4**). Fe, Mn, and Th were placed in a correlation group despite Fe and Th correlating well with REEs in enamel. This is because they increased at a different rate than REEs (similar to Mn) and they correlate less well than REEs do with each other. Enamel Fe, Mn, and Th correlations of with REEs were significantly reduced when excluding the four highest concentrated Nd samples (Fe R^2≈0.10, Mn R^2≈0.10, and Th R^2≈0.40). Correlations between Fe, Mn, and Th are similar in soil and when all enamel samples are included but drop when the four highest Nd concentration enamel samples are excluded (Fig. 7). Similar to U and V, these three elements correlated moderately well with Pb concentrations

(R^2≈0.45), but once the four highest Nd samples were excluded, the correlations dropped considerably (R^2≈0.10). This lack of correlation with Pb concentrations in the remaining samples suggests they lack significant Pb contamination.

3.2.3. Rare Earth Elements: Nd, La, Ce, Dy, and Yb

The third correlation group is Nd, La, Ce, Dy, and Yb (Fig. 8). These elements are commonly used in studies evaluating diagenesis in fossils (Kohn et al. 2013). The correlation between these elements in soil leachates (R^2≈0.99) and tooth enamel samples (R^2≈0.96) is extremely strong and can be explained by them all being REEs with similar atomic masses (Fig. 9). This correlation is only slightly reduced when the four highest concentrated Nd samples are excluded, but Dy and Yb correlations are significantly lower. This is consistent with REE correlation comparisons to modern uncontaminated Idaho bear and carnivore tooth enamel (**Fig. S5**), where Nd, La, and Ce (LREE) correlate less well with Dy and Yb (MREE-HREE). The similarly very high correlations between all REEs in soil leachates and the four contaminated ancient human tooth enamel samples suggest that soil has affected those four teeth. By contrast, the lower correlations between LREE and MREE-HREE in the "uncontaminated" ancient human tooth enamel and the modern animal tooth enamel suggest that those samples have retained their biological *in-vivo* concentrations. Unfortunately, the biological processes that result in these elements being deposited in tooth enamel are not yet well understood (Kohn et al. 2013). This aspect of the data, if verified further, could serve as a check on the validity of higher MTCs.

When the MTCs for all other REEs are adjusted, they follow Nd very closely (Fig. 8b). Another similarity between these REEs is that they are expected to have very low concentrations in tooth enamel (Kamenov et al. 2018), so any appearance of soil contamination is likely to have a major effect on the concentrations of these elements. By contrast, Fe and Mn can have high, naturally occurring concentrations in tooth enamel. Therefore, contamination from the soil may be less evident as the increased concentrations may not be discernably different from the natural variation within a population. For example, Fe and Mn concentrations in soil leachates were less than 9 and 11 times the MTC for tooth enamel, respectively, while Nd concentrations in soil leachates were sometimes greater than 125 times the MTC (**Fig. S6**).

A linear comparison with adjusted MTCs clearly shows where concentrations surge (Fig. 8d). When plotted on a linear scale, the gradual increases of concentrations show that soil contamination was not clearly apparent until Nd passed five times the MTC. At that point, several elements had passed the thresholds and concentrations drastically increased for the three samples with the most Nd. Considering the miniscule amounts of some of these elements in tooth enamel and the relatively large concentrations of some of these elements in the soil, the drastically increased concentrations for these last three samples display the clearest evidence of post-burial soil contamination. Strong increases of La and Ce in the fourth sample hint that it was affected as well.

The only elements that have any clear correlation with Pb concentrations in tooth enamel are REEs (Fig. 9). They generally correlate strongly in soil leachates ($R^2 \approx 0.62$) and tooth enamel ($R^2 \approx 0.70$), but this correlation is severely reduced when the four highest concentrated Nd samples are excluded ($R^2 \approx 0.29$). Excluding additional high concentration Nd samples (even all those above the MTC) sometimes reduces this correlation in some elements, but also increases the correlation in other elements. It is therefore interpreted that the low correlation between the REEs and Pb concentrations is likely due to *in-vivo* caused correlation while the higher correlation is more suggestive of soil contaminants. This suggests samples below an Nd MTC of 4.34 (0.25 ppm) have not been subjected to significant Pb contamination.

3.2.4. Other Elements

While not included in the correlation grouping analysis, Y and most other REEs (Pr, Sm, Eu, Gd, Tb, Ho, Er, and Tm) behaved similarly to Nd and should be similarly useful for detecting contamination (**Error! Reference source not found.**). Concentrations of Li, B, Al, Cr, Co, Ni, Cu, Zn, Mo, Ag, Cd, Ba, and Lu were also measured (**Fig. S8**). These elements did not generally have a strong relationship with contamination, although some of these elements also had poor reproducibility in animal enamel replicates. While concentrations did increase for some of these elements for the four highest concentrated Nd samples (like V, Mn, Fe, and U), they generally had many other samples with similar or higher concentrations of these same elements. This is of particular importance for Ba, which some research has used to assess contamination related to Pb isotopes (Beherec et al. 2016; Eshel et al. 2020). The use of these elemental concentrations alone could cause preserved samples to be identified as contaminated and contaminated samples to be identified as preserved. However, this is based only on the evidence at the Crenshaw site. Sites containing particular contaminants (e.g. a nickel mine) or chemicals could make these elements more useful (Kamenov et al. 2018). There are a few samples with high peaks of individual elements (like Al, Co, Ni, and Cu) which could indicate contamination, but since they contradict the rest of the elements, there may be a reason for these peaks outside of post-burial contamination (e.g. *in-vivo* exposure or lab contamination). For example, exposure to Cu could relate to *in-vivo* exposure to copper objects like those deposited in burials at the site.

3.3. Validation with Pb Isotopes from Enamel and Soil Leachates

When the Pb isotope data is compared with the analysis of contamination using trace element data, several points suggest the correlation analysis was successful at identifying contamination and the lack thereof. A 0.010v on ^{204}Pb threshold was used in this analysis as it did not involve linear patterning analysis of Pb isotope ratios. A simple comparison between the skulls and mandibles above and below the Nd MTC, excluding the four highest concentrated Nd samples, shows strong consistency in Pb isotope ratios (Fig. 10a). This suggests there is little reason on the basis of Pb isotopes to suspect those samples up to 4.34 times the Nd MTC have been significantly affected by contaminant Pb.

A Pb isotope comparison of soil leachates and the skulls and mandibles from the WSA suggests that the thresholds identified in the correlation analysis of trace elements successfully identified samples most likely to be affected by contamination (Fig. 10b). Both samples above the MTC and below the MTC do not generally look like the WSA soil average. The large differences within clusters suggest that the *in-vivo* Pb isotopes are being preserved, verifying that using a higher Nd MTC (4.34 times the original MTC) seems to be identifying uncontaminated samples. Given that the sample of modern human tooth enamel is very limited (Kamenov et al. 2018), it is worth noting that modern omnivore tooth enamel has previously been shown to have Nd concentrations as high as five times the original Nd MTC (Kohn et al. 2013). However, direct comparison between trace elements in human and animal tooth enamel should be made with caution until the differences are better understood. Many of the samples furthest from the soil average (both above and below the soil average) include those above the Nd MTC. The results show that the samples with Nd concentrations greater than 4.34 times the Nd MTC are generally close to the WSA soil average. This suggests this threshold is appropriately identifying the samples most likely to have been contaminated. However, these samples are not very different from uncontaminated samples from the same cluster, suggesting that Pb contamination may not be significantly modifying the potentially contaminated samples' *in-vivo* values. This is also supported by HU44 B, the highest concentrated Nd sample, which has a high Pb isotope ratio compared to the soil average. It is interpreted that this sample has an even higher *in-vivo* isotope ratio. Despite it having the clearest evidence of contamination, it appears that not enough contaminant Pb was added to overwhelm the original isotope ratio. It was likely moved downward to a lower ratio through the addition of lower ratio soil Pb contamination. This suggests that the other samples, with much less evidence of contamination, are unlikely to have been heavily modified from their *in-vivo* values.

The Pb isotope ratios from the NSA show a similar pattern (Fig. 10c). The skulls and mandibles from both NSA 2 and NSA 8 maintain different Pb isotope ratios from the soil for samples above and below the MTC. None of these samples were over four times the Nd MTC. NSA 1 was buried immediately next to NSA 2, allowing it to be compared to soil from NSA 2. NSA 1 also has ratios that are consistently different from this soil and includes samples from both above and below the MTC.

The similarity between the WSA skulls and mandibles and the WSA soil average might suggest general contamination of the samples, but this is contradicted when comparing the WSA to the NSA (Fig. 10d). The skulls and mandibles from both areas have ratios similar to the WSA soil average despite the NSA having higher ratio soil. In fact, the NSA remains match the WSA soil better than the WSA remains. What this suggests is that the WSA and NSA remains were coming from places with ratios that happen to be similar to the WSA soil. This is supported by the comparisons to southwest Arkansas animal teeth (Fig. 2), as many of the surrounding sites have similar Pb isotope ratios to the WSA soil.

4. Discussion

4.1. Geographic Origins of the Crenshaw Skull-and-Mandible Cemetery

The multiregional Pb isotopic background constructed using ancient animal tooth enamel illustrates that Pb isotopes are regionally sensitive, and that linear patterning analysis can successfully identify non-locals where Sr alone could not. Similarly, the Sr isotopic data were able to aid the Pb isotopic data in distinguishing additional individuals from the animal enamel isotopes of other regions. Illustrating this facilitates future research by providing a method and model that has been shown to successfully distinguish the geographic origins of ancient human remains when other approaches failed (e.g. Sr alone or using whole rock backgrounds). This encourages future studies to utilize Pb isotopes from ancient animal tooth enamel and linear patterning analysis so they can be successful at distinguishing human remains from different regions. Using limited sample sizes within sites or over large areas may distort the Pb isotope linear patterning and lead to the lack of any such patterning being evident. Therefore, sampling multiple samples per site and multiple sites per region is recommended to properly document the linear patterning within regions.

The results of this study indicate or strongly suggest that the skull-and-mandible cemetery is made up of individuals who did not come from the Southern Plains (Texas and Oklahoma), the Mississippi Valley (Northeast Arkansas, Northwest Mississippi, Southeast Missouri, and South Illinois), or Northwest Louisiana. The biologically available Pb method and the Pb isotopic background produced were successful at distinguishing the skulls and mandibles from most other regions. The Sr isotopes complemented the Pb isotopes in some cases where the Sr isotopes of the animals in other states were generally too low for the skulls and mandibles. By contrast, the skulls and mandibles have both Pb and Sr isotope ratios that are consistent with animals from sites that surround Crenshaw. Since the background sampling was limited to certain areas, the data are not able to uniquely identify an area of origin. However, the skulls and mandibles were determined to be local to southwest Arkansas and were interpreted to be non-local in all other tested regions.

Given this finding and other archaeological information (Samuelsen 2020), it is clear that the skull-and-mandible cemetery represented a great expansion of a preexisting burial practice between 1200 and 1400 CE. The Caddo had a suite of burial practices reflecting a larger population than can be described by only focusing on shaft burials in mounds. This included articulated burials, burials in various states of disarticulation, and at least a few cremations. The evidence shows that there was a co-occurrence of the skull-and-mandible cemetery at Crenshaw, the adoption of maize, public building-oriented ceremonialism, potential charnel houses or crematoriums, and the lack of burials at occupied surrounding sites. There is much evidence that other types of secondary burials were occurring in this region which could be related to the transfer of the dead to sacred locations for final burial, such as Crenshaw or Mineral Springs. The data also suggest that while the practice of skull burial seems to have become dominant at this time, examples can be seen during earlier periods and at multiple sites, including Crenshaw itself. More ornate shaft burials in mounds and in the surrounding fields also increased during this period. Therefore, the practice of skull and mandible burial was simply expanded at this time as part of a larger set of changes in the Caddo cultural system, including changes in diet, settlement patterns, ceremonialism, and the area of ritual influence.

The dietary data and biological traits (Samuelsen 2020) could suggest that the skulls represent family groupings while the mandibles represent a large cross section of the population. This is reinforced by the Pb and Sr isotopic data where the isotopes are more alike within skull clusters than between them. This is consistent with the collection and potential display of the remains of particular lineages within the community for some time prior to burial. Structures with skull pieces, teeth, and ash pits could represent places where these remains were collected, processed, or displayed, including one such structure excavated in the proximity of the skulls and mandibles (Samuelsen 2020). The collection, processing, and potential display of these remains suggest the Caddo were participating in a form of ancestor veneration that emphasized the importance of certain families within the community, at least within those family lineages themselves. While ancestor veneration, ritual, and ceremony all played major roles in the expansion of this burial practice, the expansion of the practice likely also had a functional reason. The severing of the head or mandible allowed for a larger and more geographically dispersed community to have their remains buried at Crenshaw, without having to transport entire bodies over long distances.

4.2. Correlation Analysis: *In-vivo* or Soil Contamination

Correlation analysis between trace elemental concentrations and Pb concentrations indicated the four highest concentrated Nd samples are contaminated. The lowest of the four contaminated samples has a Nd C/MTC value of 4.34. Samples below this value do not show evidence of significant modification of Pb concentrations in tooth enamel because the samples show little evidence of the strong correlations that would be expected from post-burial contamination. This was validated by comparisons of Pb isotope data from enamel and soil leachates. It is hypothesized that soil contamination should result in stronger correlations within and between correlation groups, while *in-vivo* exposure (biological processes) should result in weaker correlations, particularly between correlation groups.

The data generally support this hypothesis. The contaminated enamel samples have correlated increases of elements within correlation groups and are consistent with the correlations seen in the soil leachates. Soil leachate and enamel comparisons suggest that clear evidence of post-burial soil contamination is reflected by major increases to most elements across different correlation groups because soil has significantly higher concentrations of these elements than enamel. Soil contamination, resulting in strong correlations within and between correlation groups, can be clearly seen by comparing REE and Pb concentrations when only including the four highest concentrated Nd samples (**Fig. S9**). The R^2 values are as high as 1.00 for some elements and similarly high correlations are seen between Pb concentrations and Fe, Mn, and U. All of these, except for Yb, are statistically significant ($p<0.05$) despite representing only four samples. Correlations are not very strong with V or Th. However, the fact that Pb correlates and there are very strong correlations within and between different correlation groups (REEs, Fe, Mn, and U) is very suggestive that this relates to post-burial contamination of Pb. While it is noted that some elements may be more or less likely to penetrate enamel during diagenesis, there was little evidence of this with the elements highlighted in this study as all elements (excluding Th) correlated strongly with Pb in the samples identified as contaminated

(Fig. S9). Other elements that correlated strongly (R^2>0.8) include Cr, Mo, Y, Cd, Pr, Sm, Gd, Tb, Ho, Er, Tm, and Lu.

This contrasts with *in-vivo* exposure where correlation may be expected to be restricted to within correlation groups. This may be due to common natural occurrences of these elements or because of the way the body deposits these elements in tooth enamel, although how the body does this for some elements is not yet well understood (Kohn et al. 2013). When excluding the four contaminated human tooth enamel samples, the correlations are weaker and appear very similar to uncontaminated modern Idaho bear and carnivore tooth enamel (**Fig. S5**). With *in-vivo* exposure, Pb and other elements go through a variety of biological processes before being deposited in tooth enamel (Gulson et al. 1998). Therefore, correlations may still be expected but may be weaker. However, exposure to Pb pollution or metals during a person's lifetime could have an effect on *in-vivo* correlations between Pb and other elements.

4.3. Indigenous Maximum Threshold Concentrations

The results suggest that higher thresholds may be appropriate for different populations. While the analysis concludes that the Nd MTC for this population should be about four times the values expected in modern human tooth enamel, it is concluded that the V MTC should be more than an order of magnitude higher. This would mean that this ancient indigenous population had greater *in-vivo* exposure to many elements than has been shown among modern populations or ancient indigenous populations from Florida (at least those documented thus far). It is hypothesized that this is due to two factors: 1) different elemental exposure for modern and ancient indigenous populations and 2) different elemental exposure for different indigenous populations based on the soil content where the people grew up.

This may be particularly true for ancient populations in the US if they were significantly exposed to some type of soil ingestion or leaching of these elements from pottery vessels or other sources. Indigenous populations around the world are known to be much more likely to directly ingest soil either through intentional (geophagia) or unintentional means (Simon 1998). Intentional soil ingestion can be practiced in rituals, soil can be used as an ingredient in food preparation, and soil can be consumed for social reasons. These behaviors can be more prevalent among pregnant mothers and young children. Indigenous populations, particularly children, can also be more exposed to accidental soil exposure through clay floors in houses and many outdoor activities (Simon 1998). Many of these factors do not apply to most modern populations. The interiors of pottery vessels in the Caddo Area are often very rough and porous and are expected to be a potential source of exposure to some of these elements. Laser ablation of cross sections of ancient sherds has shown a depletion of V on the surface (Stoner and Shaulis 2021), which could be related to post-burial leaching, but may also be occurring during food preparation. While this is a relatively under-investigated topic in ancient wares, elemental exposure through leaching has been demonstrated with some modern and much less porous ceramic wares (Dinh et al. 2018).

The high concentrations of V in the ancient human tooth enamel and the lack of correlations for most elements related to V are interpreted to be for one of two potential reasons. 1) V was high *in-vivo* in this ancient population and the contamination of V is indistinguishable from the variability within the population (i.e., signal-to-noise ratio). For this to be the case, the population at Crenshaw must have had significantly more exposure to V than the previously studied modern populations (Kamenov et al. 2018). The lack of V correlation with other elements is highly suspected to be due to high *in-vivo* concentrations in V. If this is the case, then a V MTC could potentially be more useful in other studies if populations had significantly less exposure to V *in-vivo*. The difference in V concentrations between ancient Florida populations and those at Crenshaw can potentially be explained by the higher content of V in southwest Arkansas soils (Smith et al. 2019). Florida soils have unusually low V concentrations compared to the rest of the US. 2) The contamination of V has no discernible relationship to the contamination of other elements and therefore cannot be used as a reliable predictor of Pb contamination. If this is the cause, then V might not be useful in any study. Regardless, this does suggest that eliminating samples from analysis based solely on a V MTC may result in many uncontaminated samples being excluded and some contaminated samples being included, even in other studies.

The difference in V and REE concentrations between ancient Florida populations and those at Crenshaw can potentially be explained by the higher content of V and REE in southwest Arkansas soils compared to Florida soils (Smith et al. 2019). Modern animal tooth enamel has been shown to have V concentrations above the established MTC in some places where V concentrations are higher in the soil, but still well below what is reflected in some human tooth enamel at Crenshaw (Kohn et al. 2013). Therefore, there is evidence that the MTCs defined by previous research (Kamenov et al. 2018) may be appropriate for many areas, but some ancient populations may need higher MTCs for some elements.

If an MTC is modified, it should be done with evidence, like the evidence of correlations presented here. In the case of V, it is recommended that it not be used for assessing contamination of Pb. V, Mn, Fe, U, and many other elements were found to not be useful if they were used alone to assess contamination. Many studies have focused on V, U, and Ba in particular in bone and other materials and this analysis may bolster caution with relying on these elements alone (Kohn et al. 2013). However, this analysis studied human tooth enamel specifically and there are potential differences with bone and animal tooth enamel. The results and interpretations about trace element analysis' usability in detecting contamination of Pb in ancient tooth enamel may be applicable to other localities, but the present results are limited to Crenshaw. Therefore, other studies (Simonetti et al. 2021) may have related, but different findings related to which elements are most useful for identifying contamination depending on the soil contents and contaminants present at the site.

It is also possible that lower MTCs might be appropriate, like the lower thresholds used here for Fe, Yb, and Th. However, caution should be exercised if lowering thresholds would cause samples to be classified as contaminated when they would have otherwise been identified as uncontaminated. Modification of the MTCs without evidence could be dangerous as it could force samples to be included or excluded from analysis and greatly affect interpretations. A secondary variable to determine MTCs at particular sites may be needed, but a clear method for this has not yet been established beyond the correlation analysis utilized here. However, the results show different correlative expectations for Nd, La, and Ce (LREE) with Dy and Yb (MREE-HREE) for 1) soil leachates/contaminated samples (very high correlations) and 2) uncontaminated ancient human tooth enamel and modern animal tooth enamel (moderate-high correlations). This signature may be a validation that higher MTCs are justified and could be useful for future researchers to evaluate post-burial contamination of ancient human tooth enamel, possibly with some applicability to particular animal species as well. However, this needs to be verified with additional data so that the biological processes that result in the deposition of these elements in tooth enamel can be better understood.

5. Conclusions

This study evaluated the geographic origins of the Crenshaw skull-and-mandible cemetery to test if the ancient Caddo were committing large-scale acts of violence against neighboring regions. The inability to answer the questions surrounding the origins of this skull-and-mandible cemetery created starkly contrasting interpretations about the prevalence and extent of ancient warfare in the intersection between the Eastern Woodlands and the Southern Plains. The increased levels of violence in the Southern Plains and the Central and Lower Mississippi Valleys could have been related to interregional warfare with the Caddo. However, the evidence indicates that the skull-and-mandible cemetery represents a local or regional burial practice associated with Crenshaw's increasing ritual influence over surrounding areas. This, combined with the lack of other evidence of violence, suggests that 1200-1500 CE in the Caddo Area presents a contrast with neighboring regions as a time and place of relative peace. The evidence of warfare seen in these other regions is not the result of Caddo raiding parties. If interregional warfare was occurring at all, it does not appear to have involved the Caddo. This clearly changed sometime around European contact when tensions between the Caddo and other tribes boiled over. Instead, the practice of skull and mandible burial and potential storage or display of the remains in charnel structures is consistent with Native American practices related to ancestor veneration.

This study also provides scholars and the Caddo Nation of Oklahoma with a clear, research-based answer to the questions surrounding the cultural affiliation of the remains. Such positive collaborative relationships between tribes and archaeologists are critical for continued research in the US, particularly for isotopic studies which require destructive analysis on human remains. This study is one such example where the questions the tribe and researchers alike had about the remains drove the research and resulted in positive outcomes for all stakeholders.

Some studies have challenged the use of tooth enamel and the MTC method for isotopic studies (Tschetsch et al. 2020). However, the current results here suggest that the previously established (Kamenov et al. 2018) trace elemental MTC method (with modifications) was largely successful at verifying that ancient human tooth samples were uncontaminated. With correlation analysis, this study is able to successfully identify samples most likely to be contaminated. More research in identifying contamination in ancient tooth enamel is needed for Pb isotopes to be reliably used to evaluate ancient human geographic origins.

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Figures and Tables

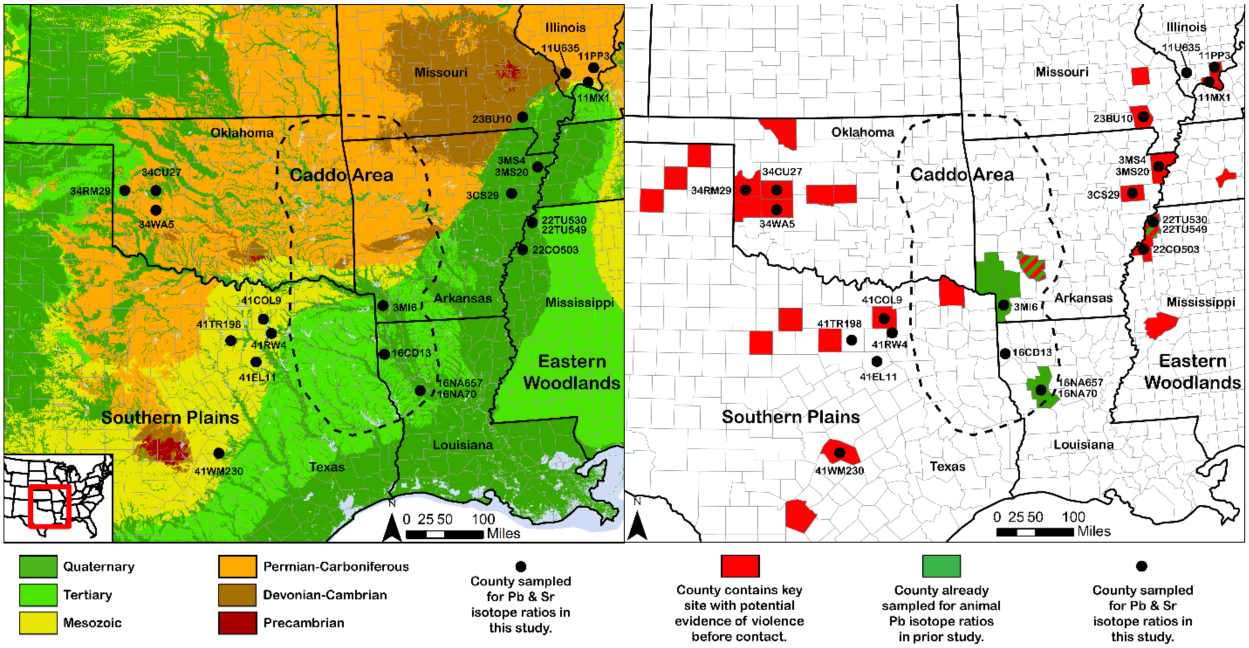

Fig. 1. Crenshaw and warfare in the southcentral US. Crenshaw is located in the Caddo Area on the edge of the Eastern Woodlands and the Southern Plains. (left) Geologies of sampled areas are shown. Counties sampled are marked with a black dot. (right) Counties with key sites having evidence of violence from the same time period as the skulls and mandibles are highlighted in red (see Supplementary Material). Counties previously sampled for Pb isotopes by Samuelsen and Potra (2020) are highlighted in green. Samples for Sr isotopes came from the both the newly sampled sites and those previously (*7*) sampled for Pb isotopes (green).

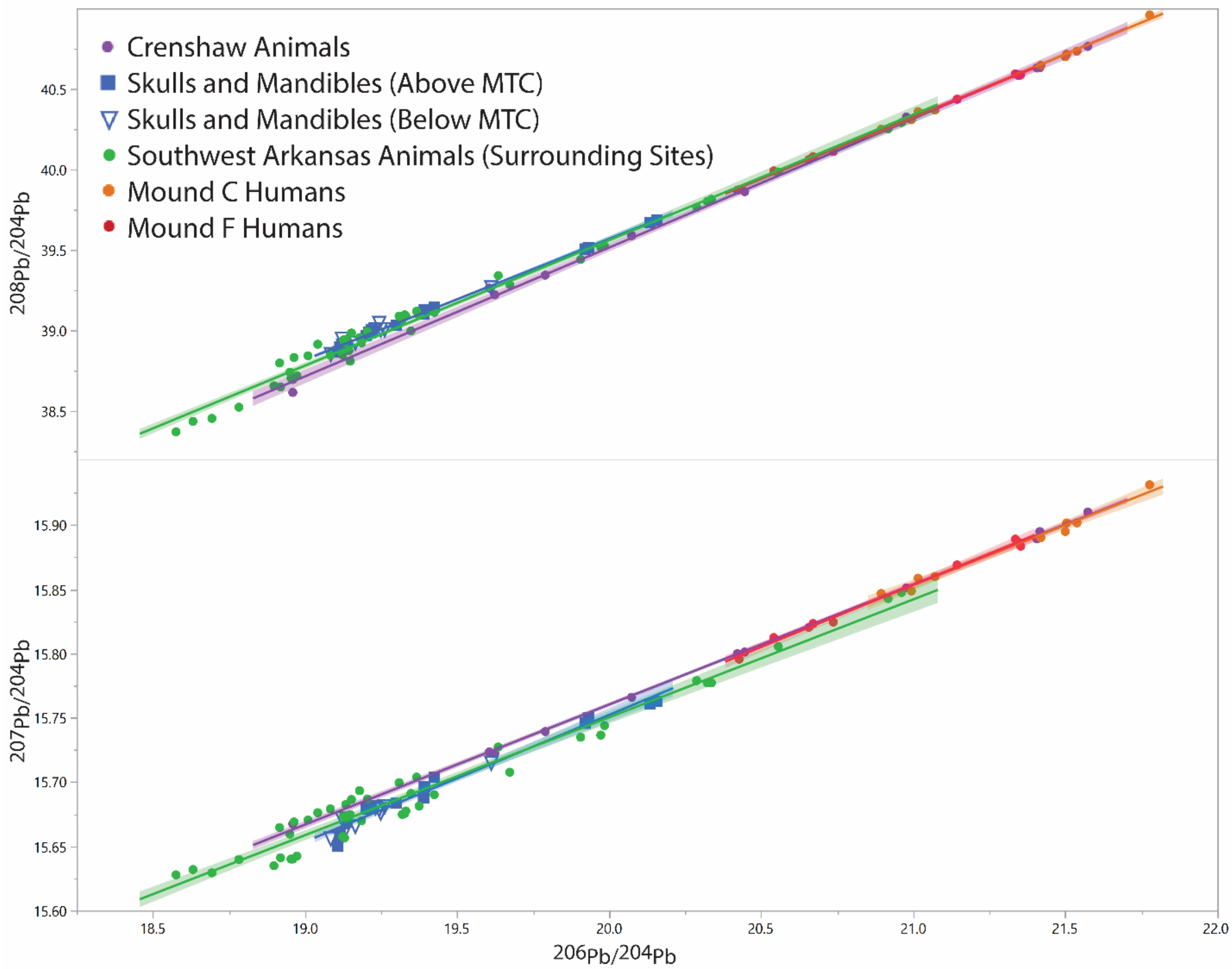

Fig. 2. Skulls and mandibles: local to southwest Arkansas. Linear patterning analysis of all 15 Pb isotope bivariate comparisons (two examples selected) shows the skulls and mandibles match southwest Arkansas sites in all comparisons. They generally match southwest Arkansas animals from surrounding sites better than the animals from the Crenshaw site itself. One sample slightly extends below the animals, but this is within two times the standard error, making the difference insignificant. The contamination analysis indicates that at least half the samples from the skull-and-mandible cemetery were not significantly contaminated by anthropogenic or soil Pb (see Analysis of Soil Contamination). This analysis suggests that the four highest concentrated Nd samples were contaminated, and less concentrated samples were not. Since the samples with Nd concentrations over the MTC are less clear, they are included in Pb isotope analysis with different symbols so that differences could be detected between the samples above and below the MTC.

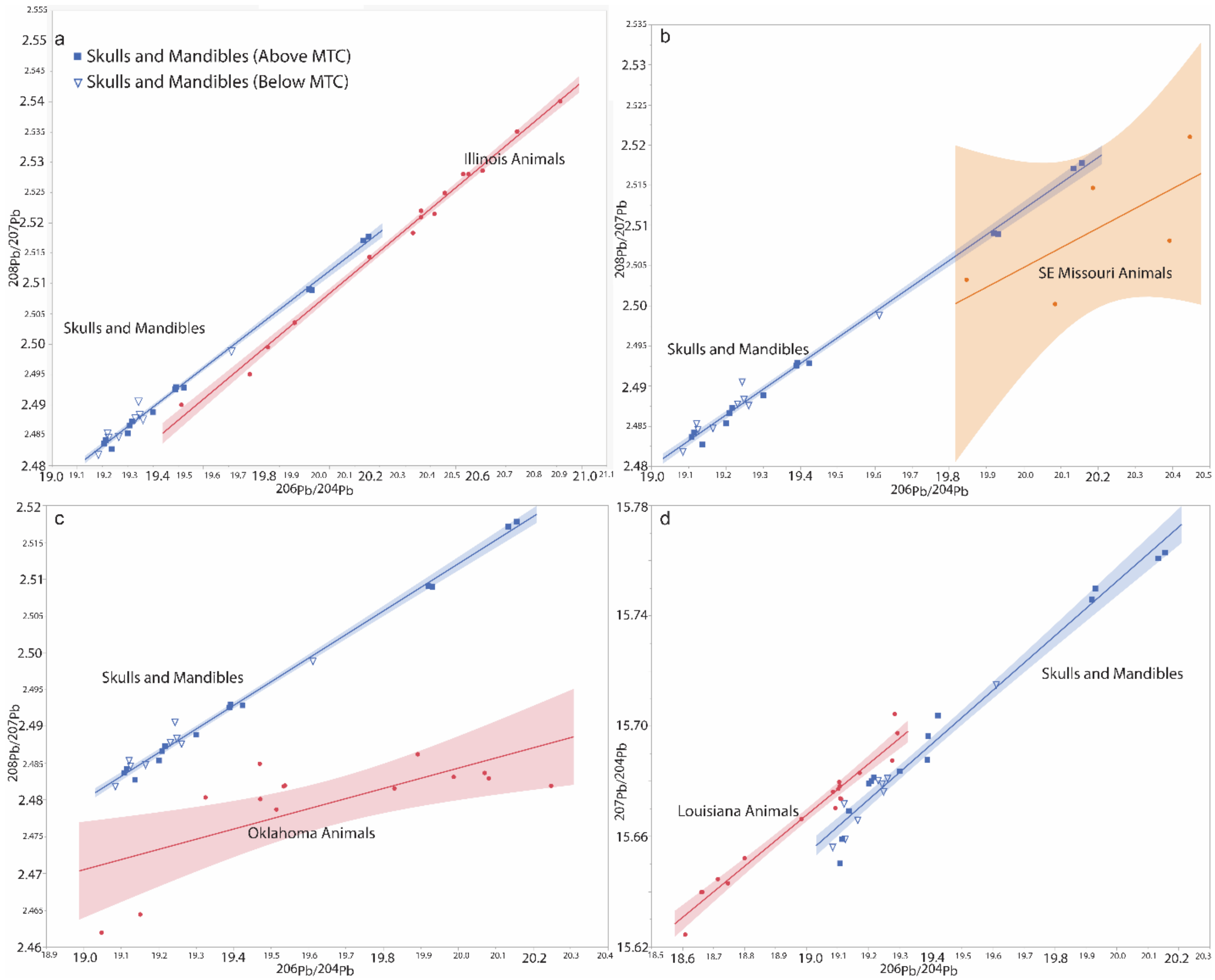

Fig. 3. Pb Isotopic Linear Patterns for Illinois, Missouri, Oklahoma, and Louisiana. Linear patterning analysis shows the skulls and mandibles have a different linear pattern than Illinois, Missouri, Oklahoma, and Louisiana animals. The Illinois animals also tend to have higher ratios. Missouri animals are a limited sample but are different from the humans. Oklahoma animals are clearly different. Louisiana animals maintain a different line, indicating they are not from this area. These results indicate the skulls and mandibles are not from these areas. An isoscape utilizing linear patterning analysis cannot be represented on a typical isoscape map since it is the linear pattern rather than a particular range or average isotope ratio that is used to assess the data.

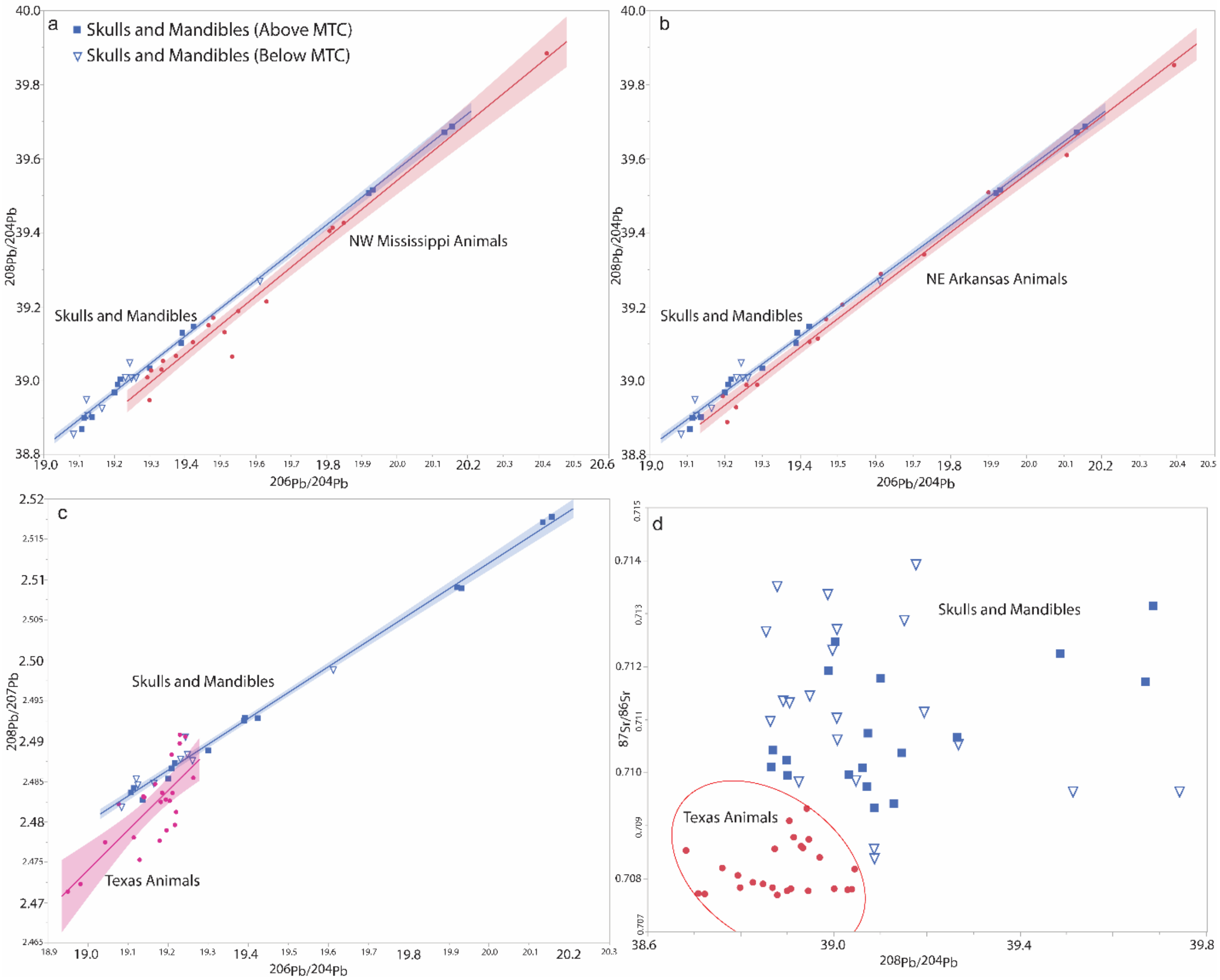

Fig. 4 Pb Isotopic Linear Patterns for Mississippi, NE Arkansas, and Texas. Linear patterning analysis of the skulls and mandibles with northwest Mississippi animals show they are similar, but the linear patterning and values are generally distinguishable. The NE Arkansas animals are similar and there is some overlap, but the linear patterning and lack of lower values among the skulls and mandibles suggest they are not coming from the same region. This is further supported by the Sr isotopes from northeast Arkansas having a very restricted range. (lower left) There is some significant overlap in the Texas animal Pb isotopic data. It is considered very unlikely that the skulls and mandibles would be coming from Texas and none of them have the lower values represented by the Texas animals. (lower right) Pb and Sr isotope comparisons to Texas animals. This definitively shows the skulls and mandibles should be classified as non-local to Texas. Since this comparison is not linear patterning analysis, a threshold of 0.010v on ^{204}Pb was used for both humans and animals. It is important to note that the skulls and mandibles would not have been differentiable in many cases without using the linear patterning analysis.

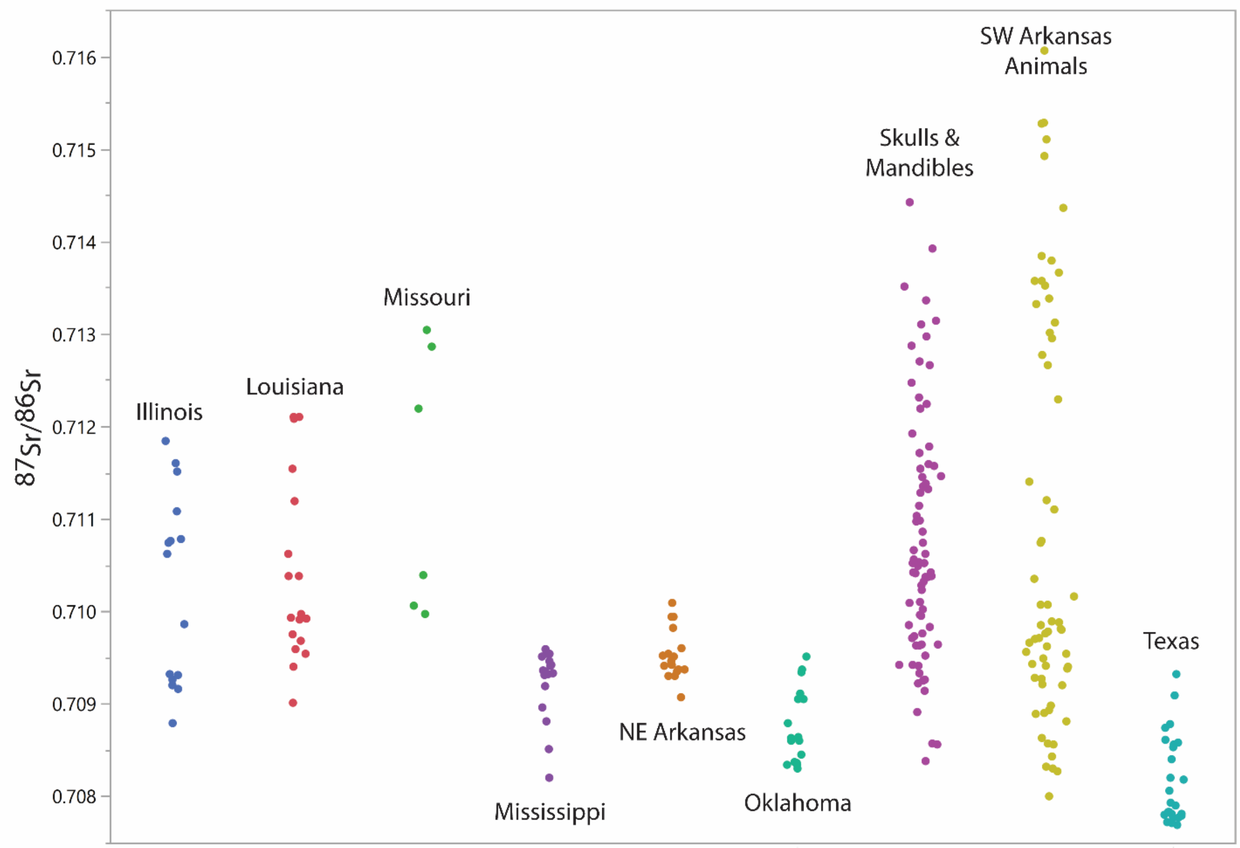

Fig. 5. Sr isoscape from ancient animal tooth enamel. The Sr isoscape is based on animal tooth enamel from south Illinois, northwest Louisiana, southeast Missouri, northwest Mississippi, northeast Arkansas, west Oklahoma, east Texas, and southwest Arkansas. The skulls and mandibles best match southwest Arkansas animals, but cannot be distinguished from Illinois, Louisiana, or Missouri. The Sr isotopes from Mississippi, northeast Arkansas, Oklahoma, and Texas are generally too low for the skulls and mandibles, particularly Texas with many values below 0.708.

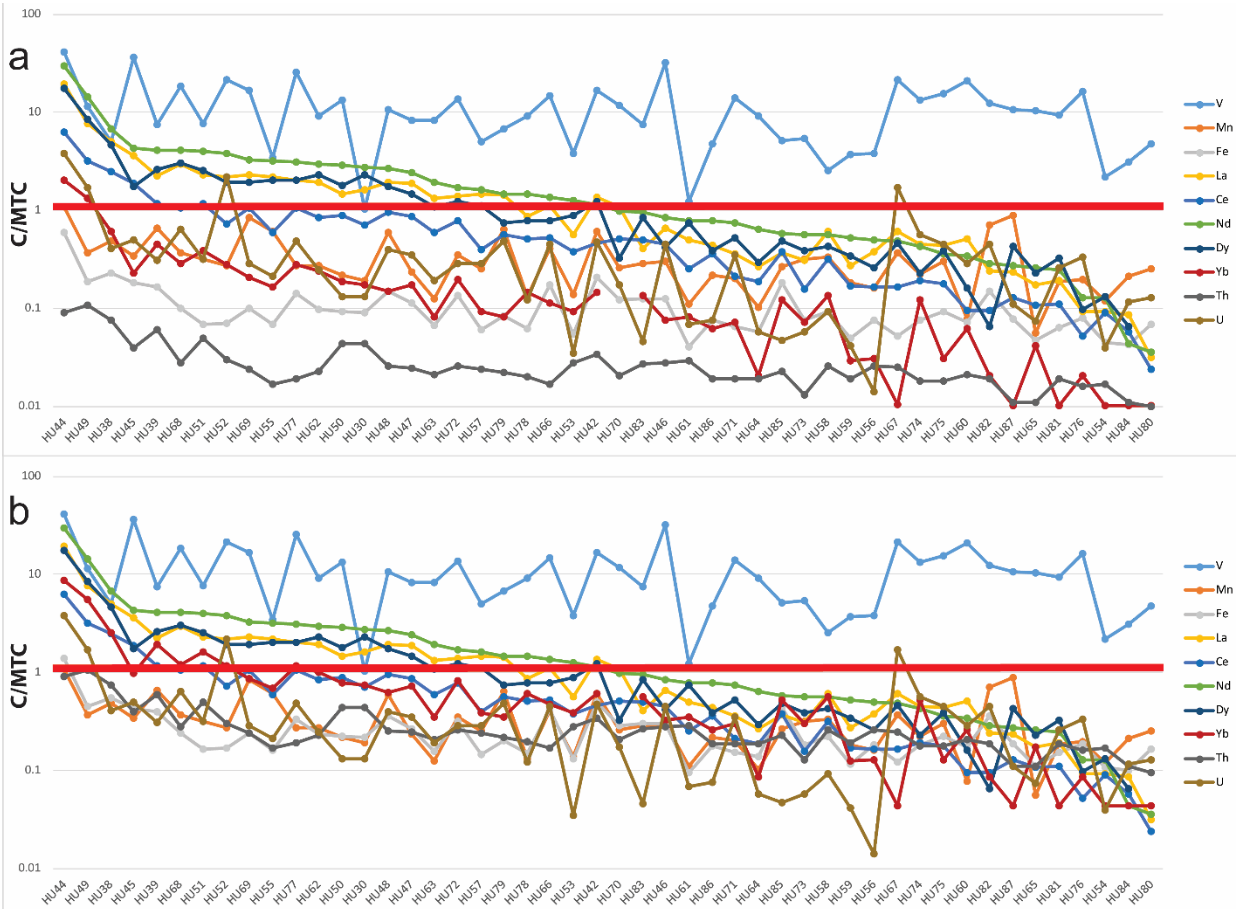

Fig. 6. Trace element concentrations of enamel. (a) Trace element concentrations, ordered by Nd concentrations, represented by concentration (C) over maximum threshold concentration (MTC) of each element. The MTCs used are those previously defined (*13*). (b) Trace element concentrations, ordered by Nd concentrations, with modified MTCs (Fe=60 ppm, Yb=0.005 ppm, Th=0.005 ppm) for display purposes. In general, REEs increase at similar rates and Fe, Mn, Th, and U increase at similar rates. V seems to have almost no relationship with the other elements.

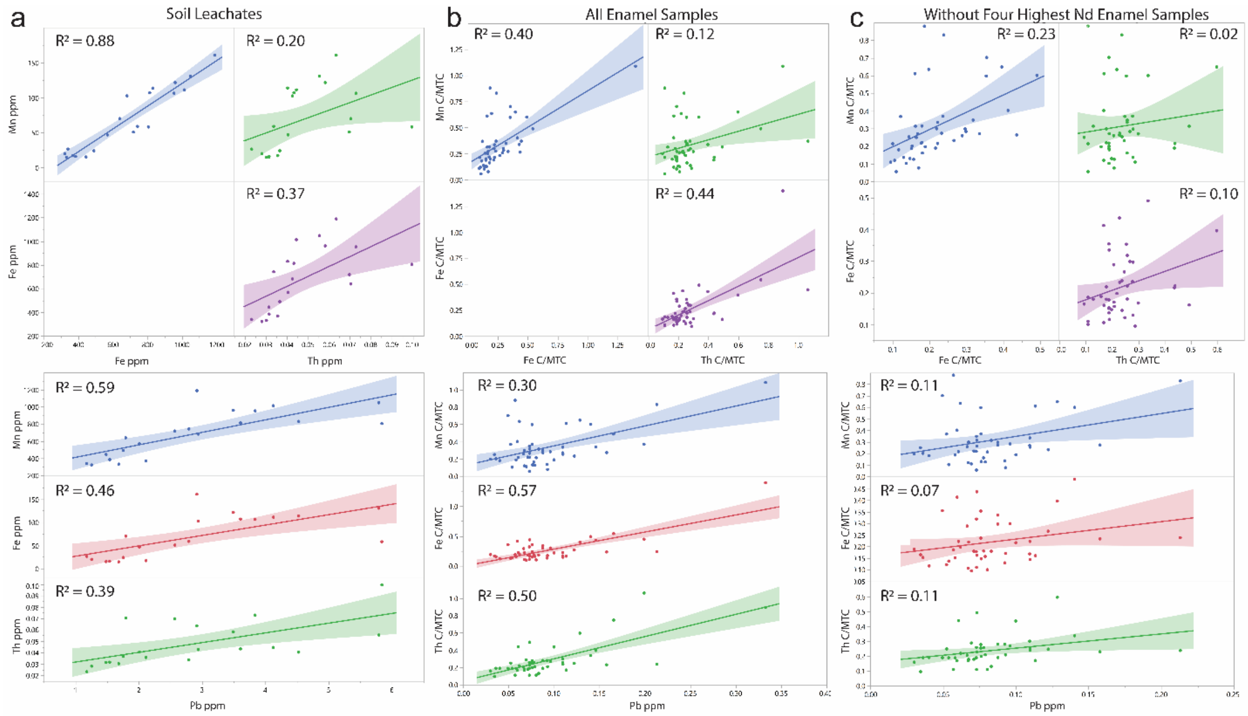

Fig. 7. Fe, Mn, Th, and Pb correlations. (a) Correlations between Fe, Mn, Th, and Pb in soil leachates from Crenshaw. (b) Correlation between Fe, Mn, Th, and Pb with all ancient human tooth enamel samples. (c) Correlation between Fe, Mn, Th, and Pb in ancient human tooth enamel with four highest concentrated Nd samples excluded. Comparisons show that correlations between all elements are very low when the four highest concentrated Nd samples are excluded.

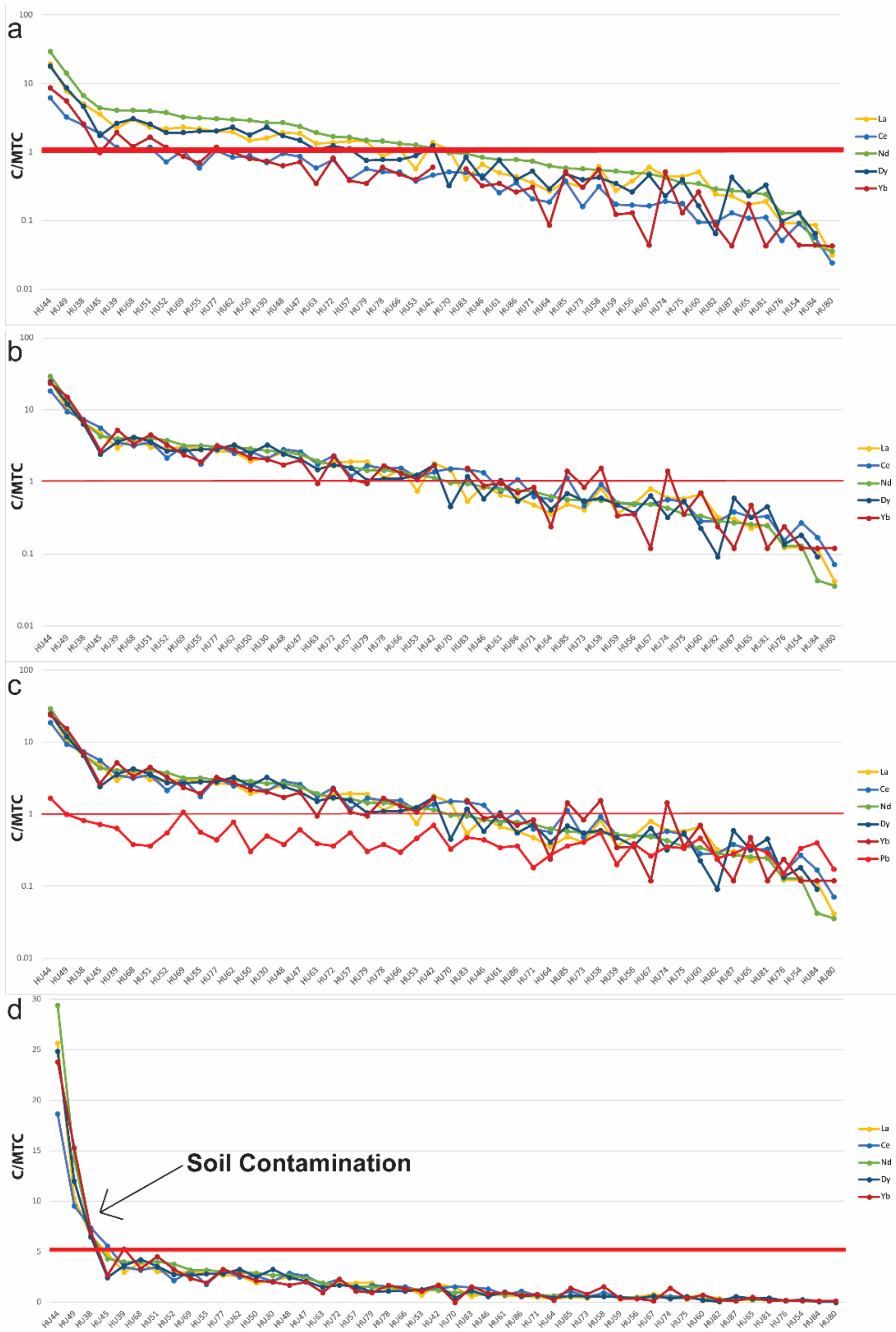

Fig. 8. REE C/MTC charts. (a) REE C/MTCs ordered by Nd concentrations and using original MTCs (*13*). (b) REE C/MTCs ordered by Nd concentrations and using modified MTCs (La=0.075 ppm, Ce=0.04 ppm, Dy=0.0064 ppm, Yb=0.0018 ppm). (c) REE and Pb C/MTCs ordered by Nd concentrations and using modified MTCs. Pb increases at a different rate than REE. (d) REE C/MTCs on a linear scale, ordered by Nd concentrations, and using modified MTCs.

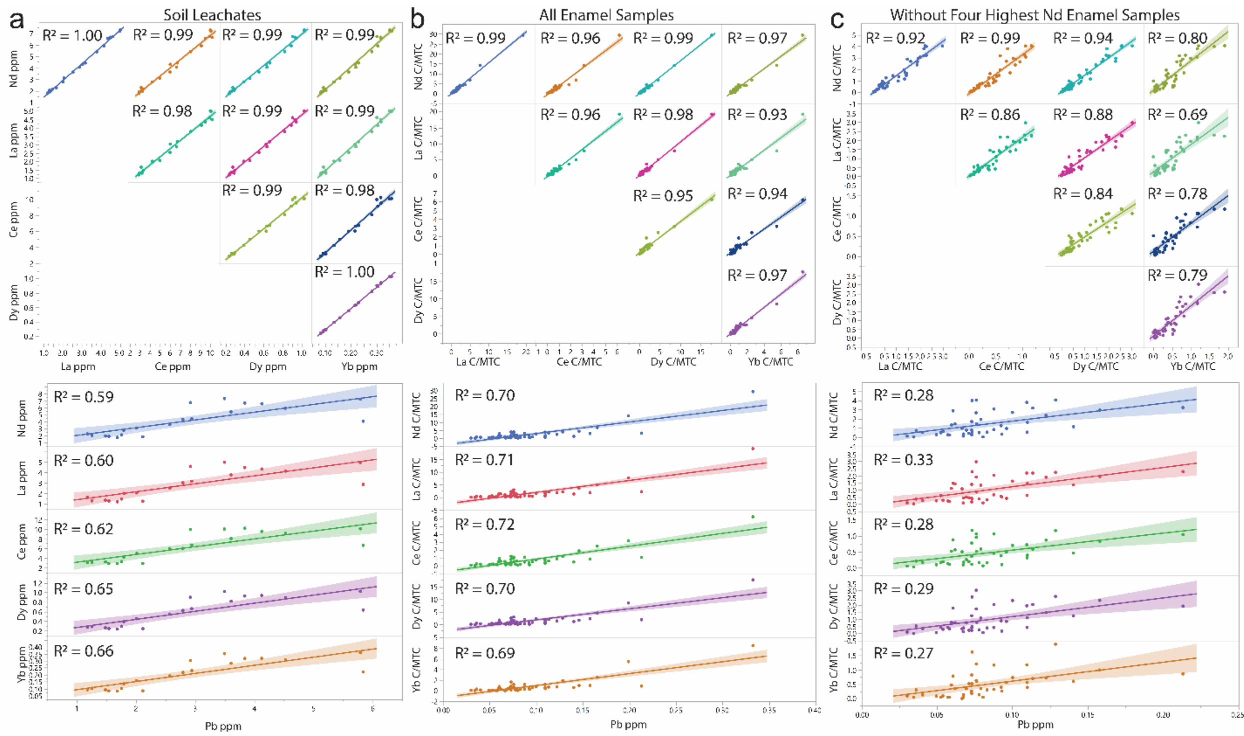

Fig. 9. Nd, La, Ce, Dy, Yb, and Pb correlations. (a) Correlations between Nd, La, Ce, Dy, Yb, and Pb in soil leachates from Crenshaw. (b) Correlation between Nd, La, Ce, Dy, Yb, and Pb with all ancient human tooth enamel samples. (c) Correlation between Nd, La, Ce, Dy, Yb, and Pb in ancient human tooth enamel with four highest concentrated Nd samples excluded. Correlations for soil leachates and all enamel samples are similar. Comparisons show that correlations between all elements are lower when the four highest concentrated Nd samples are excluded. They also show a weaker correlation between Nd, La, and Ce (LREE) and Dy and Yb (MREE-HREE).

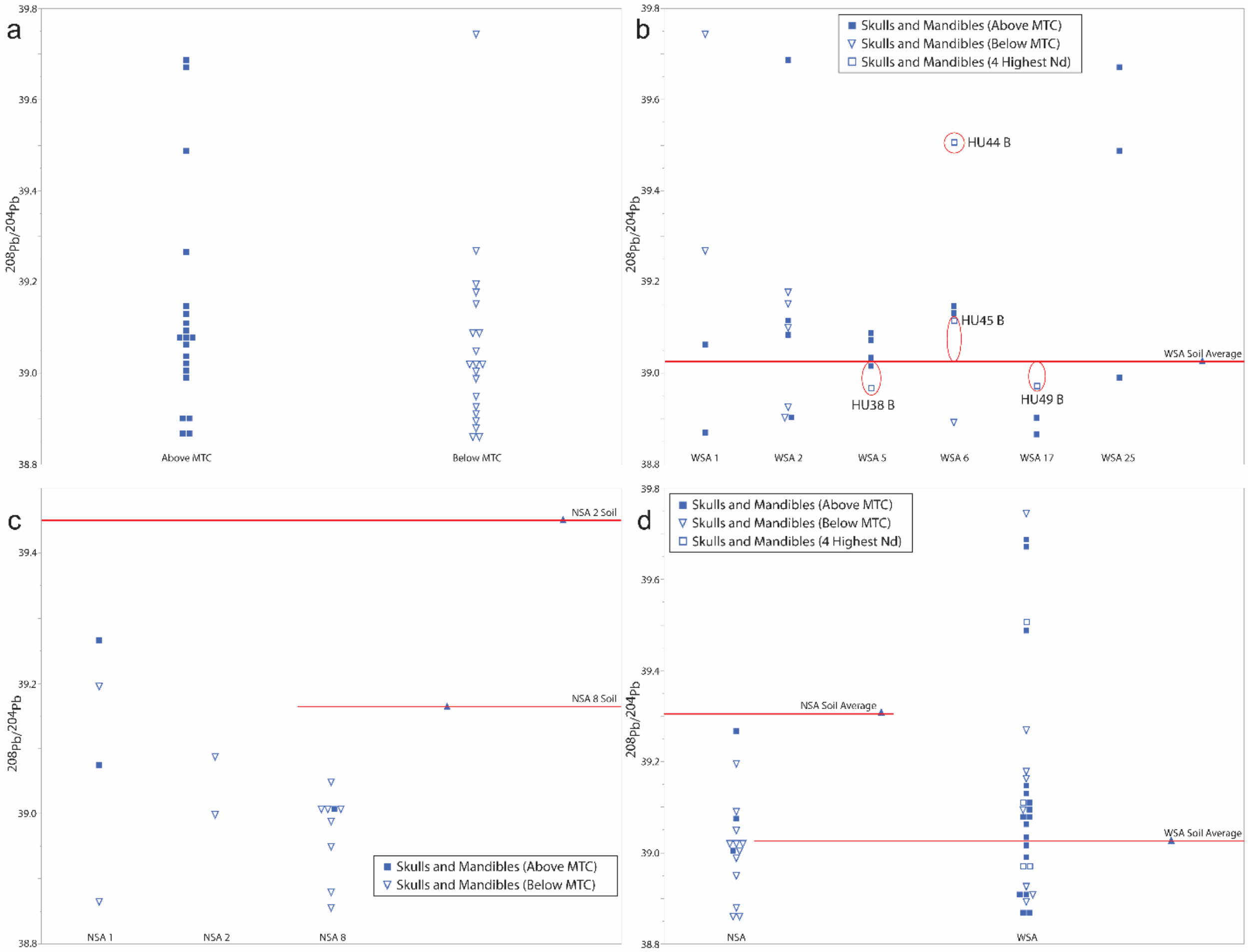

Fig. 10. Pb Isotopes Validate the Contamination Analysis. (a) Pb isotopes of samples above and below Nd MTC. Comparing skulls and mandibles above the Nd MTC and below the Nd MTC show that there is no detectable difference in ranges using Pb isotope ratios, excluding the four highest concentrated Nd samples. (b) Comparison of enamel Pb isotopes from the WSA to the WSA soil average. Both samples above and below the MTC do not generally look like the WSA soil average. A 0.010v on ^{204}Pb threshold was used in this analysis. Despite being identified as the most contaminated sample, HU44 B seems to have maintained a significant portion of *in-vivo* Pb signature since it is still much higher than the soil average. (c) Pb isotopes of enamel and soil leachates by NSA context. Comparisons of enamel Pb isotopes from the NSA show that they generally do not match the soil from their respective clusters. This is the case regardless of whether they are above or below the MTC. (d) Comparisons of Pb isotopes from the NSA and WSA skulls and mandibles to the soil averages from each location. WSA skulls and mandibles being similar to the soil average is likely a coincidence as the NSA skulls and mandibles match the WSA soil better than the WSA skulls and mandibles or the soil from the NSA.

Supplementary Materials

Multiregional Pb Isotopic Linear Patterns and Diagenesis: Isotopes from Ancient Animal Enamel Show Native American "Foreign War Trophies" Are Local Ancestors

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This PDF file includes:

Figs. S1 to S9

Data S1

Other Supplementary Materials for this manuscript include the following:

Data S1

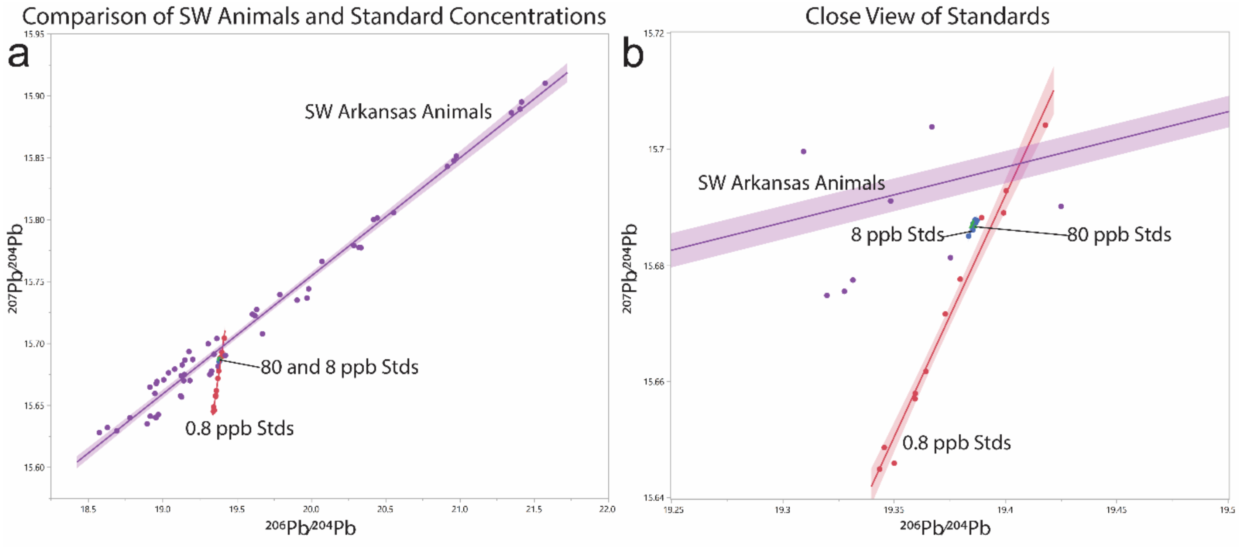

Fig. S1. Low Pb concentration tests.
Comparison of southwest Arkansas animal data with multiple concentration Pb standards (80 ppb, 8 ppb, and 0.8 ppb). Results show that lower (<0.045v on ^{204}Pb) could have significant effects on interpretations. However, the exact threshold is unclear with these data as the 8 ppb standard was accurate with only a small reduction in precision. Therefore, a threshold between the 8 ppb and 0.8 ppb standard was used based on the ^{204}Pb voltage and the potential to affect interpretations. Comparisons between animals and standards were made possible by adding a constant value to each standard ratio (^{208}Pb/^{204}Pb = +2.39, ^{207}Pb/^{204}Pb = +0.198, and ^{206}Pb/^{204}Pb = +2.45).

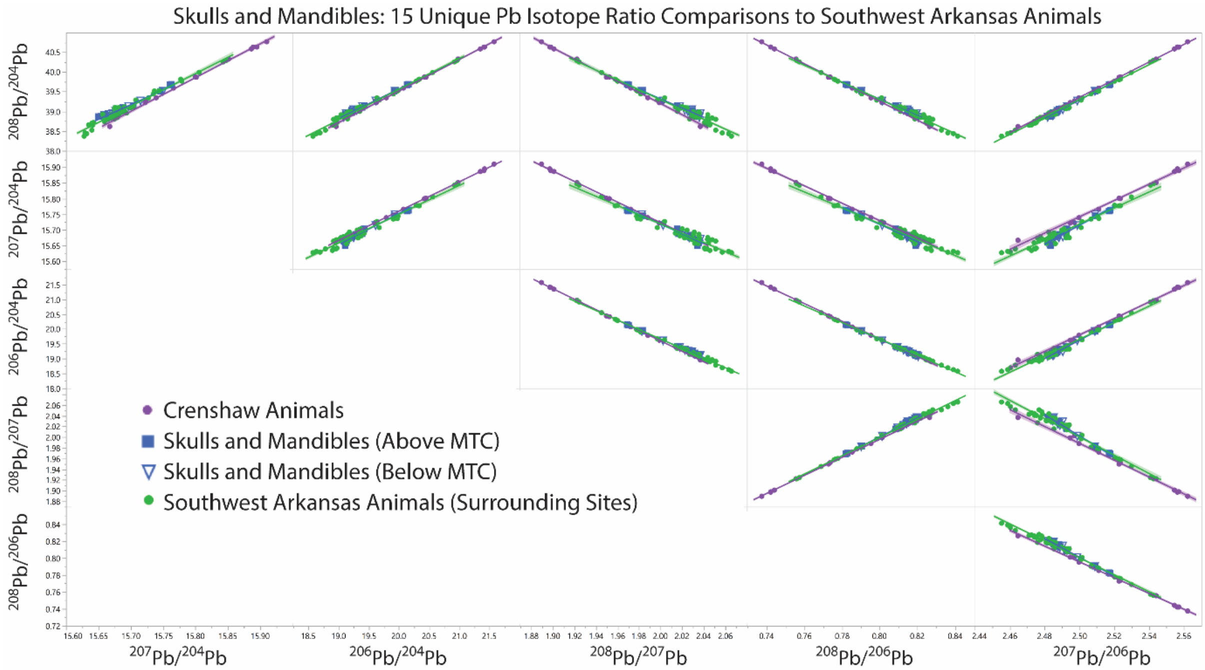

Fig. S2. Skulls and mandibles match all Pb linear patterns.
Linear patterning analysis of all 15 Pb isotope bivariate comparisons shows the skulls and mandibles match southwest Arkansas sites in all comparisons. They generally match southwest Arkansas animals from surrounding sites better than the animals from the Crenshaw site itself.

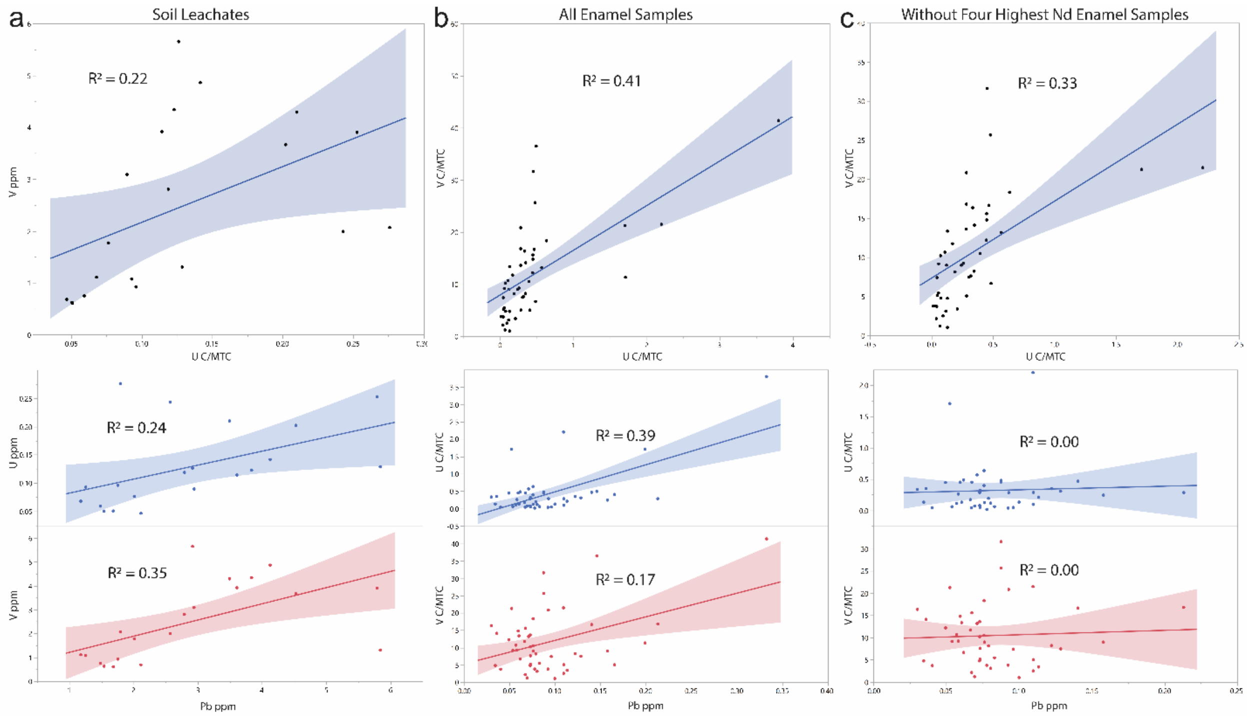

Fig. S3. V, U, and Pb correlations.
(a) Correlations between V, U, and Pb in soil leachates from Crenshaw. (b) Correlation between V, U, and Pb with all ancient human tooth enamel samples. (c) Correlation between V, U, and Pb in ancient human tooth enamel with four highest concentrated Nd samples excluded. Comparisons show that correlations between Pb and the other elements disappear when the four highest concentrated Nd samples are excluded.

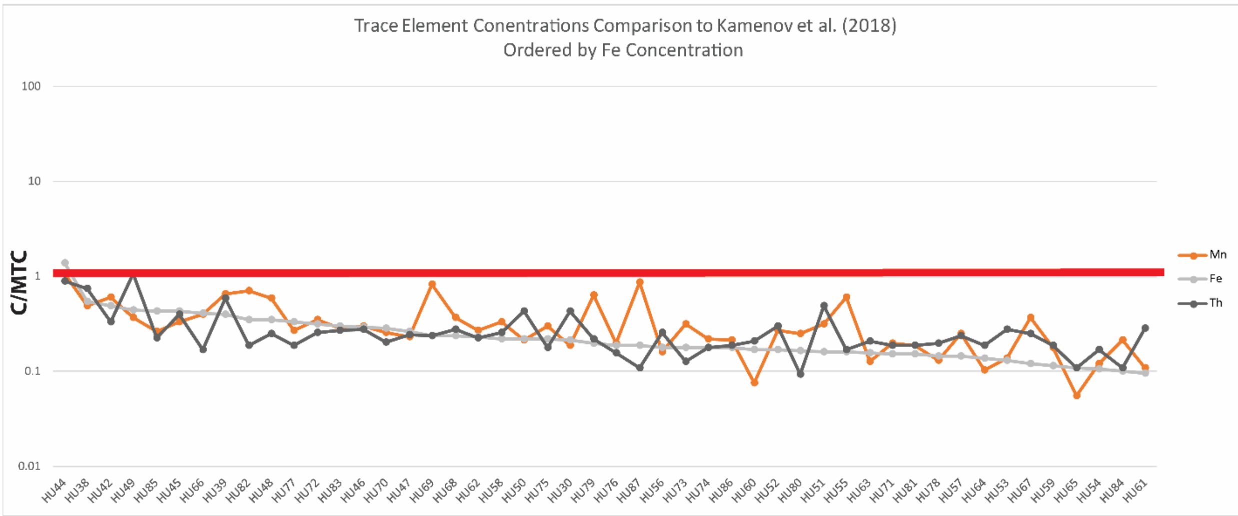

Fig. S4. C/MTCs of Mn, Fe, and Th in enamel.
Comparison of C/MTCs for Mn, Fe, and Th from human tooth enamel, ordered by Fe concentrations. Uses modified MTCs for some elements for visual comparison of rate of increase (Fe=60 ppm, Th=0.003). While correlations are not strong, these three elements tend to increase at about the same rate. They do not increase at the same rate as the REEs.

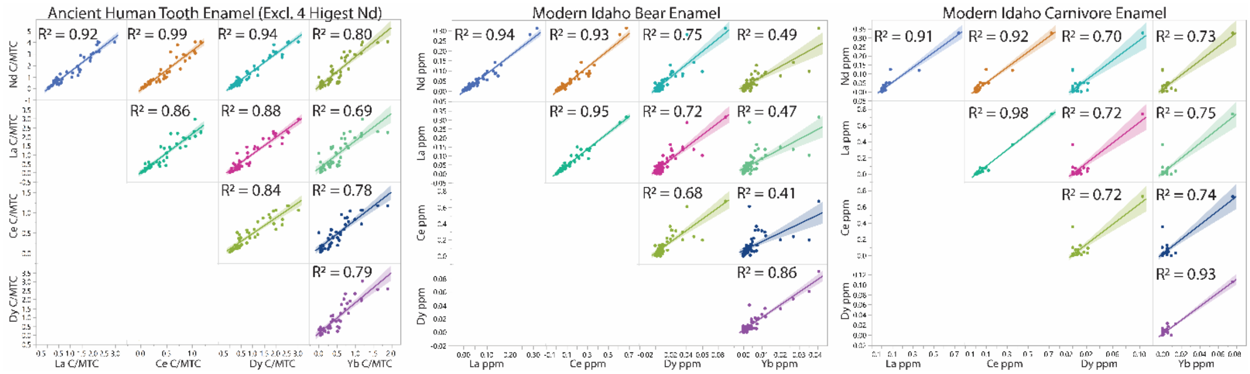

Fig. S5. REE correlations in ancient human and modern bear and carnivore enamel. Comparisons of REE correlations in ancient human tooth enamel, modern Idaho bear enamel, and modern Idaho carnivore enamel (Kohn et al. 2013). Correlations within LREE (Nd, La, and Ce) are higher than correlations between LREE and MREE-HREE (Dy and Yb). This could reflect biologically related *in-vivo* concentrations of these elements.

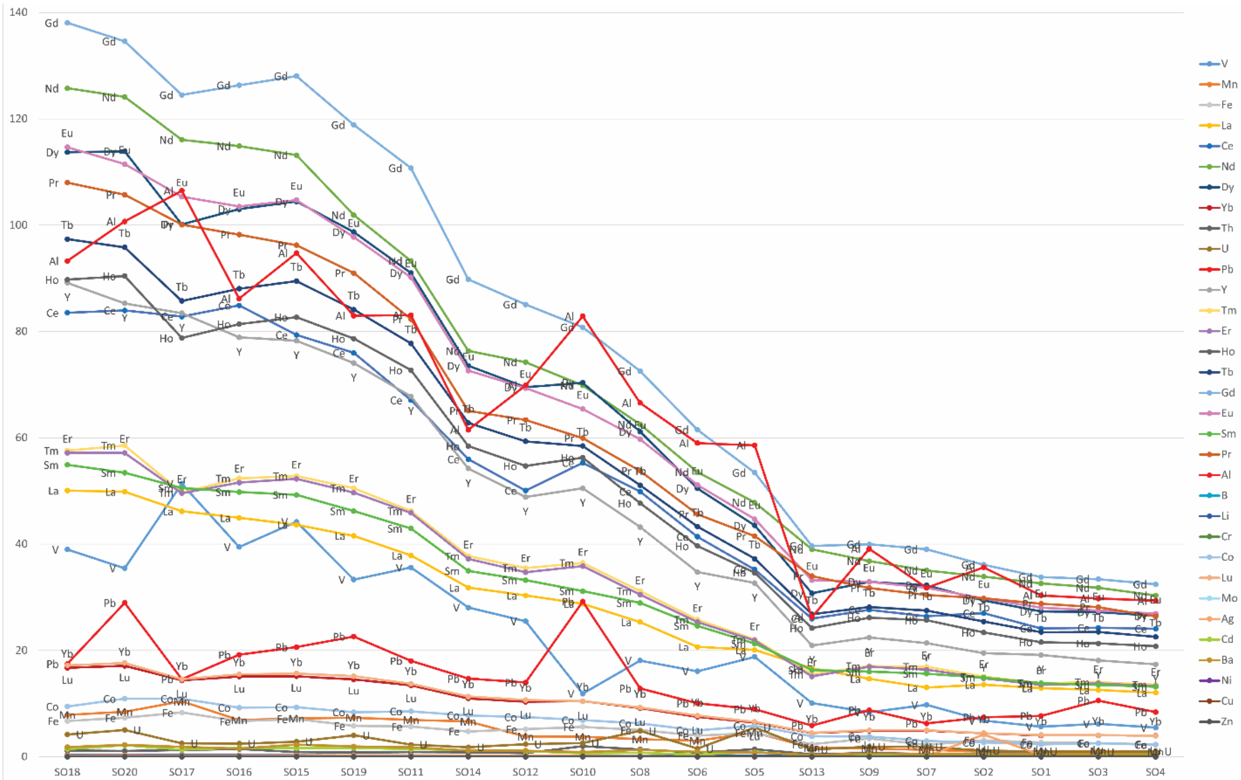

Fig. S6. C/MTCs of all elements in soil leachates.

The C/MTCs of all elements (ordered by Nd concentrations) in soil leachates using the previously defined MTCs for human tooth enamel (Kamenov et al. 2018). However, some elements use previously undefined MTCs for display purposes (Li=4 ppm, B=10 ppm, Al=10 ppm, Co=0.1 ppm, Mo= 2.5 ppm, Ag=0.1 ppm, Cd=0.03 ppm, Y=0.05 ppm, Eu=0.003 ppm, Gd= 0.01 ppm, Pb=0.2 ppb). These were based off the comparable elements in tooth enamel. This shows that some elements have far greater concentrations relative to other elements in the soil leachates compared to the expected (<1 C/MTC) for ancient human tooth enamel, particularly REEs.

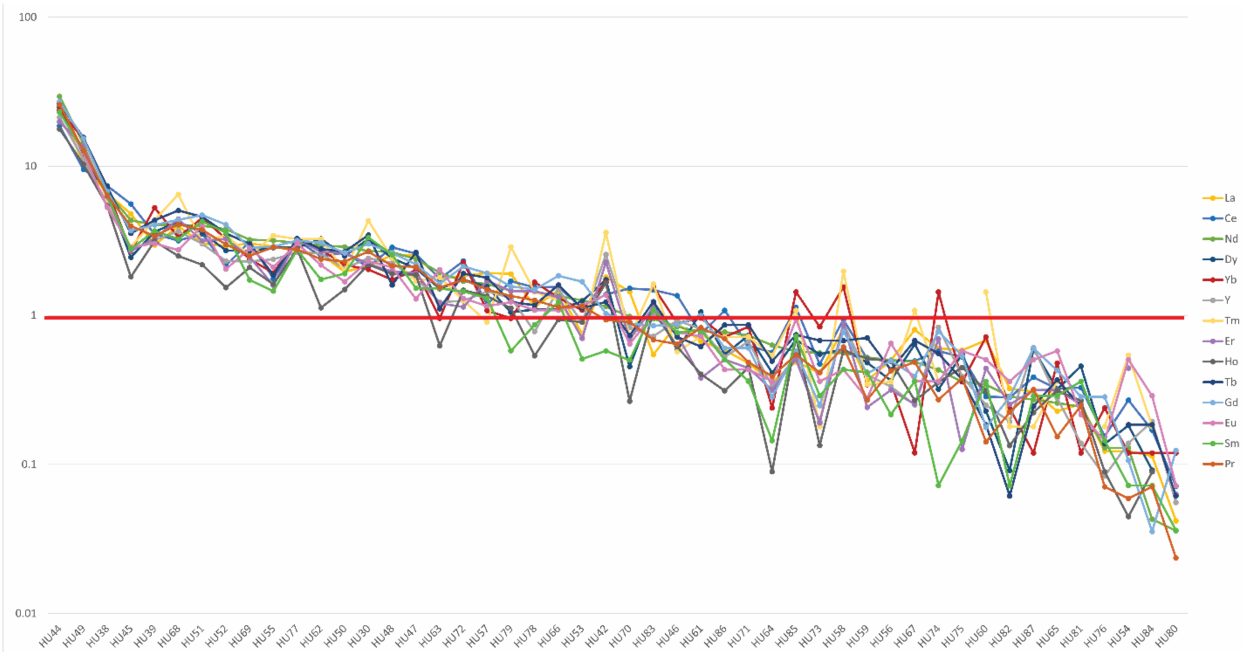

Fig. S7. C/MTCs of Y and extended list of REEs.
Uses modified MTCs for some elements for visual comparison of correlation and rate of increase (La=0.075 ppm, Ce=0.04 ppm, Pr=0.015 ppm, Nd=0.058 ppm, Sm=0.013 ppm, Tb=0.0012 ppm, Dy=0.0064 ppm, Ho=0.0015 ppm, Er=0.003 ppm, Tm=0.0003 ppm, Yb=0.0018 ppm). Some elements have no MTC previously defined and use the following MTCs (Y=0.05 ppm, Eu=0.003 ppm, Gd= 0.01 ppm). These are for display purposes only. This shows that Y and REE correlate and increase at similar rates. It is worth noting that one modern human tooth enamel sample was run for trace elements and, unlike previous research (Kamenov et al. 2018), concentrations were detected for Eu (0.0006 ppm) and Gd (0.001 ppm).

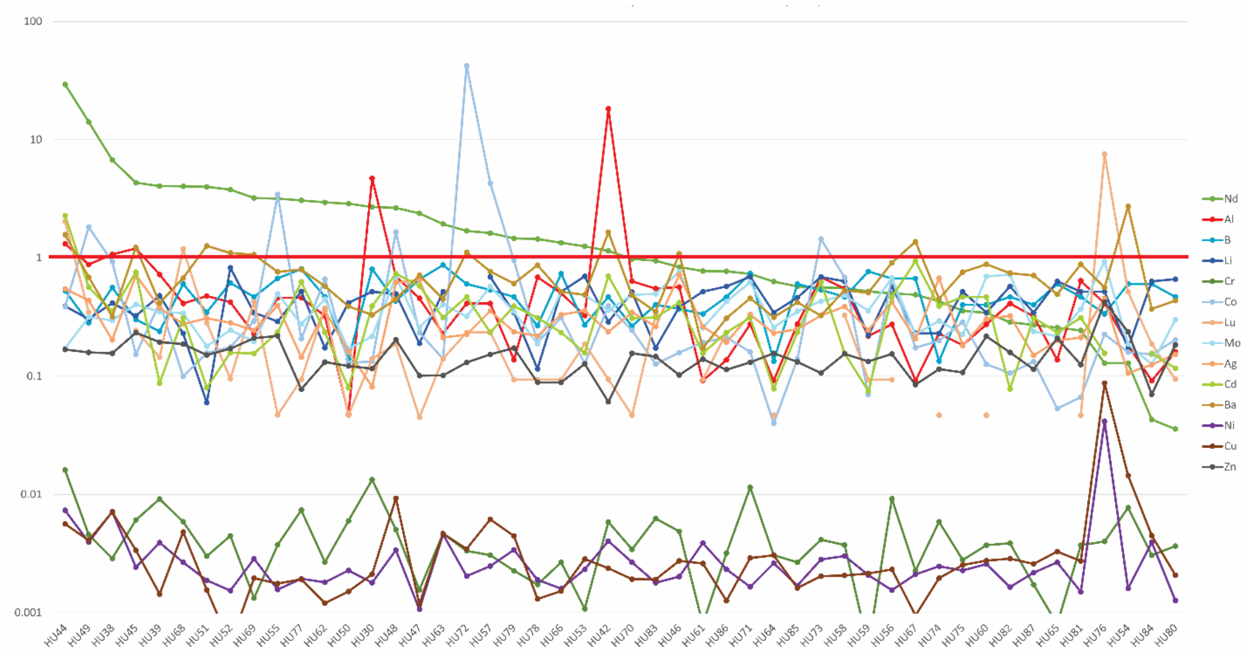

Fig. S8. C/MTCs of other elements in enamel.
The C/MTCs of other elements include Al, B, Li, Cr, Co, Lu, Mo, Ag, Cd, Ba, Ni, Cu, Zn, and Nd for comparison (ordered by Nd concentrations). MTCs used are those previously established (Kamenov et al. 2018), but some have no established MTC. In order to display those, new values were used (Li=4 ppm, B=10 ppm, Al=10 ppm, Co=0.1 ppm, Mo=2.5 ppm, Ag=0.1 ppm, Cd=0.03 ppm), for display purposes only. All of these elements (including Lu) do not correlate well with Nd and increase at different rates than Y and other REEs. It is notable that the four highest concentrated Nd samples do show a perceptible increase in some of these elements. However, they are often not higher than samples with lower Nd concentrations. Some of these elements had poor reproducibility, which would cause higher variability and lower correlations.

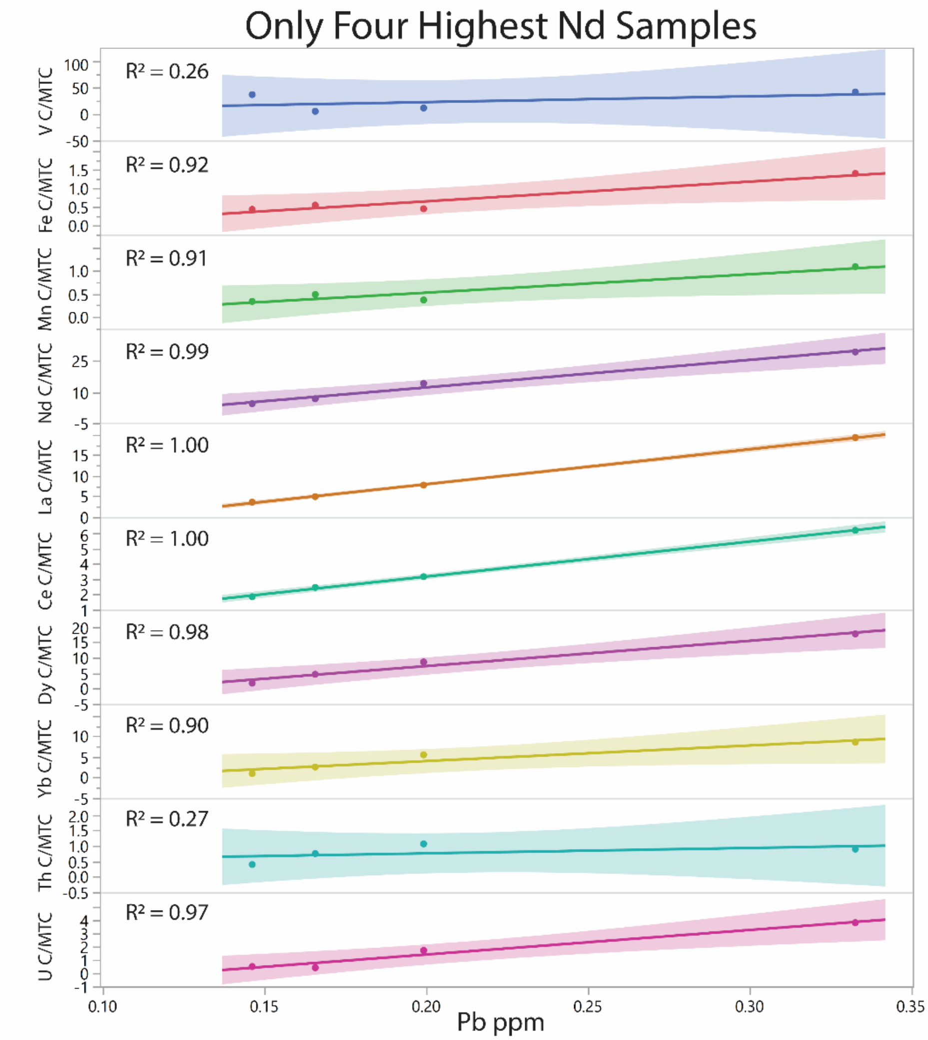

Fig. S9. Pb correlations for four highest Nd samples.
Correlation between trace elements and Pb concentrations in human tooth enamel only including the four highest concentrated Nd samples. The correlations are extremely strong for most elements. Lower correlated elements include V and Th. V does not correlate well with any other elements, so this is consistent with the rest of the analysis. Th may have a lower correlation because it has relatively high variability in Crenshaw’s soil.

Data S1.

All Pb and Sr isotopic data and trace elemental data are included.

Pb isotope ratios from human second molar enamel at Crenshaw (3MI6).

Lab ID	Accession	Cluster	Tooth Side	$^{208}Pb/^{204}Pb$	Std Error	$^{207}Pb/^{204}Pb$	Std Error	$^{206}Pb/^{204}Pb$	Std Error	v ^{204}Pb
HU30 B	69-66-589-1	Rayburn	Mand L	39.515	0.003	15.750	0.001	19.932	0.002	0.0279
HU38 B	83-377-6-1	WSA 5	Mand L	38.968	0.003	15.679	0.001	19.201	0.002	0.0506
HU39 B	83-377-6-2	WSA 5	Mand L	39.016	0.006	15.684	0.002	19.284	0.003	**0.0245**
HU40 B	83-377-6-3	WSA 5	Mand L	39.087	0.009	15.697	0.004	19.383	0.005	**0.0086**
HU41 B	83-377-6-4	WSA 5	Mand L	39.033	0.002	15.684	0.001	19.301	0.001	0.0616
HU42 B	83-377-6-5	WSA 5	Max R	39.072	0.007	15.684	0.003	19.354	0.003	**0.0138**
HU43 B	83-377-7-1	WSA 6	Mand R	39.129	0.001	15.696	0.001	19.393	0.001	0.0984
HU44 B	83-377-7-2	WSA 6	Mand L	39.507	0.001	15.746	0.001	19.921	0.001	0.1484
HU45 B	83-377-7-4	WSA 6	Mand L	39.116	0.004	15.681	0.001	19.421	0.002	**0.0218**
HU46 B	83-377-7-5	WSA 6	Mand	38.892	0.006	15.664	0.002	19.100	0.003	**0.0106**
HU47 B	83-377-7-6	WSA 6	Mand R	39.147	0.008	15.704	0.002	19.425	0.007	0.0367
HU48 B	83-377-29-1	WSA 17	Mand L	38.866	0.010	15.658	0.003	19.135	0.009	**0.0130**
HU49 B	83-377-29-2	WSA 17	Mand L	38.972	0.005	15.669	0.002	19.258	0.004	**0.0172**
HU50 B	83-377-29-3	WSA 17	Mand R	38.902	0.003	15.669	0.001	19.137	0.003	0.0420
HU51 B	83-377-61-1	WSA 25	Mand R	38.990	0.004	15.680	0.002	19.210	0.002	0.0318
HU52 B	83-377-61-2	WSA 25	Mand L	39.671	0.004	15.761	0.002	20.135	0.003	0.0338
HU53 B	83-377-61-3	WSA 25	Mand R	39.487	0.010	15.740	0.003	19.932	0.007	**0.0156**
HU54 B	83-377-24-1	NSA 1	Max R	39.195	0.005	15.698	0.002	19.475	0.003	**0.0199**
HU55 B	83-377-24-2	NSA 1	Mand R	39.266	0.007	15.696	0.003	19.639	0.004	**0.0127**
HU56 B	83-377-24-3	NSA 1	Mand R	38.780	0.022	15.667	0.009	18.997	0.018	**0.0051**
HU57 B	83-377-24-4	NSA 1	Mand R	39.074	0.024	15.665	0.005	19.469	0.021	**0.0133**
HU58 B	83-377-24-5	NSA 1	Mand R	38.864	0.008	15.651	0.003	19.097	0.004	**0.0128**
HU59 B	83-377-25-1	NSA 2	Max	38.998	0.008	15.678	0.003	19.239	0.005	**0.0139**
HU60 B	83-377-25-2	NSA 2	Mand L	38.917	0.025	15.699	0.010	19.251	0.016	**0.0039**
HU61 B	83-377-25-3	NSA 2	Mand R	39.087	0.006	15.675	0.002	19.392	0.003	**0.0146**
HU62 B	83-377-2-4	WSA 1	Mand L	38.869	0.005	15.650	0.002	19.108	0.003	0.0273
HU63 B	83-377-2-5	WSA 1	Mand R	38.964	0.010	15.656	0.004	19.270	0.007	**0.0083**
HU64 B	83-377-2-6	WSA 1	Mand R	39.744	0.005	15.765	0.002	20.291	0.002	**0.0225**
HU65 B	83-377-2-7	WSA 1	Mand L	39.269	0.005	15.715	0.002	19.613	0.003	0.0277
HU66 B	83-377-2-8	WSA 1	Mand R	39.062	0.011	15.699	0.004	19.405	0.007	**0.0108**
HU67 B	83-377-3-3	WSA 2	Mand L	39.177	0.005	15.696	0.002	19.459	0.002	**0.0210**
HU68 B	83-377-3-5	WSA 2	Mand L	39.084	0.004	15.697	0.002	19.352	0.002	**0.0234**
HU69 B	83-377-3-15	WSA 2	Mand R	39.687	0.002	15.763	0.001	20.157	0.001	0.0962
HU70 B	83-377-3-33	WSA 2	Mand R	39.088	0.012	15.676	0.005	19.433	0.006	**0.0108**
HU71 B	83-377-3-35	WSA 2	Mand L	38.944	0.019	15.654	0.009	19.254	0.009	**0.0049**
HU72 B	83-377-3-41	WSA 2	Mand L	39.090	0.010	15.670	0.004	19.442	0.007	**0.0094**
HU73 B	83-377-3-61	WSA 2	Mand R	39.152	0.008	15.688	0.003	19.487	0.004	**0.0118**
HU74 B	83-377-3-81	WSA 2	Mand R	38.925	0.003	15.666	0.001	19.166	0.002	0.0424
HU75 B	83-377-3-89	WSA 2	Mand R	38.906	0.003	15.659	0.001	19.125	0.002	0.0387
HU76 B	83-377-3-96	WSA 2	Mand L	38.633	0.020	15.615	0.009	18.814	0.010	**0.0050**
HU77 B	83-377-3-101	WSA 2	Mand L	39.102	0.002	15.688	0.001	19.390	0.001	0.0662
HU78 B	83-377-3-108	WSA 2	Mand L	38.900	0.003	15.659	0.001	19.115	0.001	0.1860
HU79 B	83-377-41-1-1	NSA 8	Mand R	39.004	0.006	15.681	0.002	19.217	0.003	0.0299
HU80 B	83-377-41-1-2	NSA 8	Max L	38.879	0.009	15.649	0.004	19.083	0.005	**0.0132**
HU81 B	83-377-41-1-3	NSA 8	Max L	38.855	0.004	15.656	0.002	19.085	0.002	0.0282
HU82 B	83-377-41-1-4	NSA 8	Max	38.988	0.008	15.681	0.003	19.215	0.005	**0.0110**
HU83 B	83-377-41-1-5	NSA 8	Mand R	39.007	0.004	15.676	0.002	19.249	0.002	0.0376
HU84 B	83-377-41-1-6	NSA 8	Mand L	39.048	0.002	15.679	0.001	19.244	0.001	0.1062
HU85 B	83-377-41-1-7	NSA 8	Mand R	39.008	0.005	15.681	0.002	19.262	0.002	0.0311
HU86 B	83-377-41-1-8	NSA 8	Mand L	39.008	0.004	15.680	0.001	19.232	0.002	0.0324
HU87 B	83-377-41-1-9	NSA 8	Max R	38.949	0.004	15.672	0.002	19.122	0.002	0.0385

Pb isotope ratios from animal tooth enamel.

Lab ID	State/Area	Site Number	Animal	Accession/ Context	$^{208}Pb/^{204}Pb$	Std Error	$^{207}Pb/^{204}Pb$	Std Error	$^{206}Pb/^{204}Pb$	Std Error	v ^{204}Pb
AN73	Illinois	11U635	Deer	95.002 Bag 101	39.0683	0.0030	15.6902	0.0013	19.4143	0.0015	0.0399
AN74	Illinois	11U635	Ground Hog	95.002 Bag 21	40.2480	0.0010	15.8456	0.0005	20.9156	0.0004	0.1982
AN75	Illinois	11U635	Squirrel	95.002 Bag 24	39.8888	0.0013	15.7982	0.0005	20.4580	0.0007	0.0959
AN76	Illinois	11U635	Squirrel	95.002 Bag 30	40.1223	0.0017	15.8271	0.0006	20.7448	0.0011	0.0999
AN77	Illinois	11U635	Squirrel	95.002 Bag 100	39.8299	0.0410	15.7964	0.0052	20.4170	0.0460	0.0224
AN78	Illinois	11U635	Raccoon	95.002 Bag 100	39.9483	0.0020	15.8022	0.0006	20.5306	0.0012	0.1020
AN79	Illinois	11U635	Deer	95.002 Bag 577	39.9625	0.0013	15.8079	0.0005	20.5523	0.0008	0.1343
AN80	Illinois	11Pp3	Beaver	14.003 Bag 162	39.3903	0.0035	15.7340	0.0014	19.8629	0.0017	0.0283
AN81	Illinois	11Pp3	Squirrel	14.002 TU26 L2	39.2317	0.0014	15.7241	0.0005	19.6850	0.0005	0.0966
AN82	Illinois	11Pp3	Raccoon	14.002 N224.5	39.8228	0.0012	15.7904	0.0005	20.3639	0.0006	0.1593
AN83	Illinois	11Pp3	Oposssum	14.002 Bag 53	39.9751	0.0016	15.8093	0.0007	20.6077	0.0010	0.0601
AN84	Illinois	11Pp3	Deer	14.002 TU26 L3	39.3094	0.0048	15.7270	0.0019	19.7569	0.0026	0.0303
AN85	Illinois	11Pp3	Deer	14.002 TU26 L2	39.7994	0.0008	15.7876	0.0003	20.3642	0.0004	0.2070
AN86	Illinois	11Mx1	Black Bear	1-115	39.6665	0.0009	15.7759	0.0004	20.1596	0.0004	0.2200
AN87	Illinois	11Mx1	Deer	1-95	39.7626	0.0009	15.7894	0.0004	20.3321	0.0005	0.1800
AN88	Texas	41RW4	Rabbit	Lot 120	38.9085	0.0091	15.6482	0.0035	19.1808	0.0049	**0.0101**
AN89	Texas	41RW4	Squirrel	Lot 33	39.0394	0.0022	15.6750	0.0009	19.2440	0.0010	0.0696
AN90	Texas	41RW4	Beaver	Lot 118	38.9006	0.0023	15.6667	0.0009	19.1413	0.0012	0.0422
AN91	Texas	41RW4	Beaver	Lot 117	38.9456	0.0004	15.6744	0.0002	19.1684	0.0002	0.3990
AN92	Texas	41RW4	Beaver	Lot 115	39.0303	0.0022	15.6768	0.0010	19.2298	0.0015	0.0551
AN93	Texas	41RW4	Raccoon	Lot 115	39.0015	0.0012	15.6740	0.0004	19.2097	0.0006	0.1480
AN94	Texas	41RW4	Deer	Lot 119	38.8738	0.0014	15.6611	0.0006	19.0773	0.0006	0.1277
AN95	Texas	41WM230	S. Rodent	Lot 597	38.8267	0.0012	15.6708	0.0004	19.1796	0.0006	0.1130
AN96	Texas	41WM230	P. Gopher	XU3	38.8690	0.0014	15.6755	0.0005	19.2179	0.0007	0.1255
AN97	Texas	41WM230	Raccoon	Lot 141-7	38.7612	0.0023	15.6593	0.0009	19.1298	0.0012	0.0605
AN98	Texas	41WM230	S. Rodent	Lot 637	38.7946	0.0052	15.6553	0.0034	19.1152	0.0026	0.0215
AN99	Texas	41WM230	S. Rodent	Lot 619	38.8486	0.0007	15.6714	0.0002	19.1969	0.0003	0.2700
AN100	Texas	41TR198	P. Gopher	Lot 445	38.9144	0.0009	15.6758	0.0004	19.1826	0.0005	0.1240
AN101	Texas	41TR198	S. Rodent	Lot 461	38.9306	0.0013	15.6815	0.0005	19.2049	0.0007	0.1000
AN102	Texas	41TR198	P. Gopher	Lot 462	38.9343	0.0012	15.6819	0.0004	19.1950	0.0005	0.1320
AN103	Texas	41TR198	S. Rodent	Lot 435	38.9471	0.0006	15.6820	0.0002	19.2121	0.0004	0.3540
AN104	Texas	41TR198	Deer	Lot 408	38.9425	0.0009	15.6799	0.0004	19.1860	0.0004	0.1580
AN105	Texas	41TR198	Deer	Lot 456	38.9052	0.0036	15.6678	0.0013	19.1388	0.0023	0.0281
AN106	Texas	41COL9	Deer	41-18C9-2	38.7994	0.0041	15.6609	0.0017	19.0440	0.0023	0.0289
AN107	Texas	41COL9	Beaver	41-18C9-2	38.6832	0.0007	15.6527	0.0003	18.9513	0.0004	0.1830
AN108	Texas	41COL9	Rabbit	41-18C9-2	38.7233	0.0078	15.6459	0.0035	19.0673	0.0048	**0.0133**
AN109	Texas	41COL9	P. Gopher	41-18C9-2	38.7091	0.0018	15.6572	0.0006	18.9827	0.0009	0.1811
AN110	Texas	41EL11	Raccoon	Lot 120	38.8793	0.0025	15.6696	0.0010	19.2207	0.0013	0.0625
AN111	Texas	41EL11	P. Gopher	Lot 240	38.9703	0.0017	15.6795	0.0010	19.2637	0.0010	0.0600
AN112	Texas	41EL11	P. Gopher	Lot 240	39.0455	0.0018	15.6761	0.0009	19.2303	0.0009	0.0744
AN113	Oklahoma	34Cu27	Rabbit	83.002	38.9917	0.0250	15.6951	0.0092	19.4252	0.0160	**0.0050**
AN114	Oklahoma	34Cu27	S. Rodent	101.011	39.0500	0.0017	15.7276	0.0005	20.0824	0.0011	0.1481
AN115	Oklahoma	34Cu27	Deer	101.011	39.0729	0.0025	15.7162	0.0010	19.8924	0.0013	0.0417
AN116	Oklahoma	34Cu27	S. Rodent	101.011	38.9805	0.0031	15.7084	0.0011	19.8301	0.0019	0.0323
AN117	Oklahoma	34Cu27	S. Rodent	101.011	39.0515	0.0013	15.7348	0.0007	20.2487	0.0009	0.0997

AN118	Oklahoma	34Cu27	S. Rodent	101.011	39.0325	0.0021	15.7194	0.0008	19.9884	0.0014	0.0995
AN119	Oklahoma	34Cu27	S. Rodent	101.011	39.0288	0.0038	15.7145	0.0018	20.0711	0.0031	0.0190
AN120	Oklahoma	34Rm29	Deer	026-A/1980/20	39.0174	0.0110	15.6939	0.0042	19.4819	0.0065	**0.0099**
AN121	Oklahoma	34Rm29	Rabbit	026-A/1980/20	38.9879	0.0024	15.6902	0.0010	19.4704	0.0017	0.0572
AN122	Oklahoma	34Rm29	S. Rodent	026-A/1980/20	38.8837	0.0064	15.6771	0.0023	19.3258	0.0038	0.0167
AN123	Oklahoma	34Wa5	Rabbit	26.007	39.0127	0.0092	15.6959	0.0044	19.5645	0.0047	**0.0124**
AN124	Oklahoma	34Wa5	P. Gopher	654.006	38.9253	0.0010	15.6953	0.0005	19.4720	0.0007	0.1232
AN125	Oklahoma	34Wa5	P. Gopher	690.004	38.9081	0.0018	15.6973	0.0007	19.5150	0.0010	0.0883
AN126	Oklahoma	34Wa5	P. Gopher	42.005	38.5201	0.0042	15.6463	0.0020	19.0484	0.0021	0.0290
AN127	Oklahoma	34Wa5	P. Gopher	97.008	38.9655	0.0017	15.6998	0.0008	19.5379	0.0021	0.1010
AN128	Oklahoma	34Wa5	P. Gopher	97.008	38.9671	0.0033	15.7012	0.0017	19.5345	0.0023	0.0415
AN129	Oklahoma	34Wa5	Deer	640	38.6047	0.0073	15.6650	0.0027	19.1514	0.0043	0.0167
AN130	Mississippi	22TU530	Raccoon	Feat. 34	38.9471	0.0010	15.6861	0.0006	19.3003	0.0005	0.1648
AN131	Mississippi	22TU530	Grey Fox	Feat. 34	39.0271	0.0024	15.6868	0.0014	19.3045	0.0013	0.0315
AN132	NE Arkansas	3CS29	Raccoon	1522094	39.2884	0.0035	15.7128	0.0013	19.6150	0.0018	0.0346
AN133	NE Arkansas	3CS29	Beaver	777	38.9746	0.0074	15.6510	0.0034	19.3295	0.0035	**0.0124**
AN134	NE Arkansas	3CS29	Raccoon	777	39.1661	0.0017	15.6957	0.0008	19.4690	0.0009	0.0888
AN135	NE Arkansas	3CS29	Beaver	780	38.8882	0.0012	15.6857	0.0005	19.2072	0.0005	0.1518
AN136	NE Arkansas	3CS29	Rabbit	774	39.2048	0.0034	15.6953	0.0014	19.5126	0.0020	0.0476
AN137	NE Arkansas	3CS29	Deer	737	39.5083	0.0009	15.7407	0.0004	19.9005	0.0005	0.1770
AN138	NE Arkansas	3CS29	Deer	777	39.3405	0.0046	15.7141	0.0018	19.7297	0.0025	0.0318
AN139	NE Arkansas	3MS20	Skunk	75-671-6145	39.6091	0.0027	15.7584	0.0016	20.1082	0.0014	0.0551
AN140	NE Arkansas	3MS20	Raccoon	75-671-3277	39.1136	0.0023	15.6904	0.0009	19.4478	0.0011	0.0420
AN141	NE Arkansas	3MS20	Deer	76-1247-297	39.8523	0.0022	15.7961	0.0009	20.3932	0.0012	0.0368
AN142	NE Arkansas	3MS20	Deer	75-671-1520	39.1133	0.0230	15.6562	0.0100	19.5799	0.0120	**0.0043**
AN143	NE Arkansas	3MS4	Raccoon	73-432-130	39.1049	0.0033	15.6907	0.0011	19.4255	0.0016	0.0458
AN144	NE Arkansas	3MS4	Raccoon	73-432-10	38.9580	0.0014	15.6739	0.0006	19.1952	0.0007	0.0923
AN145	NE Arkansas	3MS4	Raccoon	73-361	38.9887	0.0013	15.6802	0.0006	19.2865	0.0007	0.1066
AN146	NE Arkansas	3MS4	Raccoon	73-432-30	38.9885	0.0014	15.6814	0.0006	19.2583	0.0008	0.0914
AN147	NE Arkansas	3MS4	Deer	73-430-221	38.9280	0.0023	15.6757	0.0009	19.2309	0.0012	0.0556
AN148	NE Arkansas	3MS4	Deer	73-432-358	39.4876	0.0840	15.7576	0.0320	19.6495	0.0580	**0.0019**
AN157	Louisiana	16CD13	Squirrel	House 5	38.4291	0.0009	15.6521	0.0004	18.8004	0.0005	0.2671
AN158	Louisiana	16CD13	Squirrel	House 5	38.3432	0.0009	15.6398	0.0003	18.6645	0.0004	0.1770
AN159	Louisiana	16CD13	Squirrel	House 5	38.3518	0.0008	15.6445	0.0003	18.7147	0.0005	0.3063
AN160	Louisiana	16CD13	Deer	House 6	38.5307	0.0022	15.6430	0.0008	18.7471	0.0013	0.0658
AN161	Louisiana	16CD13	Deer	House 6	38.4289	0.0013	15.6398	0.0005	18.6608	0.0006	0.1319
AN162	Louisiana	16CD13	Deer	House 6	38.3723	0.0016	15.6244	0.0007	18.6092	0.0010	0.0927
AN163	Louisiana	16NA657	Oposssum	16NA657-10	39.0758	0.0006	15.6974	0.0002	19.2938	0.0004	0.3100
AN164	Louisiana	16NA657	Deer	16NA657-4	38.9810	0.0024	15.6830	0.0011	19.1716	0.0014	0.0844
AN165	Louisiana	16NA657	Deer	Feat. 1	39.0282	0.0048	15.6875	0.0020	19.2769	0.0023	0.0216
AN166	Louisiana	16NA657	Deer	Feat. 1	39.1039	0.0010	15.7043	0.0003	19.2852	0.0004	0.2240
AN167	Missouri	23BU10	Oposssum	FS 292	39.5685	0.0030	15.7764	0.0013	20.3925	0.0017	0.0429
AN168	Missouri	23BU10	Raccoon	FS 799	38.5653	0.0880	15.4853	0.0360	19.4329	0.0560	**0.0010**
AN169	Missouri	23BU10	Raccoon	FS 288	39.8407	0.0023	15.8035	0.0009	20.4474	0.0015	0.0721
AN170	Missouri	23BU10	Deer	FS 4	39.6710	0.0013	15.7760	0.0005	20.1867	0.0006	0.1731
AN171	Missouri	23BU10	Deer	FS 218	39.3721	0.0033	15.7286	0.0013	19.8470	0.0018	0.0205
AN172	Missouri	23BU10	Deer	FS 1	39.4851	0.0082	15.7929	0.0028	20.0848	0.0075	0.0205
AN173	Mississippi	22TU530	Squirrel	L1.2018.8	39.0649	0.0025	15.7084	0.0014	19.5341	0.0013	0.0580

AN174	Mississippi	22TU530	Raccoon	L1.2019.7	39.1306	0.0008	15.7059	0.0004	19.5124	0.0005	0.1424
AN175	Mississippi	22TU530	Dog	L1.2019.6	39.1496	0.0030	15.6936	0.0012	19.4673	0.0017	0.0580
AN176	Mississippi	22CO503	Raccoon	L1.2019.5	39.6054	0.0170	15.7586	0.0060	20.1051	0.0130	**0.0066**
AN177	Mississippi	22CO503	Beaver	L1.2019.2	39.2135	0.0009	15.7233	0.0004	19.6310	0.0005	0.1432
AN178	Mississippi	22CO503	Deer	L1.2019.4	39.1036	0.0072	15.6842	0.0026	19.4228	0.0041	0.0229
AN179	Mississippi	22CO503	Deer	L1.2019.3	39.8836	0.0013	15.7923	0.0004	20.4246	0.0008	0.1363
AN180	Mississippi	22CO503	Deer	L1.2019.1	39.0532	0.0020	15.6826	0.0011	19.3378	0.0013	0.0386

Sr isotope ratios from human second molar enamel at Crenshaw (3MI6).

Lab ID	Accession	Cluster	Tooth Side	$^{87}Sr/^{86}Sr$	2*Std. Error
HU30	69-66-589-1	Rayburn	Mand L	0.70964	0.00001
HU31	69-66-598-2	Rayburn	Mand R	0.71138	0.00001
HU32	69-66-598-3	Rayburn	Mand L	0.71049	0.00001
HU33	69-66-598-4	Rayburn	Max R	0.71297	0.00001
HU34	69-66-598-5	Rayburn	Max L	0.70925	0.00001
HU35	69-66-598-6	Rayburn	Mand L	0.70976	0.00001
HU36	69-66-598-7	Rayburn	Mand R	0.70913	0.00001
HU37	69-66-598-8	Rayburn	Mand R	0.70942	0.00001
HU38	83-377-6-1	WSA 5	Mand L	0.70952	0.00001
HU39	83-377-6-2	WSA 5	Mand L	0.70941	0.00001
HU40	83-377-6-3	WSA 5	Mand L	0.70933	0.00001
HU41	83-377-6-4	WSA 5	Mand L	0.70996	0.00001
HU42	83-377-6-5	WSA 5	Max R	0.70973	0.00001
HU43	83-377-7-1	WSA 6	Mand R	0.70942	0.00001
HU44	83-377-7-2	WSA 6	Mand L	0.71056	0.00001
HU45	83-377-7-4	WSA 6	Mand L	0.70922	0.00001
HU46	83-377-7-5	WSA 6	Mand	0.71135	0.00001
HU47	83-377-7-6	WSA 6	Mand R	0.71037	0.00001
HU48	83-377-29-1	WSA 17	Mand L	0.71010	0.00001
HU49	83-377-29-2	WSA 17	Mand L	0.70926	0.00001
HU50	83-377-29-3	WSA 17	Mand R	0.70995	0.00001
HU51	83-377-61-1	WSA 25	Mand R	0.71192	0.00001
HU52	83-377-61-2	WSA 25	Mand L	0.71171	0.00001
HU53	83-377-61-3	WSA 25	Mand R	0.71224	0.00001
HU54	83-377-24-1	NSA 1	Max R	0.71114	0.00001
HU55	83-377-24-2	NSA 1	Mand R	0.71066	0.00001
HU56	83-377-24-3	NSA 1	Mand R	0.71098	0.00001
HU57	83-377-24-4	NSA 1	Mand R	0.71074	0.00001
HU58	83-377-24-5	NSA 1	Mand R	0.71097	0.00001
HU59	83-377-25-1	NSA 2	Max	0.71231	0.00001
HU60	83-377-25-2	NSA 2	Mand L	0.70857	0.00001
HU61	83-377-25-3	NSA 2	Mand R	0.70856	0.00001
HU62	83-377-2-4	WSA 1	Mand L	0.71042	0.00001
HU63	83-377-2-5	WSA 1	Mand R	0.71052	0.00001
HU64	83-377-2-6	WSA 1	Mand R	0.70964	0.00001
HU65	83-377-2-7	WSA 1	Mand L	0.71053	0.00001
HU66	83-377-2-8	WSA 1	Mand R	0.71009	0.00001
HU67	83-377-3-3	WSA 2	Mand L	0.71392	0.00001
HU68	83-377-3-5	WSA 2	Mand L	0.71038	0.00001
HU69	83-377-3-15	WSA 2	Mand R	0.71314	0.00001
HU70	83-377-3-33	WSA 2	Mand R	0.70838	0.00001
HU71	83-377-3-35	WSA 2	Mand L	0.70963	0.00001
HU72	83-377-3-41	WSA 2	Mand L	0.71219	0.00001
HU73	83-377-3-61	WSA 2	Mand R	0.71287	0.00001

HU74	83-377-3-81	WSA 2	Mand R	0.70983	0.00001
HU75	83-377-3-89	WSA 2	Mand R	0.71132	0.00001
HU76	83-377-3-96	WSA 2	Mand L	0.71310	0.00001
HU77	83-377-3-101	WSA 2	Mand L	0.71178	0.00002
HU78	83-377-3-108	WSA 2	Mand L	0.71023	0.00001
HU79	83-377-41-1-1	NSA 8	Mand R	0.71247	0.00001
HU80	83-377-41-1-2	NSA 8	Max L	0.71351	0.00001
HU81	83-377-41-1-3	NSA 8	Max L	0.71266	0.00001
HU82	83-377-41-1-4	NSA 8	Max	0.71336	0.00001
HU83	83-377-41-1-5	NSA 8	Mand R	0.71103	0.00001
HU84	83-377-41-1-6	NSA 8	Mand L	0.70985	0.00001
HU85	83-377-41-1-7	NSA 8	Mand R	0.71270	0.00001
HU86	83-377-41-1-8	NSA 8	Mand L	0.71062	0.00001
HU87	83-377-41-1-9	NSA 8	Max R	0.71145	0.00001
HU88	83-377-23-1	WSA 15	Mand L	0.71146	0.00001
HU89	83-377-23-4	WSA 15	Mand L	0.71002	0.00001
HU90	83-377-23-5	WSA 15	Mand R	0.71042	0.00001
HU91	83-377-23-11	WSA 15	Mand R	0.71128	0.00001
HU92	83-377-23-18A	WSA 15	Mand R	0.70971	0.00001
HU93	83-377-23-18B	WSA 15	Mand R	0.70891	0.00001
HU94	83-377-23-31	WSA 15	Mand L	0.71442	0.00001
HU95	83-377-23-36	WSA 15	Mand R	0.71037	0.00001
HU96	83-377-32-1	WSA 18	Mand L	0.71032	0.00001
HU97	83-377-32-2	WSA 18	Mand L	0.71086	0.00001
HU98	83-377-32-3	WSA 18	Mand R	0.71028	0.00001
HU99	83-377-32-5	WSA 18	Max L	0.71041	0.00001
HU100	83-377-32-6	WSA 18	Mand L	0.71157	0.00001
HU101	83-377-32-7	WSA 18	Mand R	0.71159	0.00001
HU102	83-377-32-8	WSA 18	Mand L	0.71052	0.00001
HU103	83-377-32-9	WSA 18	Mand L	0.71154	0.00001
HU104	83-377-32-10	WSA 18	Mand L	0.70963	0.00001

Strontium isotope ratios from animal tooth enamel.

Lab ID	State/Area	Site Number	Animal	Accession/ Context	$^{87}Sr/^{86}Sr$	2*Std. Error
AN1	SW Arkansas	3MI6	Deer	69-66-591	0.71434	0.00001
AN2	SW Arkansas	3MI6	Rabbit	69-66-587	0.70925	0.00001
AN3	SW Arkansas	3MI6	Opossum	69-66-261	0.70955	0.00001
AN4	SW Arkansas	3MI6	Cottontail	69-66-317	0.70963	0.00001
AN5	SW Arkansas	3MI6	Wood Rat	69-66-230	0.70968	0.00001
AN6	SW Arkansas	3MI6	Swamp Rabbit	69-66-389	0.70941	0.00001
AN7	SW Arkansas	3MI6	Deer	69-66-469	0.71119	0.00001
AN8	SW Arkansas	3MI6	Deer	69-66-389	0.71529	0.00002
AN9	SW Arkansas	3MI6	Deer	90-634	0.71297	0.00001
AN10	SW Arkansas	3MI6	Deer	90-634	0.71513	0.00001
AN11	SW Arkansas	3MI6	Cottontail	95-449	0.70950	0.00001
AN12	SW Arkansas	3MI6	Swamp Rabbit	90-634	0.70974	0.00001
AN13	SW Arkansas	3HE92	Squirrel	83-379-114	0.70977	0.00001
AN14	SW Arkansas	3HE92	Pocket Gopher	82-450-20	0.70978	0.00001
AN15	SW Arkansas	3HE92	Rabbit	83-379-264	0.70943	0.00001
AN16	SW Arkansas	3HE92	Rabbit	83-379-101	0.70930	0.00001
AN17	SW Arkansas	3HE92	Rabbit	83-379-141	0.70927	0.00001
AN18	SW Arkansas	3HE92	Rabbit	83-379-281	0.70919	0.00001
AN19	SW Arkansas	3HE92	Pocket Gopher	84-380-158	0.71007	0.00001
AN20	SW Arkansas	3HE40	Squirrel	2002-700-76	0.71526	0.00001
AN21	SW Arkansas	3HE40	Squirrel	2002-700-345	0.70979	0.00001
AN22	SW Arkansas	3HE40	Squirrel	2003-685-84	0.70985	0.00002
AN23	SW Arkansas	3HE40	Squirrel	2002-700-34-5	0.70980	0.00001
AN24	SW Arkansas	3HE40	Squirrel	2002-700-34-5	0.70976	0.00001
AN25	SW Arkansas	3HO11	Raccoon	61-114-4686	0.70961	0.00001
AN26	SW Arkansas	3HO11	Opossum	61-114-4686	0.70826	0.00001
AN27	SW Arkansas	3HO11	Small Rodent	61-114-607	0.70830	0.00001
AN28	SW Arkansas	3HO11	Rabbit	61-114-685	0.70832	0.00002
AN29	SW Arkansas	3HO11	Opossum	61-114-473	0.70855	0.00001
AN30	SW Arkansas	3HO11	Deer	61-114-676	0.70890	0.00001
AN31	SW Arkansas	3HO11	Deer	61-114-694	0.70880	0.00001
AN32	SW Arkansas	3HO11	Deer	61-114-638	0.71076	0.00001
AN33	SW Arkansas	3HO11	Deer	61-114-468a	0.70842	0.00001
AN34	SW Arkansas	3HO11	Deer	61-114-554	0.70889	0.00001
AN35	SW Arkansas	3SV20	Deer	64-51-1	none	
AN36	SW Arkansas	3SV20	Rabbit	64-51-1	0.70856	0.00002
AN37	SW Arkansas	3SV20	Opossum	64-51-1	0.70862	0.00002
AN38	SW Arkansas	3SV20	Small Rodent	64-51-1	0.71073	0.00001
AN39	SW Arkansas	3SV20	Raccoon	64-51-1	0.70800	0.00001
AN40	SW Arkansas	3LR49	Rabbit	63-39-278	0.71301	0.00001
AN41	SW Arkansas	3LR49	Raccoon	63-39-33	0.71365	0.00001
AN42	SW Arkansas	3LR49	Raccoon	63-39-57	0.71332	0.00001
AN43	SW Arkansas	3LR49	Opossum	63-39-51	0.71338	0.00001
AN44	SW Arkansas	3LR49	Rabbit	63-39-40	0.71357	0.00001

AN45	SW Arkansas	3LR49	Deer	63-39-45	0.71383	0.00001
AN46	SW Arkansas	3LR49	Deer	63-39-43	0.71379	0.00002
AN47	SW Arkansas	3LR49	Deer	63-39-63	0.71276	0.00001
AN48	SW Arkansas	3LR49	Deer	63-39-49	0.71109	0.00002
AN49	SW Arkansas	3SV15	Deer	64-50-3196	0.70987	0.00001
AN50	SW Arkansas	3SV15	Deer	64-50-252	0.71016	0.00001
AN51	SW Arkansas	3SV15	Deer	64-50-203	0.70898	0.00001
AN52	SW Arkansas	3SV15	Deer	64-50-341	0.71139	0.00001
AN53	SW Arkansas	3SV15	Deer	64-50-325	0.70893	0.00002
AN54	SW Arkansas	3SV15	Opossum	64-50-231	0.70956	0.00002
AN55	SW Arkansas	3SV15	Rabbit	64-50-319a	0.70940	0.00001
AN56	SW Arkansas	3SV15	Rabbit	64-50-437	0.70920	0.00001
AN57	Mississippi	22TU549	Raccoon	F-944	0.70951	0.00001
AN58	Mississippi	22TU549	Opossum	F-2300	0.70896	0.00001
AN59	Mississippi	22TU549	Raccoon	F-2300	0.70932	0.00001
AN60	Mississippi	22TU549	Raccoon	F-2300	0.70919	0.00001
AN61	Mississippi	22TU549	Deer	F-799	0.70851	0.00001
AN62	Mississippi	22TU549	Deer	F-2300	0.70820	0.00001
AN63	Mississippi	22TU549	Deer	F-2300	0.70881	0.00001
AN64	Mississippi	22TU549	Deer	F-1611	0.70933	0.00001
AN65	Louisiana	16NA70	Deer	16NA70-41	0.70975	0.00001
AN66	Louisiana	16NA70	Deer	16NA70-63	0.71038	0.00001
AN67	Louisiana	16NA70	Deer	16NA70-77	0.70997	0.00001
AN68	Louisiana	16NA70	Deer	16NA70-Nat_F	0.71208	0.00001
AN69	Louisiana	16NA70	Rabbit	16NA70-27	0.70991	0.00002
AN70	Louisiana	16NA70	Rabbit	16NA70-115	0.70940	0.00002
AN71	Louisiana	16NA70	Beaver	16NA70-104	0.70954	0.00001
AN72	Louisiana	16NA70	Rabbit	16NA70-404	0.70968	0.00001
AN73	Illinois	11U635	Deer	95.002 Bag 101	0.71108	0.00001
AN74	Illinois	11U635	Ground Hog	95.002 Bag 21	0.70932	0.00001
AN75	Illinois	11U635	Squirrel	95.002 Bag 24	0.70920	0.00001
AN76	Illinois	11U635	Squirrel	95.002 Bag 30	0.70916	0.00001
AN77	Illinois	11U635	Squirrel	95.002 Bag 100	0.70931	0.00001
AN78	Illinois	11U635	Raccoon	95.002 Bag 100	0.70926	0.00001
AN79	Illinois	11U635	Deer	95.002 Bag 577	0.70879	0.00001
AN80	Illinois	11Pp3	Beaver	14.003 Bag 162	0.70986	0.00001
AN81	Illinois	11Pp3	Squirrel	14.002 TU26 L2	0.71078	0.00001
AN82	Illinois	11Pp3	Raccoon	14.002 N224.5	0.71160	0.00001
AN83	Illinois	11Pp3	Oposssum	14.002 Bag 53	0.71074	0.00001
AN84	Illinois	11Pp3	Deer	14.002 TU26 L3	0.71076	0.00001
AN85	Illinois	11Pp3	Deer	14.002 TU26 L2	0.71062	0.00001
AN86	Illinois	11Mx1	Black Bear	1-115	0.71151	0.00001
AN87	Illinois	11Mx1	Deer	1-95	0.71184	0.00001
AN88	Texas	41RW4	Rabbit	Lot 120	0.70781	0.00001
AN89	Texas	41RW4	Squirrel	Lot 33	0.70780	0.00001
AN90	Texas	41RW4	Beaver	Lot 118	0.70777	0.00001
AN91	Texas	41RW4	Beaver	Lot 117	0.70777	0.00001

AN92	Texas	41RW4	Beaver	Lot 115	0.70779	0.00001
AN93	Texas	41RW4	Raccoon	Lot 115	0.70781	0.00001
AN94	Texas	41RW4	Deer	Lot 119	0.70856	0.00001
AN95	Texas	41WM230	Small Rodent	Lot 597	0.70793	0.00001
AN96	Texas	41WM230	Pocket Gopher	XU3	0.70783	0.00001
AN97	Texas	41WM230	Raccoon	Lot 141-7	0.70820	0.00001
AN98	Texas	41WM230	Small Rodent	Lot 637	0.70806	0.00001
AN99	Texas	41WM230	Small Rodent	Lot 619	0.70790	0.00001
AN100	Texas	41TR198	Pocket Gopher	Lot 445	0.70878	0.00001
AN101	Texas	41TR198	Small Rodent	Lot 461	0.70861	0.00001
AN102	Texas	41TR198	Pocket Gopher	Lot 462	0.70858	0.00001
AN103	Texas	41TR198	Small Rodent	Lot 435	0.70874	0.00001
AN104	Texas	41TR198	Deer	Lot 408	0.70932	0.00001
AN105	Texas	41TR198	Deer	Lot 456	0.70909	0.00001
AN106	Texas	41COL9	Deer	41-18C9-2	0.70783	0.00001
AN107	Texas	41COL9	Beaver	41-18C9-2	0.70853	0.00001
AN108	Texas	41COL9	Rabbit	41-18C9-2	0.70771	0.00001
AN109	Texas	41COL9	Pocket Gopher	41-18C9-2	0.70772	0.00001
AN110	Texas	41EL11	Raccoon	Lot 120	0.70769	0.00001
AN111	Texas	41EL11	Pocket Gopher	Lot 240	0.70840	0.00001
AN112	Texas	41EL11	Pocket Gopher	Lot 240	0.70818	0.00001
AN113	Oklahoma	34Cu27	Rabbit	83.002	0.70864	0.00001
AN114	Oklahoma	34Cu27	Small Rodent	101.011	0.70837	0.00001
AN115	Oklahoma	34Cu27	Deer	101.011	0.70834	0.00001
AN116	Oklahoma	34Cu27	Small Rodent	101.011	0.70830	0.00001
AN117	Oklahoma	34Cu27	Small Rodent	101.011	0.70860	0.00001
AN118	Oklahoma	34Cu27	Small Rodent	101.011	0.70845	0.00001
AN119	Oklahoma	34Cu27	Small Rodent	101.011	0.70863	0.00001
AN120	Oklahoma	34Rm29	Deer	026-A/1980/20	0.70836	0.00001
AN121	Oklahoma	34Rm29	Rabbit	026-A/1980/20	0.70860	0.00001
AN122	Oklahoma	34Rm29	Small Rodent	026-A/1980/20	0.70834	0.00001
AN123	Oklahoma	34Wa5	Rabbit	26.007	0.70905	0.00001
AN124	Oklahoma	34Wa5	Pocket Gopher	654.006	0.70905	0.00001
AN125	Oklahoma	34Wa5	Pocket Gopher	690.004	0.70879	0.00001
AN126	Oklahoma	34Wa5	Pocket Gopher	42.005	0.70911	0.00001
AN127	Oklahoma	34Wa5	Pocket Gopher	97.008	0.70937	0.00001
AN128	Oklahoma	34Wa5	Pocket Gopher	97.008	0.70951	0.00001
AN129	Oklahoma	34Wa5	Deer	640	0.70934	0.00001
AN130	Mississippi	22TU530	Raccoon	Feat. 34	0.70933	0.00001
AN131	Mississippi	22TU530	Grey Fox	Feat. 34	0.70935	0.00001
AN132	NE Arkansas	3CS29	Raccoon	1522094	0.70942	0.00001
AN133	NE Arkansas	3CS29	Beaver	777	0.70937	0.00002
AN134	NE Arkansas	3CS29	Raccoon	777	0.70951	0.00001
AN135	NE Arkansas	3CS29	Beaver	780	0.70954	0.00001
AN136	NE Arkansas	3CS29	Rabbit	774	0.70930	0.00001
AN137	NE Arkansas	3CS29	Deer	737	0.70937	0.00001
AN138	NE Arkansas	3CS29	Deer	777	0.70960	0.00001

AN139	NE Arkansas	3MS20	Skunk	75-671-6145	0.70994	0.00001
AN140	NE Arkansas	3MS20	Raccoon	75-671-3277	0.70952	0.00001
AN141	NE Arkansas	3MS20	Deer	76-1247-297	0.71009	0.00001
AN142	NE Arkansas	3MS20	Deer	75-671-1520	0.70982	0.00001
AN143	NE Arkansas	3MS4	Raccoon	73-432-130	0.70930	0.00001
AN144	NE Arkansas	3MS4	Raccoon	73-432-10	0.70994	0.00018
AN145	NE Arkansas	3MS4	Raccoon	73-361	0.70935	0.00002
AN146	NE Arkansas	3MS4	Raccoon	73-432-30	0.70941	0.00002
AN147	NE Arkansas	3MS4	Deer	73-430-221	0.70946	0.00002
AN148	NE Arkansas	3MS4	Deer	73-432-358	0.70907	0.00002
AN149	Ouachita - SW AR	3CL418	Deer	87-710-954	0.71357	0.00001
AN150	Ouachita - SW AR	3CL418	Deer	87-710-647	0.71266	0.00001
AN151	Ouachita - SW AR	3CL418	Deer	87-710-95	0.71007	0.00001
AN152	Ouachita - SW AR	3CL418	Squirrel	87-710-417	0.71229	0.00001
AN153	Ouachita - SW AR	3CL418	Squirrel	87-710-86	0.71352	0.00001
AN154	Ouachita - SW AR	3HS60	Deer	74-746-14	0.71312	0.00001
AN155	Ouachita - SW AR	3HS60	Deer	74-746-27	0.71606	0.00001
AN156	Ouachita - SW AR	3HS60	Oposssum	74-746-28	0.71492	0.00001
AN157	Louisiana	16CD13	Squirrel	House 5	0.70993	0.00001
AN158	Louisiana	16CD13	Squirrel	House 5	0.71154	0.00001
AN159	Louisiana	16CD13	Squirrel	House 5	0.70992	0.00001
AN160	Louisiana	16CD13	Deer	House 6	0.71062	0.00001
AN161	Louisiana	16CD13	Deer	House 6	0.71038	0.00001
AN162	Louisiana	16CD13	Deer	House 6	0.70901	0.00001
AN163	Louisiana	16NA657	Oposssum	16NA657-10	0.71210	0.00001
AN164	Louisiana	16NA657	Deer	16NA657-4	0.71210	0.00001
AN165	Louisiana	16NA657	Deer	Feat. 1	0.70959	0.00001
AN166	Louisiana	16NA657	Deer	Feat. 1	0.71119	0.00001
AN167	Missouri	23BU10	Oposssum	FS 292	0.71219	0.00001
AN168	Missouri	23BU10	Raccoon	FS 799	0.71286	0.00001
AN169	Missouri	23BU10	Raccoon	FS 288	0.71039	0.00001
AN170	Missouri	23BU10	Deer	FS 4	0.70997	0.00001
AN171	Missouri	23BU10	Deer	FS 218	0.71006	0.00001
AN172	Missouri	23BU10	Deer	FS 1	0.71304	0.00001
AN173	Mississippi	22TU530	Squirrel	L1.2018.8	0.70931	0.00001
AN174	Mississippi	22TU530	Raccoon	L1.2019.7	0.70946	0.00001
AN175	Mississippi	22TU530	Dog	L1.2019.6	0.70941	0.00001
AN176	Mississippi	22CO503	Raccoon	L1.2019.5	0.70954	0.00001
AN177	Mississippi	22CO503	Beaver	L1.2019.2	0.70959	0.00001
AN178	Mississippi	22CO503	Deer	L1.2019.4	0.70954	0.00001
AN179	Mississippi	22CO503	Deer	L1.2019.3	0.70936	0.00001
AN180	Mississippi	22CO503	Deer	L1.2019.1	0.70942	0.00001

Sample	Sample Letter	Context	Catalog Number	Material	Li (ppm)	B	Al	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Y	Mo	Ag	Cd	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Th	U	Pb
HU44	B	WSA CL 6	83-377-7-2	enamel	1.566	5.307	13.176	4.555	0.224	16.738	83.863	0.039	0.338	0.271	105.635	1.064	0.431	0.055	0.069	63.184	1.925	0.746	0.388	1.707	0.300	0.070	0.272	0.032	0.159	0.027	0.060	0.008	0.043	0.006	0.004	0.190	0.333
HU49	B	WSA CL 17	83-377-29-2	enamel	1.221	2.837	8.803	1.246	0.064	5.693	26.825	0.183	0.182	0.197	100.202	0.560	0.790	0.044	0.017	27.564	0.773	0.381	0.191	0.822	0.166	0.037	0.153	0.019	0.077	0.015	0.041	0.005	0.028	0.001	0.005	0.086	0.199
HU38	B	WSA CL 5	83-377-6-1	enamel	1.666	5.643	10.725	0.553	0.040	7.518	32.547	0.093	0.329	0.340	98.318	0.283	0.743	0.020	0.011	12.774	0.494	0.297	0.096	0.390	0.084	0.016	0.068	0.009	0.041	0.008	0.019	0.002	0.013	0.000	0.004	0.020	0.166
HU45	B	WSA CL 6	83-377-7-4	enamel	1.299	3.017	12.044	4.014	0.085	5.203	25.745	0.015	0.112	0.162	146.966	0.139	1.014	0.072	0.023	49.227	0.360	0.223	0.060	0.252	0.036	0.009	0.037	0.004	0.016	0.003	0.008	0.001	0.005	0.001	0.002	0.025	0.146
HU39	B	WSA CL 5	83-377-6-2	enamel	1.925	2.394	7.257	0.822	0.128	9.991	23.780	0.042	0.181	0.069	122.433	0.160	0.878	0.038	0.003	16.671	0.223	0.140	0.051	0.235	0.048	0.009	0.040	0.005	0.023	0.005	0.010	0.001	0.009	0.000	0.003	0.015	0.129
HU68	B	WSA CL 2	83-377-3-5	enamel	0.923	6.036	4.130	2.016	0.082	5.696	14.195	0.010	0.123	0.232	117.537	0.184	0.855	0.028	0.009	27.040	0.297	0.127	0.061	0.234	0.042	0.008	0.044	0.006	0.027	0.004	0.013	0.002	0.006	0.004	0.001	0.032	0.076
HU51	B	WSA CL 25	83-377-61-1	enamel	0.239	3.471	4.773	0.838	0.042	4.833	9.743	0.016	0.086	0.075	94.884	0.151	0.448	0.031	0.002	50.629	0.228	0.141	0.056	0.232	0.056	0.012	0.047	0.005	0.023	0.003	0.009	0.001	0.008	0.001	0.002	0.016	0.073
HU52	B	WSA CL 25	83-377-61-2	enamel	3.304	6.171	4.236	2.364	0.062	4.157	10.090	0.018	0.071	0.026	107.601	0.116	0.615	0.028	0.005	44.142	0.218	0.087	0.045	0.220	0.047	0.006	0.041	0.004	0.017	0.002	0.010	0.001	0.006	0.000	0.001	0.110	0.110
HU69	B	WSA CL 2	83-377-3-15	enamel	1.381	4.682	2.288	1.849	0.019	12.784	14.326	0.029	0.132	0.094	132.005	0.115	0.492	0.024	0.005	42.712	0.228	0.125	0.038	0.187	0.022	0.008	0.028	0.004	0.017	0.003	0.007	0.001	0.004	0.001	0.001	0.014	0.213
HU55	B	NSA CL 1	83-377-24-2	enamel	1.161	6.745	4.615	0.373	0.052	9.398	9.660	0.344	0.072	0.085	137.791	0.119	1.243	0.040	0.007	30.477	0.217	0.071	0.043	0.184	0.019	0.006	0.029	0.002	0.018	0.002	0.005	0.001	0.003	0.000	0.001	0.011	0.113
HU77	B	WSA CL 2	83-377-3-101	enamel	2.085	8.079	4.607	2.822	0.102	4.175	20.137	0.021	0.089	0.092	48.790	0.133	0.689	0.014	0.019	31.937	0.203	0.127	0.041	0.178	0.036	0.009	0.032	0.004	0.018	0.004	0.010	0.001	0.006	0.000	0.001	0.024	0.088
HU62	B	WSA CL 1	83-377-2-4	enamel	0.695	4.716	3.227	0.990	0.037	4.213	14.003	0.066	0.083	0.058	82.839	0.130	1.125	0.036	0.007	23.088	0.194	0.100	0.036	0.171	0.023	0.007	0.031	0.003	0.021	0.002	0.008	0.001	0.005	0.001	0.001	0.012	0.158
HU50	B	WSA CL 17	83-377-29-3	enamel	1.670	1.386	0.477	1.470	0.083	3.313	13.326	0.013	0.105	0.073	76.694	0.103	0.426	0.016	0.002	15.616	0.147	0.105	0.034	0.167	0.025	0.005	0.026	0.003	0.016	0.002	0.008	0.001	0.004	0.000	0.002	0.006	0.061
HU30	B	Rayburn Cluster	69-66-589-1	enamel	2.078	8.052	47.288	0.112	0.186	2.911	13.011	0.013	0.083	0.102	72.927	0.121	0.544	0.008	0.012	13.213	0.161	0.084	0.040	0.157	0.043	0.007	0.030	0.004	0.021	0.003	0.007	0.001	0.004	0.000	0.002	0.006	0.100
HU48	B	WSA CL 17	83-377-29-1	enamel	1.987	4.329	6.986	1.155	0.070	9.199	21.219	0.166	0.156	0.446	128.150	0.112	1.730	0.062	0.022	17.876	0.190	0.115	0.032	0.154	0.033	0.006	0.026	0.002	0.016	0.003	0.006	0.001	0.003	0.001	0.001	0.020	0.076
HU47	B	WSA CL 6	83-377-7-6	enamel	0.757	6.598	4.569	0.904	0.022	3.575	15.980	0.023	0.049	0.057	63.752	0.089	0.648	0.065	0.017	28.656	0.189	0.104	0.032	0.138	0.020	0.004	0.022	0.003	0.013	0.003	0.006	0.001	0.004	0.000	0.001	0.017	0.122
HU63	B	WSA CL 1	83-377-2-5	enamel	2.079	8.727	2.297	0.896	0.065	1.943	9.443	0.014	0.212	0.224	64.021	0.061	1.014	0.021	0.009	17.996	0.133	0.070	0.023	0.112	0.020	0.006	0.016	0.001	0.010	0.001	0.004	0.001	0.002	0.000	0.001	0.010	0.079
HU72	B	WSA CL 2	83-377-3-41	enamel	0.000	6.033	4.128	1.497	0.046	5.358	19.114	4.233	0.094	0.167	82.196	0.063	0.801	0.023	0.014	44.816	0.138	0.093	0.026	0.098	0.019	0.004	0.021	0.002	0.011	0.002	0.003	0.000	0.004	0.001	0.001	0.014	0.073
HU57	B	NSA CL 1	83-377-24-4	enamel	2.771	5.368	4.132	0.556	0.043	3.902	8.674	0.428	0.114	0.296	96.233	0.072	1.434	0.036	0.007	30.720	0.144	0.047	0.022	0.094	0.017	0.003	0.019	0.002	0.010	0.002	0.005	0.000	0.002	0.001	0.001	0.014	0.110
HU79	B	NSA CL 8	83-377-41-1-1	enamel	1.385	4.697	1.377	0.734	0.032	9.771	11.905	0.095	0.157	0.214	109.214	0.065	0.882	0.024	0.012	24.294	0.142	0.068	0.020	0.085	0.008	0.004	0.016	0.001	0.007	0.002	0.004	0.001	0.002	0.000	0.001	0.024	0.062
HU78	B	WSA CL 2	83-377-3-108	enamel	0.461	2.680	6.876	0.991	0.024	2.004	8.830	0.019	0.087	0.063	55.865	0.039	0.470	0.022	0.009	34.858	0.086	0.062	0.019	0.084	0.011	0.003	0.015	0.001	0.007	0.001	0.004	0.000	0.003	0.000	0.001	0.006	0.076
HU66	B	WSA CL 1	83-377-2-8	enamel	2.075	7.369	5.042	1.627	0.037	6.193	24.791	0.031	0.074	0.073	55.852	0.075	1.300	0.033	0.007	20.643	0.111	0.062	0.017	0.078	0.016	0.003	0.018	0.002	0.007	0.001	0.004	0.000	0.002	0.000	0.001	0.022	0.060
HU53	B	WSA CL 25	83-377-61-3	enamel	2.806	2.718	3.260	0.416	0.015	2.103	7.808	0.013	0.107	0.137	80.247	0.045	1.210	0.036	0.005	19.535	0.056	0.045	0.017	0.073	0.007	0.003	0.017	0.001	0.008	0.001	0.002	0.000	0.002	0.001	0.001	0.002	0.092
HU42	B	WSA CL 5	83-377-6-5	enamel	1.153	4.690	182.901	1.833	0.082	9.246	29.462	0.039	0.186	0.114	38.241	0.128	0.901	0.024	0.021	66.126	0.136	0.055	0.014	0.067	0.008	0.004	0.010	0.001	0.011	0.002	0.007	0.001	0.003	0.000	0.002	0.023	0.140
HU70	B	WSA CL 2	83-377-3-33	enamel	2.057	2.656	6.361	1.291	0.048	3.996	17.336	0.024	0.123	0.092	98.292	0.041	1.218	0.035	0.009	19.293	0.108	0.061	0.014	0.057	0.007	0.002	0.009	0.001	0.003	0.000	0.002	0.000	0.000	0.000	0.001	0.009	0.067
HU83	B	NSA CL 8	83-377-41-1-5	enamel	0.693	4.028	5.512	0.815	0.087	4.356	17.950	0.013	0.082	0.092	92.199	0.036	1.243	0.026	0.009	14.074	0.041	0.059	0.010	0.055	0.014	0.003	0.009	0.001	0.008	0.002	0.003	0.000	0.003	0.001	0.001	0.002	0.096
HU46	B	WSA CL 6	83-377-7-5	enamel	1.538	3.722	5.678	3.478	0.068	4.581	17.817	0.016	0.093	0.132	64.426	0.046	1.912	0.072	0.013	43.394	0.066	0.054	0.010	0.049	0.010	0.002	0.009	0.001	0.004	0.001	0.002	0.000	0.002	0.000	0.001	0.023	0.088
HU61	B	NSA CL 2	83-377-25-3	enamel	2.080	3.358	0.919	0.134	0.011	1.691	5.703	0.019	0.179	0.125	87.802	0.040	0.641	0.026	0.005	6.928	0.050	0.030	0.012	0.045	0.010	0.002	0.010	0.001	0.007	0.001	0.001	0.000	0.002	0.000	0.001	0.003	0.069
HU86	B	NSA CL 8	83-377-41-1-8	enamel	2.304	4.686	1.374	0.526	0.044	3.349	10.690	0.021	0.107	0.061	71.564	0.026	1.071	0.019	0.007	12.414	0.044	0.043	0.010	0.045	0.007	0.001	0.006	0.001	0.004	0.000	0.002	0.000	0.001	0.001	0.001	0.004	0.073
HU71	B	WSA CL 2	83-377-3-35	enamel	2.773	7.387	2.757	1.553	0.160	3.089	9.192	0.016	0.076	0.139	82.630	0.033	1.559	0.033	0.009	18.311	0.036	0.025	0.007	0.043	0.005	0.001	0.006	0.001	0.005	0.001	0.001	0.000	0.002	0.000	0.001	0.017	0.036
HU64	B	WSA CL 1	83-377-2-6	enamel	1.385	1.342	0.918	1.008	0.043	1.584	8.246	0.004	0.121	0.147	98.526	0.017	0.647	0.023	0.002	12.615	0.027	0.023	0.006	0.037	0.002	0.001	0.003	0.001	0.003	0.000	0.001	0.000	0.000	0.000	0.001	0.003	0.054
HU85	B	NSA CL 8	83-377-41-1-7	enamel	1.848	6.040	2.755	0.565	0.037	4.062	26.198	0.014	0.078	0.078	83.310	0.026	0.882	0.025	0.007	16.879	0.037	0.045	0.008	0.033	0.009	0.003	0.006	0.001	0.004	0.001	0.002	0.000	0.003	0.000	0.001	0.002	0.073
HU73	B	WSA CL 2	83-377-3-61	enamel	2.770	5.366	6.884	0.599	0.058	4.834	10.796	0.145	0.130	0.098	66.894	0.010	1.079	0.033	0.019	13.018	0.031	0.019	0.006	0.032	0.004	0.001	0.002	0.001	0.004	0.000	0.001	0.000	0.002	0.000	0.001	0.003	0.083
HU58	B	NSA CL 1	83-377-24-5	enamel	2.537	4.691	5.502	0.277	0.052	5.163	13.334	0.069	0.139	0.099	97.333	0.044	1.205	0.039	0.005	21.270	0.061	0.038	0.009	0.032	0.006	0.001	0.008	0.001	0.004	0.001	0.003	0.001	0.003	0.001	0.001	0.005	0.110
HU59	B	NSA CL 2	83-377-25-1	enamel	0.883	7.699	2.195	0.409	0.007	2.766	6.993	0.007	0.096	0.103	83.891	0.020	0.896	0.025	0.002	20.352	0.027	0.020	0.004	0.030	0.005	0.001	0.004	0.001	0.003	0.001	0.001	0.000	0.001	0.000	0.001	0.002	0.040
HU56	B	NSA CL 1	83-377-24-3	enamel	2.305	6.697	2.749	0.414	0.128	2.489	10.864	0.067	0.072	0.112	96.949	0.017	1.695	0.043	0.014	36.440	0.037	0.020	0.006	0.029	0.003	0.002	0.005	0.001	0.002	0.001	0.001	0.000	0.001	0.000	0.001	0.001	0.078
HU67	B	WSA CL 2	83-377-3-3	enamel	0.925	6.719	0.919	2.338	0.032	5.676	7.323	0.017	0.097	0.046	53.330	0.013	0.564	0.021	0.028	55.008	0.060	0.020	0.007	0.028	0.005	0.001	0.004	0.001	0.004	0.000	0.001	0.000	0.000	0.000	0.001	0.085	0.052
HU74	B	WSA CL 2	83-377-3-81	enamel	0.923	1.341	2.293	1.450	0.082	3.389	10.790	0.020	0.114	0.094	72.418	0.042	0.735	0.068	0.012	18.080	0.045	0.023	0.004	0.025	0.001	0.001	0.008	0.001	0.002	0.001	0.002	0.000	0.003	0.000	0.001	0.028	0.071
HU75	B	WSA CL 2	83-377-3-89	enamel	2.077	4.023	1.835	1.716	0.039	4.604	13.173	0.029	0.105	0.122	67.845	0.019	0.565	0.018	0.014	30.335	0.044	0.021	0.006	0.021	0.002	0.002	0.005	0.000	0.004	0.001	0.000	0.000	0.001	0.000	0.001	0.022	0.068
HU60	B	NSA CL 2	83-377-25-2	enamel	1.382	4.015	2.747	2.292	0.052	1.182	10.263	0.013	0.119	0.133	136.983	0.012	1.743	0.031	0.014	35.410	0.051	0.011	0.002	0.020	0.005	0.002	0.002	0.000	0.001	0.000	0.001	0.000	0.001	0.000	0.001	0.014	0.093
HU82	B	NSA CL 8	83-377-41-1-4	enamel	2.305	4.688	4.125	1.343	0.054	10.814	21.306	0.011	0.076	0.138	99.928	0.010	1.814	0.033	0.002	29.801	0.024	0.011	0.003	0.017	0.001	0.001	0.003	0.000	0.001	0.000	0.001	0.000	0.000	0.000	0.001	0.022	0.050
HU87	B	NSA CL 8	83-377-41-1-9	enamel	1.381	4.012	3.202	1.173	0.024	13.545	11.186	0.013	0.101	0.124	72.041	0.031	0.600	0.015	0.009	28.550	0.023	0.015	0.005	0.016	0.004	0.002	0.006	0.000	0.004	0.000	0.001	0.000	0.000	0.000	0.001	0.005	0.057
HU65	B	WSA CL 1	83-377-2-7	enamel	2.538	6.035	1.377	1.123	0.011	0.862	6.629	0.005	0.123	0.158	131.483	0.014	0.544	0.020	0.007	19.769	0.017	0.013	0.002	0.015	0.004	0.002	0.004	0.000	0.002	0.000	0.001	0.000	0.001	0.000	0.001	0.004	0.073
HU81	B	NSA CL 8	83-377-41-1-3	enamel	2.074	4.688	6.415	1.016	0.052	2.876	9.082	0.007	0.069	0.131	78.694	0.007	0.927	0.021	0.009	35.367	0.019	0.013	0.004	0.014	0.005	0.001	0.003	0.000	0.003	0.000	0.001	0.000	0.000	0.000	0.001	0.013	0.058
HU76	B	WSA CL 2	83-377-3-96	enamel	2.077	3.354	4.131	1.798	0.056	3.033	11.306	0.023	1.916	4.194	266.981	0.004	2.334	0.046	0.005	22.503	0.009	0.006	0.001	0.007	0.002	0.000	0.003	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.023	0.001	0.017	0.030
HU54	B	NSA CL 1	83-377-24-1	enamel	0.692	6.034	1.835	0.237	0.108	1.847	6.372	0.016	0.074	0.697	149.344	0.007	0.465	0.011	0.000	109.325	0.009	0.011	0.001	0.007	0.001	0.002	0.001	0.000	0.001	0.000	0.001	0.000	0.000	0.002	0.001	0.002	0.067
HU84	B	NSA CL 8	83-377-41-1-6	enamel	2.536	6.029	0.917	0.343	0.043	3.293	6.028	0.015	0.181	0.216	44.303	0.010	0.315	0.013	0.005	14.805	0.009	0.007	0.001	0.002	0.001	0.001	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.001	0.001	0.006	0.080
HU80	B	NSA CL 8	83-377-41-1-2	enamel	2.649	4.686	1.603	0.525	0.051	3.846	9.883	0.020	0.058	0.100	115.943	0.003	0.751	0.015	0.004	17.451	0.003	0.003	0.000	0.002	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.006	0.035
HU40	B - Lab contam.	WSA CL 5	83-377-6-3	enamel	1.637	11.092	31.549	1.325	0.546	9.162	65.010	0.691	2.754	7.482	158.683	0.134	2.101	0.633	0.168	13.868	0.193	0.168	0.037	0.152	0.019	0.006	0.028	0.002	0.014	0.003	0.005	0.001	0.005	0.001	0.009	0.007	2.585
HU41	B - Lab contam.	WSA CL 5	83-377-6-4	enamel	1.080	5.486	4.922	1.070	0.215	7.693	33.242	0.139	0.720	2.184	131.220	0.102	1.452	0.303	0.034	10.839	0.154	0.133	0.024	0.119	0.011	0.005	0.015	0.002	0.011	0.002	0.004	0.001	0.002	0.000	0.006	0.006	0.672
HU43	B - Lab contam.	WSA CL 5	83-377-7-1	enamel	0.265	4.617	9.642	0.573	0.090	10.781	17.777	0.058	0.293	0.888	65.006	0.122	0.161	0.170	0.018	7.470	0.211	0.105	0.029	0.144	0.017	0.003	0.025	0.003	0.015	0.002	0.003	0.001	0.002	0.000	0.006	0.006	0.284
Modern Human				enamel	0.344	4.487	29.772	0.057	0.057	1.190	9.360	0.017	0.066	0.317	170.025	0.027	0.368	0.052	0.003	6.872	0.010	0.006	0.002	0.006	0.001	0.001	0.001	0.000	0.002	0.000	0.002	0.000	0.001	0.000	0.006	0.004	0.194
SO18		Crenshaw Core 17 - 125cmbs, soil		soil weak acid leachate	1.217	0.880	932.610	4.290	0.735	121.382	961.279	0.946	1.557	2.585	2.888	4.458	0.014	0.022	0.043	72.966	5.007	10.022	1.620	7.294	1.648	0.344	1.381	0.195	1.024	0.180	0.457	0.058	0.351	0.052	0.058	0.210	3.494
SO20		Crenshaw Core 8 - 50cmbs, soil		soil weak acid leachate	1.350	0.544	1007.077	3.900	0.840	130.335	1048.577	1.094	1.994	2.992	4.829	4.264	0.005	0.026	0.065	90.240	4.987	10.076	1.586	7.199	1.603	0.334	1.346	0.192	1.025	0.181	0.457	0.059	0.359	0.053	0.055	0.253	5.793
SO17		Crenshaw Core 17 - 50cmbs, soil		soil weak acid leachate	1.617	0.736	1064.766	5.652	0.963	160.579	1189.561	1.092	1.618	2.171	2.700	4.173	0.008	0.017	0.040	74.302	4.619	9.937	1.501	6.732	1.517	0.316	1.245	0.171	0.901	0.158	0.397	0.050	0.302	0.044	0.063	0.126	2.918
SO16		Crenshaw Core 17 - 25cmbs, soil		soil weak acid leachate	1.245	0.914	861.739	4.341	0.692	106.140	954.070	0.923	1.416	2.152	3.063	3.945	0.008	0.021	0.050	61.674	4.495	10.188	1.473	6.664	1.494	0.311	1.263	0.176	0.927	0.163	0.413	0.052	0.317	0.047	0.073	0.123	3.838
SO15		Crenshaw Core 7 - 50cmbs, soil		soil weak acid leachate	1.241	0.746	947.533	4.862	0.712	110.935	1014.457	0.932	1.644	2.225	2.802	3.913	0.008	0.026	0.049	91.063	4.365	9.523	1.443	6.564	1.478	0.314	1.281	0.179	0.940	0.165	0.418	0.053	0.318	0.047	0.045	0.142	4.126
SO19		Crenshaw Core 8 - 25cmbs, soil		soil weak acid leachate	1.137	0.621	829.636	3.665	0.605	113.445	830.829	0.838	1.708	2.042	3.814	3.703	0.004	0.025	0.049	77.590	4.155	9.118	1.365	5.910	1.387	0.293	1.189	0.168	0.888	0.157	0.397	0.051	0.305	0.045	0.040	0.202	4.527
SO11		Crenshaw Core 6 - 25cmbs, soil		soil weak acid leachate	1.101	0.756	830.799	3.916	0.608	106.816	813.392	0.854	1.428	1.896	2.526	3.390	0.006	0.021	0.044	71.608	3.787	8.050	1.235	5.410	1.289	0.271	1.107	0.155	0.819	0.145	0.367	0.046	0.282	0.041	0.043	0.114	3.607
SO14		Crenshaw Core 7 - 25cmbs, soil		soil weak acid leachate	0.919	0.766	614.963	3.087	0.495	102.436	681.393	0.778	1.161	1.519	2.540	2.711	0.006	0.014	0.036	46.807	3.181	6.716	0.976	4.428	1.049	0.218	0.898	0.126	0.662	0.117	0.298	0.038	0.230	0.034	0.043	0.090	2.941
SO12		Crenshaw Core 6 - 50cmbs, soil		soil weak acid leachate	0.913	0.339	698.665	2.805	0.578	58.763	742.459	0.748	0.882	1.724	2.018	2.442	0.005	0.017	0.031	45.516	3.034	6.009	0.950	4.305	0.997	0.208	0.851	0.119	0.626	0.109	0.278	0.035	0.217	0.032	0.034	0.119	2.791
SO10		Mound C - Center Block, Stratum A, soil	62-40-21a	soil weak acid leachate	0.602	0.945	828.595	1.305	0.518	57.943	805.672	0.689	1.054	2.076	4.892	2.525	0.004	0.014	0.019	35.641	2.878	6.637	0.899	4.052	0.935	0.196	0.808	0.117	0.633	0.113	0.287	0.036	0.220	0.031	0.099	0.129	5.841
SO8		NSA Cluster 8 - soil	83-377-41-4	soil weak acid leachate	0.918	0.292	665.796	1.991	0.568	50.764	718.423	0.629	0.879	1.222	2.697	2.161	0.006	0.013	0.023	51.845	2.535	5.986	0.807	3.627	0.869	0.179	0.726	0.102	0.550	0.095	0.244	0.031	0.192	0.028	0.070	0.243	2.569
SO6		WSA Cluster 1 - soil	83-377-2-2	soil weak acid leachate	0.803	0.347	589.929	1.770	0.456	46.628	568.416	0.497	0.718	0.975	1.707	1.737	0.004	0.012	0.011	37.860	2.066	4.966	0.685	3.106	0.739	0.153	0.615	0.087	0.454	0.079	0.203	0.026	0.158	0.023	0.041	0.076	2.010
SO5		WSA Cluster 1 - soil	83-377-2-1	soil weak acid leachate	0.792	0.383	585.844	2.067	0.535	69.974	638.994	0.583	0.948	1.042	2.972	1.635	0.011	0.012	0.026	32.958	2.010	4.227	0.623	2.774	0.639	0.134	0.534	0.075	0.392	0.069	0.175	0.022	0.135	0.020	0.070	0.276	1.794
SO13		Crenshaw Core 6 - 125cmbs, soil		soil weak acid leachate	0.392	0.275	262.541	1.109	0.293	26.389	339.444	0.384	0.467	0.493	1.046	1.047	0.003	0.006	0.010	13.470	1.664	3.118	0.510	2.263	0.489	0.100	0.397	0.054	0.277	0.048	0.121	0.016	0.094	0.013	0.023	0.068	1.177
SO9		NSA Cluster 2 - soil	83-377-25-1	soil weak acid leachate	0.509	0.158	390.943	0.921	0.393	24.078	489.253	0.379	0.515	0.704	1.850	1.122	0.003	0.008	0.010	23.725	1.466	3.317	0.477	2.135	0.480	0.099	0.400	0.056	0.296	0.052	0.135	0.017	0.103	0.015	0.037	0.096	1.755
SO7		WSA Cluster 25 - soil	83-377-61-3	soil weak acid leachate	0.421	0.154	317.903	1.073	0.292	20.040	320.931	0.298	0.364	0.504	1.020	1.069	0.004	0.007	0.006	19.467	1.303	3.171	0.456	2.033	0.469	0.095	0.390	0.055	0.290	0.051	0.131	0.017	0.104	0.015	0.028	0.093	1.254
SO2		Rayburn Cluster - soil inside cranium	69-66-589-6	soil weak acid leachate	0.475	0.158	356.211	0.751	0.373	15.243	443.824	0.269	0.463	0.557	1.614	0.975	0.003	0.419	0.007	19.985	1.357	3.240	0.447	1.967	0.446	0.089	0.361	0.051	0.265	0.047	0.118	0.015	0.093	0.013	0.031	0.059	1.482
SO1		Rayburn Cluster - soil outside cranium	69-66-589-6	soil weak acid leachate	0.386	0.245	303.549	0.624	0.320	15.887	384.105	0.233	0.352	0.386	1.791	0.957	0.003	0.036	0.008	20.024	1.291	2.895	0.432	1.890	0.415	0.084	0.338	0.047	0.246	0.043	0.108	0.014	0.084	0.012	0.032	0.051	1.539
SO3		Rayburn Cluster - soil outside cranium	69-66-589-7	soil weak acid leachate	0.347	0.299	297.631	0.681	0.315	17.098	368.158	0.254	0.369	0.441	1.938	0.906	0.003	0.016	0.015	19.595	1.256	2.910	0.422	1.844	0.405	0.082	0.334	0.047	0.245	0.043	0.110	0.014	0.085	0.012	0.036	0.047	2.114
SO4		Rayburn Cluster - soil inside cranium	69-66-589-7	soil weak acid leachate	0.423	0.189	293.511	0.604	0.299	14.703	330.650	0.227	0.406	0.453	1.695	0.869	0.002	0.028	0.014	19.754	1.205	2.892	0.396	1.760	0.395	0.081	0.324	0.045	0.239	0.042	0.106	0.014	0.084	0.012	0.030	0.051	1.683

(Raw corrected in ppb)	Context	Material	Li (ppb)	B	Al	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Y	Mo	Ag	Cd	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Th	U	Pb
Animal Replicate (raw)	Crenshaw	enamel	0.1305	1.4758	3.3845	0.2443	0.0278	0.5286	1.0913	0.0030	0.0195	0.0124	4.4782	0.0117	0.0327	0.0016	0.0009	38.2038	0.0116	0.0113	0.0031	0.0139	0.0045	0.0013	0.0028	0.0005	0.0028	0.0005	0.0011	0.0002	0.0011	0.0002	-0.0007	0.0012	0.0285
Animal Replicate (raw)	Crenshaw	enamel	0.1492	1.0385	1.6554	0.2590	0.0076	0.5459	1.4940	0.0025	0.0186	0.0166	4.1053	0.0133	0.0049	0.0015	0.0006	39.7724	0.0107	0.0143	0.0032	0.0148	0.0035	0.0015	0.0034	0.0005	0.0024	0.0004	0.0014	0.0001	0.0011	0.0002	-0.0015	0.0013	0.0277
Animal Replicate (raw)	Crenshaw	enamel	0.2729	1.3196	3.0461	0.2433	0.0258	0.4973	1.4409	0.0040	0.0217	0.0106	4.0277	0.0113	0.0203	0.0028	0.0011	34.6209	0.0114	0.0125	0.0032	0.0115	0.0045	0.0010	0.0032	0.0003	0.0020	0.0005	0.0011	0.0001	0.0009	0.0000	0.0017	0.0013	0.0247
Replicates STD as % of average			42.01	17.34	34.00	3.53	54.54	4.70	16.30	24.68	7.91	23.25	5.73	8.89	72.25	35.68	27.81	7.04	4.37	12.09	1.29	12.81	13.77	21.08	10.10	17.29	16.48	6.81	11.87	29.94	8.84	56.28	-1100.37	2.98	7.33