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Reconstructing the origins of the Perrins Ledge cremains using strontium isotope analysis☆

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ABSTRACT

Strontium isotope ($^{87}Sr/^{86}Sr$) analyses have been used effectively to reconstruct the origin of osteological remains that have not been exposed to increasing temperatures. However, previous research has shown that no thermally induced changes occur to original strontium isotope values ($^{87}Sr/^{86}Sr$) of bone and tooth specimens that have been subjected to temperatures between 100 and 1000 degrees Celsius, though the published literature regarding strontium isotope ratio stability and survivorship in thermally altered bone and teeth is limited. This is surprising given the potential implications for geolocation inquiries of cremains. This research demonstrates the utility and potential of strontium isotope analysis ($^{87}Sr/^{86}Sr$) in the contexts of thermally altered osteoarchaeological materials with the focus to reconstruct the geographic origins of the prehistoric cremated human remains from the Late Woodland period (600–850 CE) Perrins Ledge crematory, located in the Lower Illinois River Valley of the American Midwest. This mortuary site is unique in both regional and temporal contexts as an isolated crematorium structure containing at least 13 individuals (ten adults and three non-adults) represented by burned human skeletal remains of unknown origins. Strontium isotope signatures derived from bone and enamel samples of the cremains are compared with values obtained from osteoarchaeological faunal remains from three contemporary neighboring sites (Carlin, Apple Creek, and Newbridge) using thermal ionization mass spectrometry. Results indicate that the majority of the Perrins Ledge individuals reflect signatures beyond the standard (two-sigma) range considered local, with one adult bone and enamel sample and two of the three non-adult enamel samples that mirror local signatures.

1. Introduction

Burned skeletal remains from archaeological crematoria have been recovered from sites all over the world and represent a unique mortuary practice and taphonomic process (Cerezo-Román et al., 2017; Dias et al., 2018; Kuijt et al., 2014; Potter et al., 2011). Prehistoric Late Woodland communities of the Lower Illinois River Valley present the opportunity to better understand cremation practices by coupling data from individuals recovered from burial sites and proxies from neighboring contemporary habitation sites. Where the cremated individuals were transported from and how many were cremated are a few of the fundamental research questions with seemingly unattainable answers due to the overwhelming extensive damage of fire to skeletal remains. Insights into these and other research questions with elusive answers surrounding cremains are now illuminated by strontium isotope analysis because $^{87}Sr/^{86}Sr$ ratios do not fractionate with increasing temperatures (Beard and Johnson, 2000; Grupe and Hummel, 1991; Harbeck et al., 2011). Previous attempts to analyze light isotope ratios from Late Woodland period (400 to 1000 CE) cremains of this region experienced the problematic fractionated values common in light isotope ratios exposed to thermal alteration (Schurr et al., 2008). Given the fractionation resistant properties of heavier strontium isotope ratios to thermal exposure, strontium provides a solution to previous problems in isotopic analyses of burned human remains while providing temporally and spatially fixed reference points that can be used repeatedly to assess different questions and that complement efforts to characterize the pattern of bioavailable strontium signatures in developing isoscapes (Beehr, 2011; Hedman et al., 2018; Widga et al., 2017) (Fig. 1). The purpose of this study is to investigate the geographic origins of the thirteen individuals cremated at the prehistoric, Lower Illinois River Valley, Late Woodland period crematorium known as Perrins Ledge. This is accomplished by comparing bioavailable

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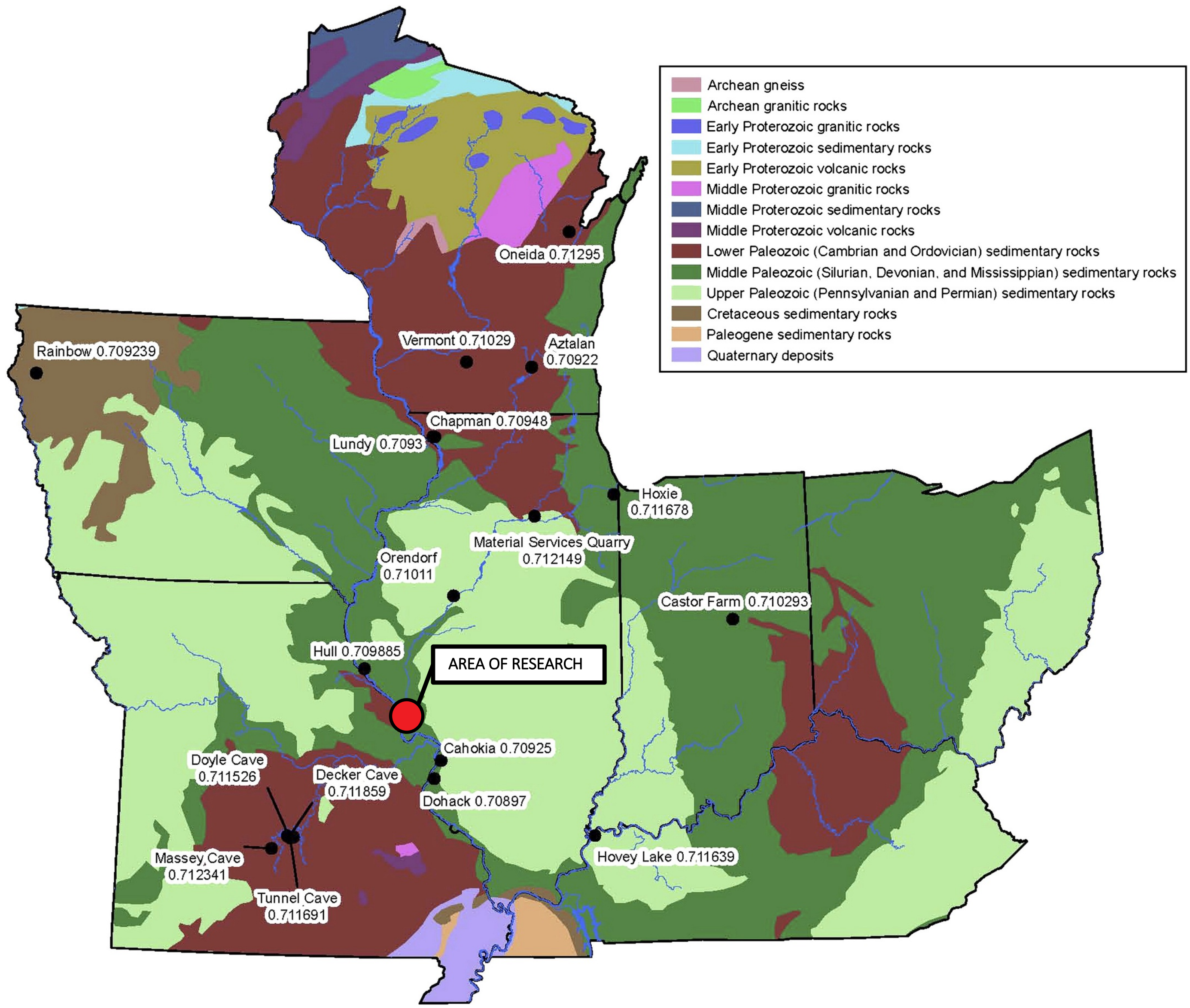

Fig. 1. Map showing area of research, including Perrins Ledge and baseline sites indicated in red, and surrounding bioavailable strontium signatures that characterize the developing isoscapes of the American Midwest (Hedman et al., 2009; Price et al., 2002, 2007). Modified from Hedman et al., 2009:66. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

strontium $^{87/86}$ signatures of the cremains with baseline archaeological faunal remains recovered from three neighboring contemporary habitation sites. Given that living bone tissue remodels but dentition does not, samples of both tissue types can be compared in an individual with regional baseline signatures to assess residency, migration and mobility inquiries (Beard and Johnson, 2000; Bentley, 2006; Ericson, 1985; Slovak and Paytan, 2011).

1.1. Perrins Ledge

Perrins Ledge Crematorium is located within a prehistoric Late Woodland (400 to 1000 CE) mortuary site located two miles north of Kampsville, Illinois on a southern talus slope of a bluff overlooking the western Illinois River floodplain in the Woods Creek Valley (Buikstra and Goldstein, 1973). The crematorium is the only one of two structures able to be excavated in conjunction with the Lower Illinois Valley Archaeological Program between late 1967 and 1968 (Figs. 2 and 3).

Radiocarbon dating places this site at around 600–850 CE which is consistent with the associated dating from artifacts recovered from the crematory basin. These include ceramic sherds, lithic debris, a scraper, a knife, an internally scorched conoidal base of a ceramic bowl, and a ceramic elbow pipe (Buikstra and Goldstein, 1973; Goldstein and Meyers, 2014). Burned human remains were recovered from the center eight by eight foot basin portion of the 20 by 20 ft structure of overlapping limestone slabs (Figs. 4, 5 and 6) (Buikstra and Goldstein, 1973).

Osteological assessment of the cremains determined the minimum number of individuals to be 13 with an approximately equal number of males and females per adult age group including four young adults, two middle-aged adults, two older adults, two children, one infant, and two sets of adult human remains too fragmentary to assess sex or age with any degree of certainty (Buikstra and Goldstein, 1973). Scattered remains, exhibiting both wet and dry, differential burning patterns at joint surfaces, as a result of thermal alteration with adhering soft tissue while in articulation, were recovered surrounding two individuals in situ that showed evidence only of wet burning (Fig. 7). This has been interpreted as evidence for at least two episodes of sequential burning and that fleshed individuals were placed in the crematorium, burned,

Fig. 2. Northern view of Perrins Ledge Crematory on the bluffs as indicated by the arrow. Image was provided by the Illinois State Museum.

and then moved aside to make room for subsequent cremation burning episodes of other individuals (Buikstra and Goldstein, 1973). Although cremation is not uncommon in the American Midwest, in situ burning and burial is rare among sites of this region (Goldstein and Meyers, 2014).

Typological assessment of the few artifacts recovered from within the crematorium could not provide direct cultural affiliation as they exhibit characteristics similar with those associated from a number of different contemporary nearby groups (Buikstra and Goldstein, 1973) (Figs. 8 and 9).

Archaeologists specializing in the region have put forth hypotheses as to which groups may have utilized Perrins Ledge crematorium. Initial hypotheses suggest that it was used by groups from nearby contemporary habitation sites based on proximity of those sites to Perrins Ledge (Buikstra and Goldstein, 1973; Goldstein and Meyers, 2014). Another proposes it was one of several mortuary sites used by non-sedentary Late Woodland hunter-gatherer groups who lived in widely dispersed homesteads (Schurr and Cook, 2014). This idea is based primarily on structural similarities between Perrins Ledge and other burned blufftop limestone tomb structures containing human remains in the extended region.

1.2. Cremation in the late woodland lower Illinois River valley

Although inhumation was the primary burial mode across time among the prehistoric groups of the Midwest, cremation has been interpreted, independent of ethnographic accounts, to have occurred among them all in significantly diverse forms (Baby, 1954; Binford,

Fig. 3. North facing view of the Perrins Ledge crematory excavation. Image provided by the Illinois State Museum.

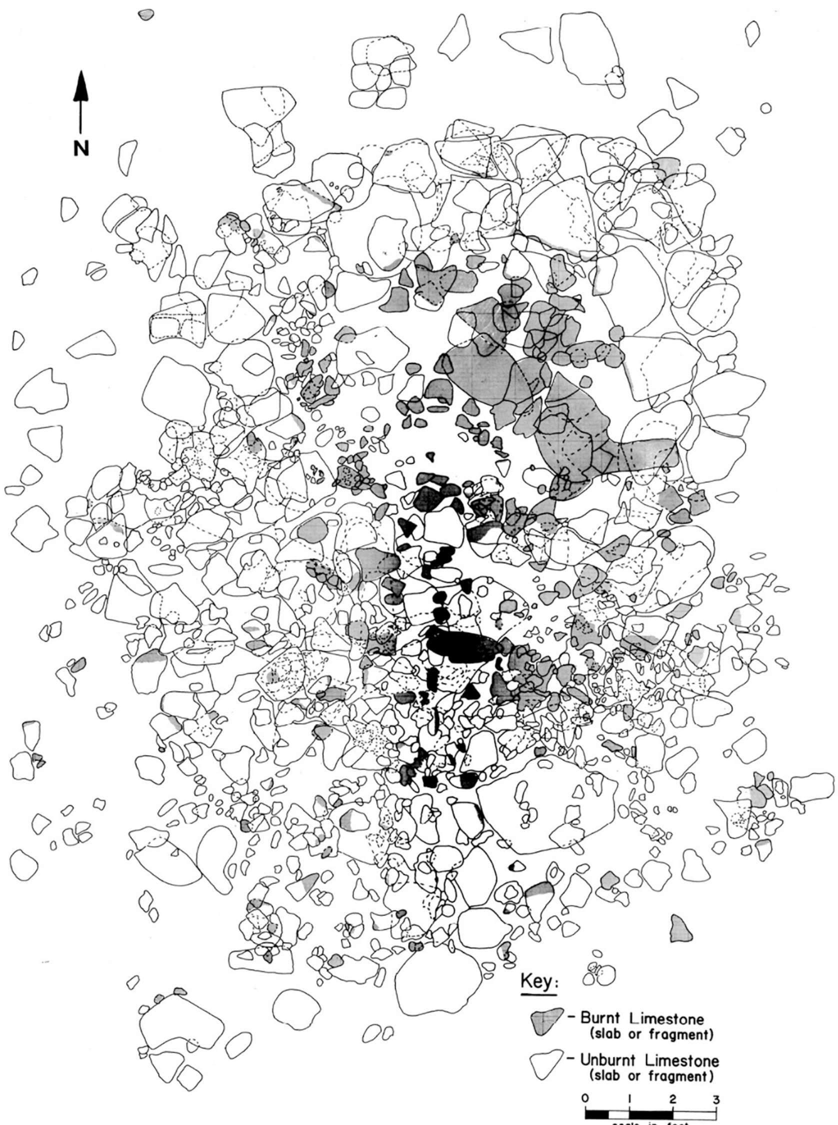

Fig. 4. Map of recovered limestone and associated thermal exposure. Gradient indicates an increase of temperatures with darker shading. Image provided by the Illinois State Museum.

1963; Freeman, 1966; Goldstein and Meyers, 2014; Haas, 1996; Hertz, 1960; Pleger, 2000; Rakita and Buikstra, 2005; Schurr and Cook, 2014; Thompson and Jakes, 2005). The archaeological record of the Late Woodland period (400 to 1000 CE) indicates that mortuary practices are more variable than before relating to the fact that this period is temporally defined by population dispersal and a greater emphasis on food production, although maize is not a staple until the latter half of the period (Buikstra and Milner, 1991; Goldstein and Meyers, 2014; Rose, 2008; VanDerwarker et al., 2013). Cremation in the Lower Illinois River Valley is not common during this time but appears farther north where secondary cremation burials have been recovered from within oval and linear mounds and, in a few examples, within alters buried at the hearts of animal effigy mounds. Most of these examples, of what can best be interpreted as intentional cremation, exist as deposits of remains previously cremated elsewhere, interred with secondary bundle and primary flexed burials (Goldstein and Meyers, 2014).

Perrins Ledge is unique in that the remains were recovered from within the location they were burned (in situ) with evidence suggesting two episodes of burning where the cremains and artifacts from the initial cremation event were swept aside to make way for the second event that left two burned individuals in the flexed position (Buikstra and Goldstein, 1973). This suggests that this site was constructed with the intent to process the human remains through the act of cremation. Similar contemporary structures in the extended region provide less certainty of the intention of burning. Fifteen miles northwest of Perrins Ledge, at a middle Late Woodland (600 to 900 CE) Yokem bluff-top mound site overlooking the Mississippi river, are several limestone slab and log-roofed crypts that have been either completely or partially burned but also contain human remains in situ (Buikstra and Goldstein, 1973; Schurr and Cook, 2014). Whether these crypts were burned to cremate the remains inside, to destroy the structures like the burning of charnel houses in later periods (Rowe, 1958; Brown, 1979; Goldstein, 2010), or if they incidentally caught fire is not entirely clear. Especially since at least one of these structures appears to have been only partially burned and distances between carbon dates from bone and wood indicate that in one case the structure was burned much later than the burials were placed (Schurr and Cook, 2014).

1.3. Strontium isotope analyses to reconstruct origins

Archaeological investigations of residential mobility are most effectively addressed using a method that compares strontium isotope

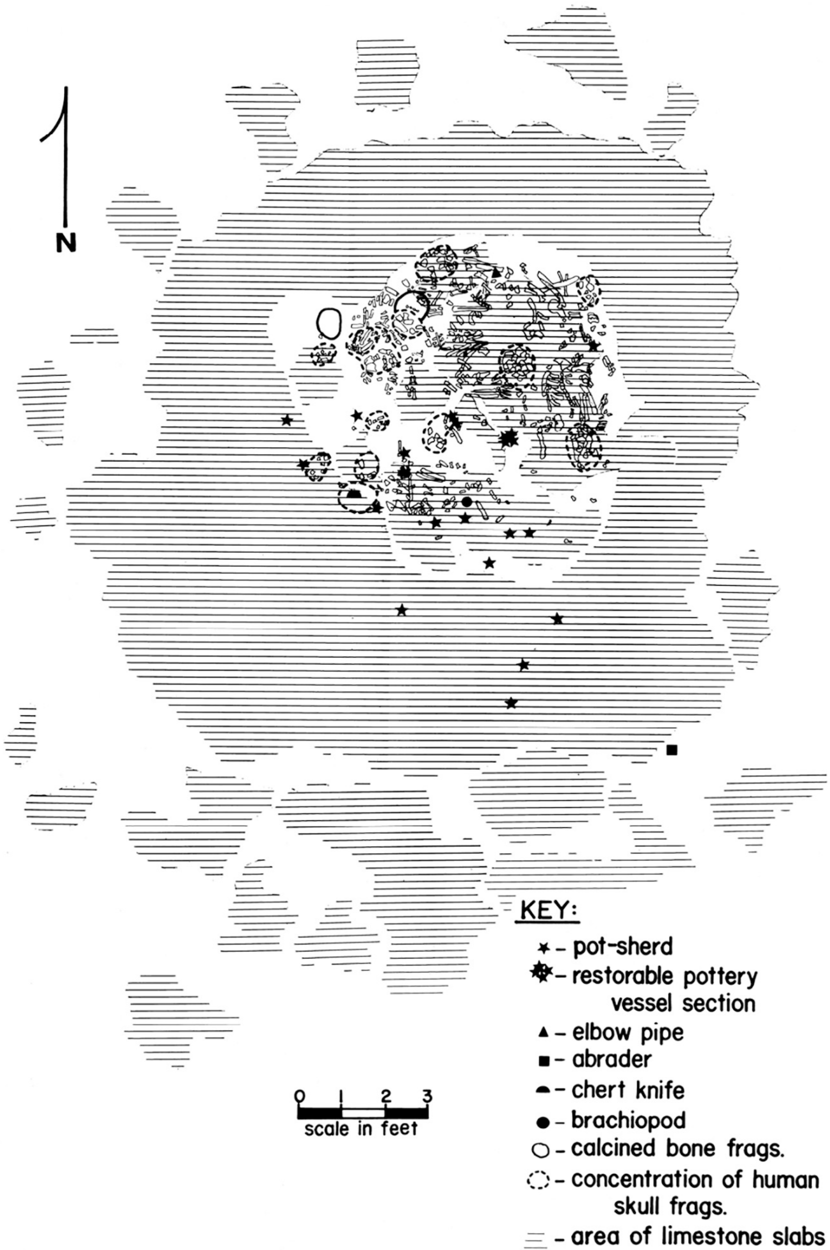

Fig. 5. Map of cremains and artifact concentrations in relation to limestone concentration. Image provided by the Illinois State Museum.

signatures between human skeletal remains and regional proxies (Bentley, 2006). The element strontium is an alkali earth metal that has four stable and naturally occurring isotopes: ^{84}Sr (0.56%), ^{86}Sr (9.86%), ^{87}Sr (7.0%), and ^{88}Sr (82.58%), defined by having a different number of neutrons than protons and thus different atomic mass (protons + neutrons).

In residential mobility studies, strontium isotope signatures of a sample are measured by the abundance ratio of radiogenic strontium isotope ^{87}Sr, formed as a result of the decay of rubidium-87, to non-radiogenic isotope ^{86}Sr (Beard and Johnson, 2000; Bentley, 2006; Faure and Powel, 1972; Faure, 1986). Geological strontium signatures vary greatly within a region due to differences in the timing and processes of bedrock formation and its age and composition at the time of sampling (Beard and Johnson, 2000; Faure and Powel, 1972; Faure, 1986; Stueber et al., 1993).

As rock weathers it releases exchangeable strontium into the local environment that is transported and dispersed via wind and water systems and is considered bioavailable strontium once it is absorbed by local flora and ingested by local fauna (Bentley, 2006). Strontium contributes to skeletal samples via the food chain due to similarities between the atomic properties of calcium and strontium that allow the bioavailable strontium to replace some calcium in the mineral components of the bone and teeth of the consumer. Animals ingest strontium from a variety of resources within the perimeter of the foraging range specific to their species. Therefore, animal remains can be used to calculate an average signature of the bioavailable strontium of a spatially defined region thus provide a baseline signature to which signatures derived from human skeletal samples can be compared (Price et al., 2002). Ideally, dental enamel samples will reflect isotope signatures of the region in which that individual lived during dental tissue development while bone samples will reflect the region occupied the last decade of life.

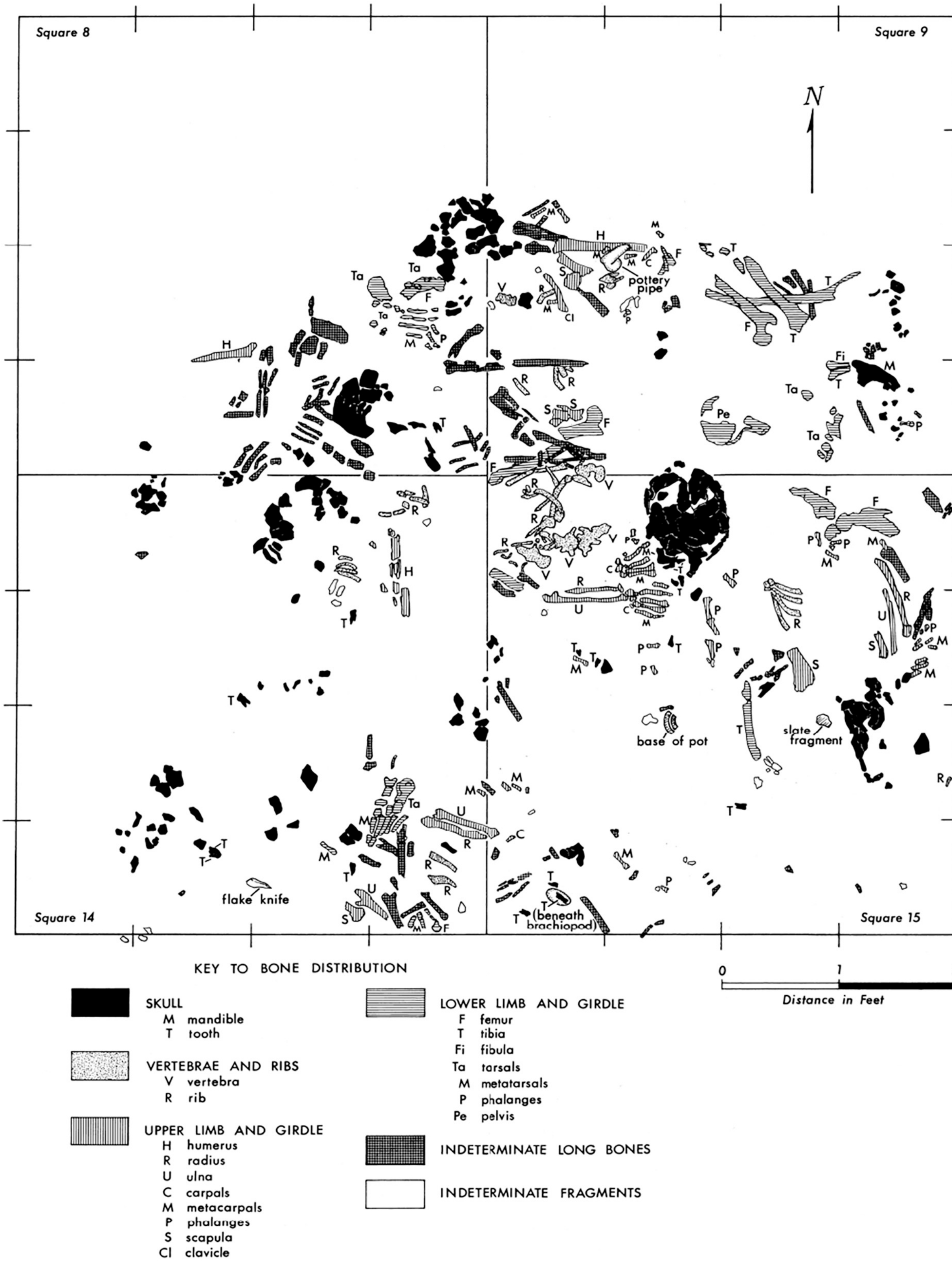

Fig. 6. Map of the Perrins Ledge cremains concentrations. Image provided by the Illinois State Museum.

2. Materials and methods

2.1. Data collection

Archaeological faunal remains collections, housed at the Illinois State Museum in Springfield, Illinois, containing procurable skeletal tissue samples from small-bodied non-human mammals from three previously excavated archaeological sites, were identified for their utility for deriving meaningful baseline data. The three habitation sites used to define the local strontium signature range that provided the faunal specimens used in this study include Carlin (11C124), Newbridge (11GE456) and Apple Creek (11GE2) and were chosen for their physical (< 10 miles) and temporal proximity to the Perrins Ledge Crematorium. Carlin and Newbridge were both occupied during the late

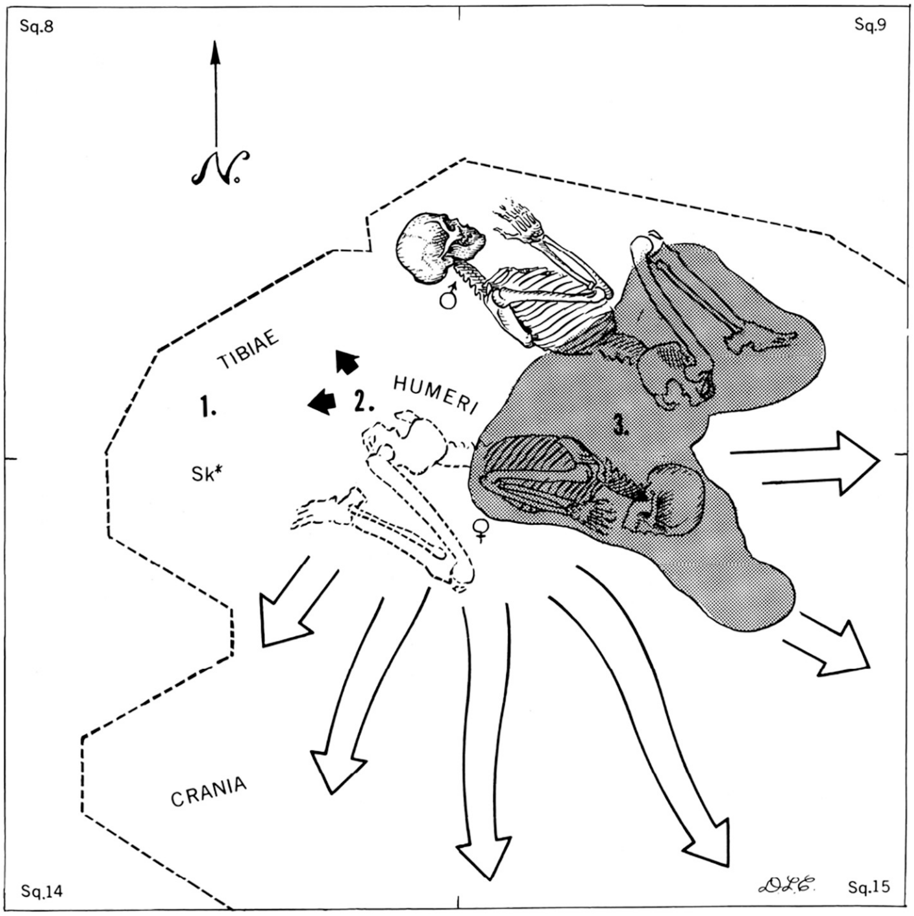

Fig. 7. Schematic representation of the Perrins Ledge Crematory basin with numerals indicating sites of sequential burning. Arrows show directions of bone scatter after cremation episodes and figures represent individuals from most recent mortuary event. Shaded areas indicate region of calcined bone. Image provided by the Illinois State Museum.

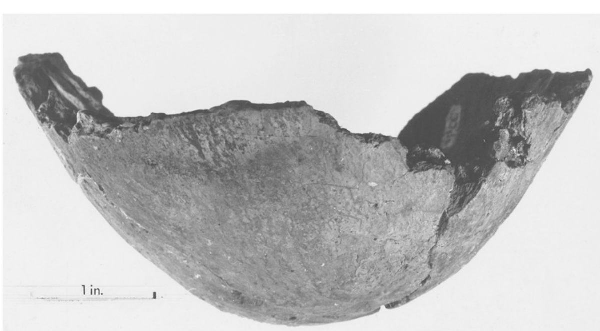

Fig. 8. Partially reconstructed internally charred conoidal base of a ceramic bowl, recovered from the south-central portion of the crematory basin. Image provided by the Illinois State Museum.

Fig. 9. Elbow-shaped ceramic pipe recovered between the upper left arm and rib cage of a flexed burial within the northeastern portion of the crematory basin. Image provided by the Illinois State Museum.

Woodland period (Asch and Asch, 1981) and Apple Creek contains a late Woodland component from which the baseline faunal samples were derived (Buikstra and Goldstein, 1973). Given that the variability of bioavailable strontium signatures in this region is not well understood, our definition of "local", based on these three habitation sites, is expected to encompass overlapping foraging ranges of the faunal species used in this study to appropriately represent the region inhabited by the prehistoric locals. Therefore, these sites are appropriate for testing if Perrins Ledge crematorium was utilized by contemporary prehistoric peoples inhabiting the immediate region as suggested by Buikstra and Goldstein (1973) and Goldstein and Meyers (2014). The Newbridge, Carlin, and Apple Creek specimens were transported from the Illinois State Museum, on loan, to the Boston University School of Medicine clean lab for tissue procurement and analysis. The human remains from the Perrins Ledge Crematorium (CAA project #280) are housed at the Center for American Archeology in Kampsville, Illinois. Tissue procurement of the Perrins Ledge Crematorium specimens used in the study, took place on site at the Center for American Archeology repository lab in the summer of 2013, then transported to Boston University School of Medicine for subsequent preparation, and analysis.

2.1.1. Baseline specimens

Small non-human mammal remains of taxa associated with short non-migratory foraging distances were carefully selected from the Newbridge, Carlin, and Apple Creek site osteoarchaeological assemblages to maintain regional variability of the bioavailable strontium

Table 1
Species and tissue types associated with the procured specimens used in this study from the faunal assemblages of each of the three baseline sites.

Specimen	Taxonomic classification	Common name	Origin	Tissue type
425b	*Ictidomys tridecemlineatus*	13-lined Ground Squirrel	Apple Creek	Enamel
341b	*Sylvilagus floridanus*	Eastern Cottontail	Apple Creek	Enamel
F267c	*Mustela vison*	Mink	Apple Creek	Crushed molar
600	*Urocyon cinereoargenteus*	Gray Fox	Apple Creek	Enamel
151	*Urocyon cinereoargenteus*	Gray Fox	Apple Creek	Enamel
121C-W	*Sciurus niger*	Eastern Fox Squirrel	Newbridge	Crushed molar
129C	*Ondatra zibethicus*	Muskrat	Newbridge	Enamel
120B	*Sylvilagus floridanus*	Eastern Cottontail	Newbridge	Enamel
113B	*Microtus* spp.	Vole	Newbridge	Bone
117C	*Scalopus aquaticus*	Mole	Newbridge	Bone
101–3.1	*Orozomys palustris*	Marsh Rice Rat	Carlin	Enamel
101–3.2	*Sylvilagus floridanus*	Eastern Cottontail	Carlin	Bone
60–2	*Ondatra zibethicus*	Muskrat	Carlin	Enamel
9–1	*Marmota manox*	Woodchuck	Carlin	Enamel
101–3	*Marmota manox*	Woodchuck	Carlin	Enamel

signatures of the study region (Table 1). Due to the destructive nature of strontium analyses and limited availability of faunal material meeting the criteria of this study, a conservative approach was applied to sampling. A total of 15 faunal specimens (5 per site) were chosen to be destroyed or permanently altered to provide baseline data for this study. Recent work testing variability of bioavailable strontium signatures suggests that multiple archaeological sites may be used to characterize strontium signature range of variation within a county or locality of human population (Hedman et al., 2018). Research has also shown that meaningful bioavailable strontium signatures can be effectively calculated for baseline data of a site using multiple specimens derived from a combination of faunal tissue types including enamel, bone and whole crushed molars (Hedman et al., 2009; Slater et al., 2014). For this study enamel was preferred to bone or tiny whole molars due to the resistant properties of enamel to diagenetic alteration compared to the other tissue types (Bentley, 2006). However, when the available enamel specimens that fit the criteria of this study were exhausted, bone ($n = 3$) and tiny whole crushed molars composed of both enamel and underlying dentin were used ($n = 2$) (Table 1).

2.1.2. Perrins Ledge cremains specimens

The standard sampling approach of strontium research aims to minimize the destruction to archaeological human remains and for this study this approach was employed. One sample of enamel and one of bone were sampled, per individual, when possible. Bone and dental tissue samples from the highly fragmented and commingled human remains were each identified using the same methods to derive the initial minimum number of individuals (MNI) as determined by Dr. Jane Buikstra during the original osteological assessment of the remains (Buikstra and Goldstein, 1973). Bone was procured from the posterior medial aspect of ten fully developed right petrous portions of the temporal bone and dental tissue samples were extracted from the dental enamel of five adults and three subadults totaling 18 specimens representing 13 individuals. Table 2 shows the approximate age range of crown development for the Perrins Ledge dental specimens. Based on observed variation of dental development between modern White populations and prehistoric Native American populations (Owsley and Jantz, 1983: AlQahtani et al., 2014) Ubelaker's (1979) chart was preferred to that of AlQahtani et al. (2010) and was used to derive approximate age ranges.

2.2. Specimens preparation

2.2.1. Tissue procurement and pretreatment

For all human and non-human specimens used in this study, of either bone or dental tissues, procurement was conducted using a diamond disc fitted to a rotary tool (Dremel®) on medium low speed to minimize the potential for thermal abrasion induced recrystallization with contaminants prior to standard mechanical and chemical cleaning steps. Weights of the tissues procured from the Perrins Ledge cremains ranged from 0.01 to 0.14 g and 0.0062 to 0.123 g from the Newbridge, Apple Creek, and Newbridge faunal remains samples. Diamond discs were changed and cleaned with 70% alcohol between each specimen processed. Procured tissues were each sonicated dry and loose infiltrating soils were removed three times. Then samples were mechanically cleaned with a diamond bit fitted to a low speed micro engraver.

For bone and teeth samples the outer surfaces were abrasively removed and for enamel samples dentine was additionally removed. The mechanical cleaning was observed under 100× bifocal microscopy with dual oblique lighting sources. Between specimens the diamond drill bit was sonicated in epure® water, then in a 1:1 solution of epure® water and 1 M hydrochloric acid (HCl) for fifteen minutes, in epure® water again, then dried under a flow hood. Samples were then stored in microcentrifuge tubes and transported to continue processing at the Class 100 workstations in the Boston University, Department of Earth and Environment's geochemistry clean lab and TIMS facility.

2.2.2. Strontium extraction

Samples were transferred into capped Teflon beakers and sonicated

Table 2
Crown development age ranges for Perrins Ledge dental specimens (Ubelaker, 1979).

Specimen	Tooth procured	Approximate age range of crown development
PLC11	Permanent First Molar (#30)	0 to 2.5 years
PLC12	Permanent First Molar (#19)	0 to 2.5 years
PLC13	Permanent First Molar (#14)	0 to 2.5 years
PLC14	First Premolar (#5)	0 to 2.5 years
PLC15	Permanent Second Molar (#15)	2.5 to 7 years
PLC16	Deciduous Second Molar (T)	0 to 9 months
PLC17	Permanent First Molar (#30)	0 to 2.5 years
PLC18	Deciduous Second Molar (T)	0 to 9 months

for thirty minutes in milliQ® water, three times. MilliQ® rinse leachates were created and stored for each sample for later assessment of diagenetic signatures if necessary. The samples were uncapped and dried on a hotplate at 120° Celsius (°C) under a flow hood. Once dried, samples were sonicated in weak acetic acid for fifteen minutes twice and rinsed with milliQ® water between baths. This is standard protocol for eliminating exogenous and external biogenic sources of strontium. Acetic acid leachates were also stored to assess diagenetic signatures at a later date if necessary. Bone samples were then ashed in lidded ceramic crucibles in a muffle oven for two hours at 1000 °C until completely calcined. Enamel and tooth specimens were dried down again and then both they and the bone samples were digested whole in 500 mL of 3.5 N nitric acid (HNO_3) capped and placed on the hotplate (120 °C) overnight. Samples were then dried down and drawn up in 500 ml of 5 N HNO_3 and transferred to microcentrifuge tubes and centrifuged at 1500rpms for five minutes before being loaded into pre-cleaned Teflon® ion exchange columns stored in 3.5 N HNO_3. Isolated strontium from the samples was then uncapped and dried down on the hotplate at 120 °C then re-dissolved in 2 μL 3.5 N nitric acid and loaded onto pre-outgassed single Re filaments with 2 μL of an emitter slurry (Ta_2O_2) and force dried at 0.6 amps then flash baked.

2.2.3. TIMS analysis

Samples, procedural blanks, and 100 ng Sr standards (SRM-987) were analyzed with a high precision (250–800 cycles analyzed per sample) Triton Finnigan™ Thermal Ionization Mass Spectrometer. The average $^{87}Sr/^{86}Sr$ signature of eight analyzed SRM-987 standards was 0.710249 (± 0.000004; 2 RSE uncertainty).

3. Results

The local signature was derived from combining the two-sigma ranges from the three baseline sites. In residential mobility research using strontium isotope ratios, the standard definition of an immigrant of a region is typically defined as an individual whose remains reflect strontium ratios that are beyond two standard deviations of the mean ratio of the regional baseline data with meaningful differences beginning at the fourth decimal place (Price et al., 1994, 2002, 2012; Slater et al., 2014). The resulting calculated two-sigma ranges for each site are as follows: 0.709371–0.710179 for Apple Creek, 0.709346–0.710480 for Newbridge, and 0.709270–0.710250 for Carlin (Table 3). The two-sigma range for all three sites combined is 0.709339–0.710293 (mean of 0.709816 with a standard deviation of 0.0002385). Following Hedman et al. (2018), the combined strontium signature calculations from the two sites (Applecreek and Newbridge; $N = 10$) may help characterize the values of this specific region of Greene County and include a two-sigma range of 0.709358–0.710331, a mean of 0.709844 and a standard deviation of 0.0002432.

Results indicate that four of the 18 human remains samples from Perrins Ledge Crematorium fall within two standard deviations of the mean strontium ratio for at least one of the three baseline signatures and thus classify as local. Of those that classify as local the strontium signature derived from sample PLC09A is 0.710291 falling within the two-sigma range for Newbridge, the signature derived from sample PLC14A, 0.710355, also falls within the two-sigma range for Newbridge, the signature derived from PLC16A is 0.710228, falling within the two-sigma range for both Newbridge and Carlin, and the calculated signature for PLC18A is 0.710122, which falls within the two-sigma range for all three sites: Apple Creek, Newbridge and Carlin. Overall, only one of the 10 adult bone samples and one of the five adult enamel samples reflect signatures that classify as local and two of the three non-adults also classify as local. Among those that classify as local are the two youngest children (PLC16A and PLC18A) who reflect signatures within the two-sigma range of at least two of the three baseline sites: the nine-month old (PLC18A) classifies as a local within all three baseline site ranges and the four-year-old (PLC16A) falls within range of both Newbridge and Carlin. Only two signatures derived from adult remains (one enamel sample from a first premolar and one bone sample) classify as local, and both of those signatures are only within the range of Newbridge. Tables 3, 4, 5 and Fig. 10 show the resulting mean signatures, standard deviation, and two-sigma range for each baseline site as well as the mean signatures for each of the Perrins Ledge samples.

Table 3
Mean $^{87}Sr/^{86}Sr$ signatures and ranges for each baseline site.

Site name	Smithsonian trinomial	$^{87}Sr/^{86}Sr$ mean	2 sigma (±)	2 sigma range
Apple creek	11GE2	0.709775	0.000404192	0.709371–0.710179
Newbridge	11GE456	0.709913	0.000566901	0.709346–0.710480
Carlin	11C124	0.709760	0.000489798	0.709270–0.710250

Table 4
$^{87}Sr/^{86}Sr$ signatures of faunal remains from baseline sites.

Specimen	Tissue type	$^{87}Sr/^{86}Sr$	2 sigma (±)	Site
151	Tooth	0.709542	0.000005	Apple Creek
425b	Tooth	0.709620	0.000004	Apple Creek
341B	Tooth	0.709928	0.000002	Apple Creek
600	Tooth	0.710023	0.000005	Apple Creek
F267c	Tooth	0.709763	0.000004	Apple Creek
117C	Bone	0.709739	0.000003	Newbridge
121C-W	Tooth	0.709517	0.000003	Newbridge
129C	Tooth	0.710170	0.000004	Newbridge
120B	Tooth	0.710167	0.000007	Newbridge
113B	Bone	0.709974	0.000006	Newbridge
101-3	Tooth	0.709916	0.000006	Carlin
101-3.1	Tooth	0.709510	0.000005	Carlin
9-1	Tooth	0.709927	0.000008	Carlin
101-3.2	Bone	0.709476	0.000003	Carlin
60-2B	Tooth	0.709971	0.000005	Carlin

4. Discussion

4.1. On Perrins Ledge cremains results

4.1.1. Diagenetic alteration

Reconstructing origins relies heavily upon the isolation of biogenic Sr from diagenetic Sr that can otherwise contaminate samples with Sr derived from the surrounding burial environment (Budd et al., 2004). As previously mentioned, sampling strategies and methods involving mechanical and chemical cleaning were carefully employed to eliminate exogenous and external biogenic sources of strontium as effectively as possible, especially from bone samples. Enamel is more resistant to diagenesis than bone (Bentley, 2006). Recent work, however, has shown that once bone has reached thermal induced recrystallization (or calcination) it is as resistant, if not more so, than enamel (Snoeck et al., 2015). The extent of thermal exposure exhibited in the Perrins Ledge cremains appears to encompass the known spectrum of thermal alteration to bone from uncharred to calcined. This pattern of exposure can be approximated from Figs. 4 and 5. Assessment of temperatures reached during the cremation events was originally determined to be in excess of 932 °C based on the presence of complete exfoliation of tooth enamel (Buikstra and Goldstein, 1973; Furuhata and Yamamoto, 1967). At least four of the samples procured from the Perrins Ledge cremains appear to have been calcined (PLC3, PLC5, PLC7 and PLC8). It is possible that more of the samples may have been calcined as well considering that the identification of calcined bone can be easily obscured by soil staining over time (Buikstra and Goldstein, 1973).

In addition, the petrous portion of the temporal bone tends to

Table 5
$^{87}Sr/^{86}Sr$ signatures, tissue type, age, and locality of the Perrins Ledge cremains.

Specimen	$^{87}Sr/^{86}Sr$	2 sigma	Tissue type	Age group	Locality
PLC01A	0.711520	0.000005	Bone	Adult	Non-local
PLC02A	0.710621	0.000005	Bone	Adult	Non-local
PLC03A	0.710916	0.000005	Bone	Adult	Non-local
PLC04A	0.710640	0.000004	Bone	Adult	Non-local
PLC05A	0.710778	0.000004	Bone	Adult	Non-local
PLC06A	0.710757	0.000004	Bone	Adult	Non-local
PLC07A	0.711023	0.000005	Bone	Adult	Non-local
PLC08A	0.710728	0.000003	Bone	Adult	Non-local
PLC09A	0.710291	0.000006	Bone	Adult	Newbridge
PLC10A	0.711137	0.000004	Bone	Adult	Non-local
PLC11A	0.711226	0.000004	Enamel (M1;#30)	Adult	Non-local
PLC12A	0.711143	0.000003	Enamel (M1;#19)	Adult	Non-local
PLC13A	0.711062	0.000003	Enamel (M1;#14)	Adult	Non-local
PLC14A	0.710355	0.000004	Enamel (PM1;#5)	Adult	Newbridge
PLC15A	0.711311	0.000005	Enamel (M2;#15)	Adult	Non-local
PLC16A	0.710228	0.000004	Enamel (m2;T)	~ 4 years old	Newbridge, Carlin
PLC17A	0.710528	0.000004	Enamel (M1;#30)	~ 7 years old	Non-local
PLC18A	0.710122	0.000006	Enamel (m2:T)	~ 9 months old	Apple Creek, Newbridge, Carlin

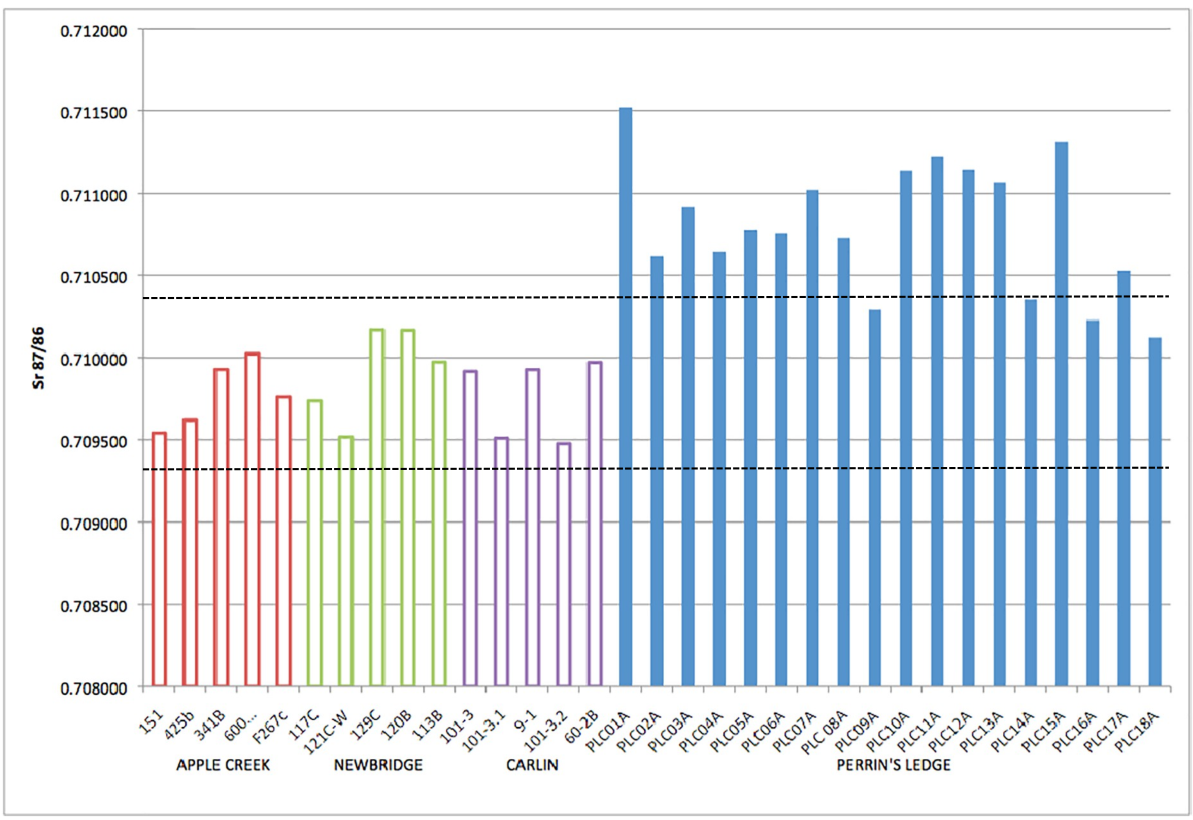

Fig. 10. $^{87}Sr/^{86}Sr$ ratios of each baseline site specimen and Perrins Ledge samples. Dotted horizontal lines indicate the upper and lower signature limits for the calculated "local" range.

remain more protected than outer regions of the cranium and post-cranial elements until fragmentation occurs. Heavy mechanical cleaning greatly reduced the size of the specimens thus removing outer layers of bone that may have been in contact with exogenous contaminants that are potentially capable of altering biogenic signatures during recrystallization.

Of concern was the possibility of the carbonate rock (i.e. limestone), of which the structure is constructed, to alter the true biogenic signatures of the samples. However, the limestone of the Lower Illinois River Valley reflects reported $^{87}Sr/^{86}Sr$ signatures that range from between 0.7076 and 0.7098 (Stueber et al., 1993). If the limestone has contaminated the Perrins Ledge osseous cremains beyond the ability to be removed by chemical treatments, then the limestone values would have pulled the signatures down. Instead the signatures are quite high.

4.1.2. *Origins and mobility*

As previously stated, the signature from the bone sample from one adult sample (PLC09A) falls within the upper range (0.70935–0.71048) for Newbridge at 0.71029. This suggests that this individual may have lived in this region for the later part of their life. All other bone samples from the other Perrins Ledge cremains fall beyond two standard deviations of any of the local baseline signatures suggesting that during the last decade of life these individuals did not live at those baseline habitation sites for long enough for the local strontium isotope signatures to develop within the mineral components of their bones. A fully developed first premolar from one individual reflects a signature that falls within the upper Newbridge range. The region sampled (mid-buccal aspect) from the crown of the first premolar of this individual (PLC14A) is known to develop between the ages of three and five (Hillson, 1996) suggesting that this individual may have lived near the Newbridge site during that period of development. The excavation field notes were inaccessible at the time of tissue procurement and therefore it not known whether these two tissue samples are from the same individual at this time. However, the signatures from the two deciduous second molars representing the two youngest individuals (the four-year-old and nine-month-old) that reflect local signatures raise some interesting inquiries about possible familial relations.

Without access to the initial field excavation or osteological assessment notes it was not possible at the time that the samples were collected to confirm which sex and age estimation belonged to each specimen as initially determined by Dr. Jane Buikstra. Time constraints during data collection limited the ability to assess the cremains beyond determining the minimum number of individuals and identifying the non-adults by sorting dentition. Only five completely developed teeth could be isolated as belonging to separate adult individuals based on duplicate representation. It is assumed that the teeth belong to five of the ten individuals also represented by bone samples. With that said, the two adult signatures that classify as local for Newbridge may or may not be from a single individual.

4.2. On archaeological interpretations of Perrins Ledge

Overall, due to the relatively poor condition and commingling of the cremains, and without access to original field notes and osteological analyses, these results do little to investigate detailed life histories of these individuals. However, they do imply that this crematorium was used to dispose of primarily non-local individuals. This is unusual considering that it is situated on a slope near the upper bluffs where burials were most often reserved for productive members of local society (Charles and Buikstra, 1983). The fact that some of the samples reflect signatures from within the local region suggests that interaction between two separate groups is possible. Intragroup marriage between more distantly located Late Woodland populations is one suggestion. Research exploring biological distance in the region indicates that Late Woodland groups had a larger sphere of biological interaction when compared to the later Mississippian populations (1000–1300 CE) (Steadman, 2001). It is not surprising then that the elbow-shaped pipe, recovered near the upper arm of one of the flexed burials at Perrins Ledge, is morphologically similar to four pipes excavated from mounds 6–9 of the Yokem site, given that many components of Yokem are contemporary with Perrins Ledge and is only 15 miles from it (Buikstra and Goldstein, 1973; Schurr and Cook, 2014). One of these burned limestone tomb structures, situated between mounds 6 and 7, contained ten adults, two children and an infant ($n = 13$), an interestingly similar mortality profile to what was recovered from Perrins Ledge crematorium (Buikstra and Goldstein, 1973; Schurr and Cook, 2014).

Buikstra and Goldstein (1973) consider possible seasonal use of the crematorium, when frozen ground during winter months would make inhumation more difficult. Although construction of a crematorium may appear to require more investment, repeated use of the structure for the processing of multiple individuals at once for, perhaps, redeposit of cremains in warmer months may conserve effort and allow for immediate disposal of the dead during the winter. It has been suggested that the Perrins Ledge Crematorium was possibly used as a processing site where cremains were intended to be eventually redeposited in a cemetery elsewhere as a secondary cremation (Goldstein and Meyers, 2014). If this site was used to dispose of non-locals, however, it is unlikely that their remains would be redeposited in any local cemeteries reserved for the local inhabitants of the area.

There are no indications of trauma due to conflict that would result in the individuals from either of the two cremation events, to lose their lives simultaneously. In fact, other than extensive thermal trauma, only one small well-healed, depression fracture was noted, occurring on the frontal bone of the pathological cranium of an older male individual (Buikstra and Goldstein, 1973). The pattern of extensive fracturing of the cremated bone appears to be thermally induced from the cremation events.

It is unclear whether there is any relationship of disease and the individuals cremated.

The identification of stage, severity, and pattern distribution of pathological conditions can be obscured by extensive taphonomic destruction caused by thermal exposure to skeletal remains further complicated by commingling of multiple individuals represented by highly fragmented elements. The few pathological manifestations extensive enough to have affected the bone include thickening of diploë in the frontal, parietal, and occipital bones of an incomplete cranium and periostitis of the proximal end of a fragmented femur (Buikstra and Goldstein, 1973). The mortality profile could be interpreted to be consistent with that which is caused by infectious disease and was even suggested as a possibility in the initial osteological assessment (Buikstra and Goldstein, 1973). Infectious disease can kill a host before leaving traces to bone and cremation has been recorded as a mortuary ritual with intent to control the spread of disease in early ethnographic accounts of Yumen groups (Spier, 1933). However, paleoepidemiological investigations of temporal groups in the area indicate that Late Woodland populations exhibited nearly half the frequency of pathological manifestations when compared to the later Mississippian groups associated with greater population densities and sedentism (Lallo et al., 1978). Even still, Perrins Ledge crematorium could be a unique mortuary site for a unique circumstance.

4.3. On strontium analysis of thermally altered osseous materials

It is well documented that light isotope ratios (i.e. carbon, nitrogen, and oxygen) are significantly fractionated by thermal alteration (Grupe and Hummel, 1991; Harbeck et al., 2011; Herrmann and Grupe, 1988; Schurr et al., 2008). However, strontium isotope ratio ($^{87}Sr/^{86}Sr$) values remain unaltered in bone and dental specimens exposed to increasing temperatures of up to 1832 °F (1000 °C) (Beard and Johnson, 2000; Grupe and Hummel, 1991; Harbeck et al., 2011).

Although strontium isotope analysis has been the standard approach for assessing residential mobility in archaeological contexts since the early 1980's, it is surprising that the potential of strontium isotope analyses of cremated remains has been largely ignored with few researchers having intentionally explored the application of strontium isotope analysis of previously thermally altered remains (Grupe and Hummel, 1991; Harbeck et al., 2011). However, more recently the number of studies in this area has increased (Graham and Honn, 2015; Harvig et al., 2014; Snoeck et al., 2015; Snoeck et al., 2018) and further work in this effort may result in progressive utility of this method in the many contexts where cremation or thermally altered remains exist, considering it can provide robust data where methods are lacking due to the destructive nature of thermal alteration to bone.

The applications of the present study may also have utility in non-archaeological, modern, contexts where burned human remains or cremains are encountered. Globalization and mass distribution of present-day food stuffs is a predicted confounding factor for efforts to reconstruct origins of individuals given that contemporary human populations seldom ingest the bioavailable strontium of the geographical region in which they live. Instead, it is sourced from foods gathered and distributed from a variety of different geographical locations. Temporal regional human population profiles can be developed as baseline data similar to how local faunal remains are used by archaeologists in residential mobility research. Effective regional population profiles for comparison, however, cannot only consist of strontium isotope values due to the broadening variation between populations as an effect of the globalization of modern food stuffs. They must also include other trace element data and isotope values simultaneously. For a current review of these seminal efforts used on modern unburned human remains see Chesson et al. (2018).

5. Conclusion

The data from the present analyses more firmly support the hypothesis suggesting that Perrins Ledge Crematorium was used by non-sedentary hunter-gatherers from widely dispersed homesteads or hamlets (Schurr and Cook, 2014). Non-sedentary individuals with a wide foraging range will likely reflect the sum of strontium signatures acquired from resources across the landscape they travel and thus may not provide meaningful data for assessing origins.

However, results of this study indicate that at least one of the 13 adult individuals and two of the three children reflect signatures fall within those ranges calculated as local from the three baseline sites in the local region (Apple Creek, Newbridge, and Carlin). Therefore, results also indicate that Perrins Ledge Crematorium may have been used by groups inhabiting the local area, as other specialists in the region have suggested (Buikstra and Goldstein, 1973; Goldstein and Meyers, 2014). Furthermore, these results do not rule out the possibility that Perrins Ledge could have been used by the local community to dispose primarily of non-locals.

This study has demonstrated the utility of strontium isotope research in the contexts of cremation that includes a level of extensive fragmentation and organic destruction to the extent of calcination.

6. Implications for future research

Combining the results from this study and information from the Perrins Ledge Crematorium excavation site, field notes, and osteological assessment may provide more information for interpreting life histories of the cremated individuals. Even standard modern methods used to effectively assess age and sex in prehistoric cremains is greatly limited by the extensive damage to useful indicators caused by thermal alteration and burial conditions over extended periods. The original osteological methods, as detailed in Buikstra and Goldstein (1973), to determine age (e.g. endocranial suture closure, hypercementosis of tooth roots, secondary dentin deposition, etc.) and sex (cranial robusticity and maximum occipital thickness, etc.) are not that far off from the limited options currently available to assess cremains of this condition. However, these initial assessments were conducted long enough ago, that revisiting the cremains with more current approaches may provide even further insights into life histories of the Perrins Ledge individuals.

While goals to characterize the Greater Midwest are currently underway (Hedman et al., 2018) there is still much work to be done to test the range of variability of bioavailable strontium in the Lower Illinois River Valley. The baseline data from the present study hints at the potential of this landscape to provide enough variability to differentiate between regions within this area (Greene versus Calhoun counties) but future research should expand sample sizes per site where possible and more archaeological sites need to be assessed within closer proximity to one another.

With regards to burned remains in general, as previously mentioned, current research is in the process to test the applicability of incorporating standard strontium isotope research into modern contexts with early efforts focused on reconstructing the origins of those individuals that die attempting to cross the U.S. - Mexican borders (Juarez, 2008). More recent work has shown that strontium isotope ratios can be extracted from human hair samples (Tipple et al., 2013) and fingernails (Mancuso and Ehleringer, 2018). Comparing isotope ratios between the living and unknown decedents may prove to be useful in identification efforts given that soft and hard tissues contain comparable components. Considering the current movement in strontium isotope work and the potential of baseline data derived from modern human population profiles constructed from multiple types of geochemical data sets, the broader implications of the present study are illuminated. The opportunity to reconstruct the origins of the thousands of individuals represented by highly fragmented calcined bone, from which DNA cannot be extracted become a realistic possibility in the future.

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