Isotopic Evidence for Long-Distance Connections of the AD Thirteenth-Century Promontory Caves Occupants

Jessica Z. Metcalfe, John W. Ives, Sabrina Shirazi, Kevin P. Gilmore, Jennifer Hallson, Fiona Brock, Bonnie J. Clark, and Beth Shapiro

The Promontory caves (Utah) and Franktown Cave (Colorado) contain high-fidelity records of short-term occupations by groups with material culture connections to the Subarctic/Northern Plains. This research uses Promontory and Franktown bison dung, hair, hide, and bone collagen to establish local baseline carbon isotopic variability and identify leather from a distant source. The ankle wrap of one Promontory Cave 1 moccasin had a $\delta^{13}C$ value that indicates a substantial C4 component to the animal’s diet, unlike the C3 diets inferred from 171 other Promontory and northern Utah bison samples. We draw on a unique combination of multi-tissue isotopic analysis, carbon isoscapes, ancient DNA (species and sex identification), tissue turnover rates, archaeological contexts, and bison ecology to show that the high $\delta^{13}C$ value was not likely a result of local plant consumption, bison mobility, or trade. Instead, the bison hide was likely acquired via long-distance travel to/from an area of abundant C4 grasses far to the south or east. Expansive landscape knowledge gained through long-distance associations would have allowed Promontory caves inhabitants to make well-informed decisions about directions and routes of movement for a territorial shift, which seems to have occurred in the late thirteenth century.

Keywords: stable isotopes, migration, mobility, bison, Great Basin, Promontory Caves, Franktown Cave, Dene, Athapaskan, Apachean

Las cuevas Promontory (Utah) y la Cueva Franktown (Colorado) contienen registros de alta fidelidad en cuanto a las ocupaciones de corto término de grupos humanos con cultura material conectada al Subártico/Planicies del Norte. Esta investigación utiliza excremento, pelo, piel de cuero y colágeno del hueso de bisonte provenientes de los sitios Promontory y Franktown para establecer una base de datos isotópicos locales y variabilidad isotópica de carbono e identifica la piel de cuero de procedencia lejana. La envoltura de tobillo de un mocasín recuperado de la Cueva 1 de Promontory tuvo un valor $\delta^{13}C$ que indica un componente C4 considerable en la dieta del animal, lo que es un resultado distinto a las dietas C3 que se identificaron a partir del análisis de 171 muestras de bisonte provenientes de Promontory y el norte de Utah. Aplicamos una combinación única de análisis isotópico de tejidos múltiples, mapas isotópicos (“isoscapes”) de carbono, ADN antiguo (identificación de sexo y especie), tasa de remodelación de tejidos, contextos arqueológicos y la ecología del bisonte para demostrar que el valor alto $\delta^{13}C$ probablemente no es un resultado debido al consumo de plantas locales, movilidad del bisonte o comercio. En cambio, la piel de cuero del bisonte fue probablemente adquirida a través de viajes de larga distancia hacia zonas con

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American Antiquity 86(3), 2021, pp. 526–548

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doi:10.1017/aaq.2020.116

526

https://doi.org/10.1017/aaq.2020.116 Published online by Cambridge University Press
pastos C₄ abundantes muy al sur o al este. El conocimiento extenso sobre el paisaje obtenido a través de asociaciones de larga distancia debió permitir a los habitantes de las cuevas Promontory tomar decisiones bien informadas sobre las direcciones y rutas de movimiento para realizar un cambio territorial, el cual parece haber ocurrido a finales del siglo XIII.

Palabras clave: isótopos estables, migración, movilidad, bisonte, Gran Cuenca, Cueva Promontory, Cueva Franktown, Dene, Atapascano, Apacheano

The standard practice of eliminating apparent “anomalous” results preclude[s] the possibility of discovering the unexpected, identifying the unusual, and uncovering individual short-lived visitation events [Seymour 2010:158].

In the quotation above, Seymour (2010) argues that chronometric dating outliers can provide critical evidence of periodic short-term occupations, particularly among highly mobile populations. In this article, we argue that Seymour’s statement is even more relevant for stable isotope analyses. In radiocarbon dating, tiny amounts of contaminant carbon can have extremely large effects on measurement results and hence on inferred dates (e.g., Wood et al. 2016; Zazula et al. 2014). In contrast, stable carbon isotope ($\delta^{13}C$) values measured from purified materials such as bone collagen and hair keratin are less susceptible to contamination. Only large-scale biochemical alteration and/or contamination significantly alters $\delta^{13}C$ values, and such changes can usually be detected using quality-control indicators (Ambrose 1990; van Klinken 1999). Consequently, a single carbon stable isotope outlier can provide robust insight into aspects of human or animal behavior, including migration and mobility. Outlying $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ values measured from tooth enamel are well established as indicators of human and animal migrations where local isotopic baselines are well constrained (e.g., Bentley and Knipper 2005; Hodell et al. 2004). In some contexts, outlying $\delta^{13}C$ values obtained from animal tissues may provide similarly valuable insights (Hobson and Wasenaar 2019). Obtaining a robust baseline of local isotope values is crucial for this type of research.

While engaged in a comprehensive AMS radiocarbon dating study of early Promontory Phase materials from the Promontory caves of northern Utah (Steward’s 1937 Promontory Culture), we noticed that one leather sample from the ankle wrap of a fragmentary moccasin recovered in our 2011 excavations had a $\delta^{13}C$ value ($-12.5\%o$) that was much higher than any of the other 51 values obtained from materials in the same archaeological context (Ives, Froese, et al. 2014). In contrast to the moccasin’s unusual $\delta^{13}C$ value, its AMS and calibrated calendar dates (725 ± 24 years BP, OxA-25234; 95% probability range AD 1252–1290) fell firmly within both the measured and Bayesian-modeled ranges of the other Promontory samples (Ives, Froese, et al. 2014).

In this study, we examine the significance of this isotopically unusual moccasin leather. Is it feasible that its high $\delta^{13}C$ value came from a bison consuming plants near the Promontory caves? Or did it come from somewhere else? If so, where? To address these questions, we present a local carbon isotope baseline of 157 samples of Promontory caves bison dung, hair, hide, and bone collagen; 14 samples of modern Antelope Island bison hair and dung; and 8 samples of Promontory-era Franktown Cave bison hair and hide (Figure 1). We use these isotopic data along with a grassland carbon isoscip, ancient DNA (species and sex identification), tissue turnover rates, and analogies with modern bison behavior to evaluate competing explanations for the outlying Promontory moccasin $\delta^{13}C$ value. These alternative hypotheses include the following: (1) the leather was from a local Promontory-area animal that consumed unusually large amounts of C₄ and/or CAM plants, (2) the leather was from an animal that migrated into the Promontory region from a faraway location, (3) the leather was obtained from a faraway location through trade, or (4) the leather was obtained during long-distance travel by people.

The Promontory Caves

The Promontory caves were excavated in 1930–1931 by Julian Steward (1937) and again between 2011 and 2014 by Ives, Janetski, and
colleagues (Billinger and Ives 2015; Ives 2014, 2020; Ives, Froese, et al. 2014). Both research episodes recovered an abundance of exquisitely preserved organic remains, including moccasins, basketry, and cordage; many varied gaming pieces; a complete range of stone and bone tools, from hunting weaponry to hide processing tools; ceramics; items of adornment; indications of ceremonial life such as rock art and incised tablets; and animal bone, hide, hair, and dung (Figure 2; Ives, Froese, et al. 2014; Thomas 2018; Yanicki and Ives 2017). Two aspects of the Promontory occupation are abundantly clear: bison and other large game animals were intensively hunted near the caves, and Cave 1 (42BO1) was a residential location at which women, men, subadults, and children were present at various seasons for extended periods of time over one or two human generations.

Cave 1 contains faint, discontinuous traces of Archaic use, but the vast majority of deposits are Promontory Culture. Cave 2 (42BO2) has some preceding Archaic occupations and a substantial Promontory Culture layer, although fewer deposits than Cave 1. Steward (1937) found that the Promontory Culture layer in Cave 1 covered much of the roughly 240 m² of habitable space and averaged about 65 cm in depth. Although we made similar stratigraphic findings in Steward’s Trench B area, in his Trench A area toward the front of Cave 1, we discovered intact midden deposits that were 2 m deep. These Cave 1 deposits produced a large assemblage of radiocarbon dates with a tight range of ages Bayesian modeled between AD 1240 and 1295 (95% probability estimate; Ives, Froese, et al. 2014). Although our excavations were minor (roughly 3 m³ of deposit) we recovered more than 30,000 whole and fragmentary faunal remains, supporting Steward’s (1937) contention that the Promontory cave occupants focused almost exclusively on large-game hunting, particularly...
of bison and pronghorn (see Johansson 2013). Our excavations yielded few small mammals or aquatic resources and scant evidence of seed processing (Ives, Johansson, et al. 2014). The Promontory Culture occupation postdates the cessation of maize horticulture among the local Fremont, although relatively sedentary populations were still present in the area, including the nearby Chournos Springs site (e.g., Yanicki 2019).

For Promontory Cave 1, discard and accumulation formulae along with space syntax analyses suggest a group size of roughly 35 persons, an estimate of 1.8 million whole and fragmentary faunal remains, and an extrapolated total of 2,400 moccasins within the deposits (Hallson 2017; Lakevold 2017). Seasonality indicators are still being refined, but a range of evidence—from deer skulls with cast antlers to abundant bulrush seeds (by-products of summer mat making)—indicates that Cave 1 was occupied during various seasons of the year. Obsidian sourcing and ceramic evidence further suggest that Promontory cave occupants ranged into southern Idaho (Arkush 2016; Ives 2020). Altogether, the Cave 1 Promontory Culture deposits reflect a sudden, substantial, but seasonally intermittent residential occupation of about 55 years’ duration, supported by intensive large-game hunting. The high volume of material culture resulted from the domestic presence of many children, subadults, and adult women and men.

Steward (1937) concluded that the Promontory Culture deposits had been created by a population with northern Plains and Subarctic affinities. He voiced the suspicion that they were Dene ancestors who had lingered long enough to absorb material culture characteristics.
from neighboring terminal Fremont communities. The potential attribution of a proto-
Apachean identity to the Promontory cave occupants is an underlying interest in our research

Triggered by the massive White River Ash east lobe eruption at AD 846–848, a small
foundling population of Apachean ancestors may have gradually made their way south in
ensuing centuries (e.g., Achilli et al. 2013; Kristensen, Andrews, et al. 2019; Kristensen, Hare,
et al. 2019; Kristensen et al. 2020). Promontory caves material culture linkages to the Subarctic
include moccasins constructed in a characteristically Subarctic style (Bata Shoe Museum clas-
sifications BSM 2[Bb] and BSM 2[Ab]), fine leather from a sophisticated hide-processing tra-
dition, and distinctive artifacts such as chi-thos (tabular bifaces used for hide softening), which
are common in the Subarctic but unknown in Fremont assemblages (Ives, Froese, et al. 2014;
Webber 1989). The Promontory moccasins stand in visible contrast to many surrounding
forms of footwear, from hide and plant fiber san-
dals to hock moccasins (e.g., Clark 1885:257;
Hatt 1916; Lycett 2015). The Promontory moc-
casins are completely unlike Fremont footwear
or most other footwear in a broader arc in interior
western North America (Ives 2020:103–104;
other forms of clothing, moccasins signal cul-
tural identity (in the caliber of leather, the knowl-
dge of requisite patterns, execution of fine
motor skills, and decorative techniques). As for
absorbing regional traits, the rare basketry in the Promontory caves is characteristic of Great
Basin forms, and Promontory pottery was
influenced by Fremont forms (Ives, Froes, et al.
2014; Yanicki 2019). We are nevertheless
mindful of other explanations for the Promontory
Culture expressions. These would include the
possibility of Kiowa involvement (although this
would have its own Dene dimension, given the
long-term Kiowa relationship with Ndee [Plains
Apache] peoples) or the prospect that Promon-
tory expressions might be yet more broadly poly-
ethnic in character (Ives 2014, 2020; Mooney
1898; Ortman and McNeil 2017).

Whatever the cultural identities involved, the
Promontory record raises an important and
broader set of issues. The AD thirteenth century

Franktown Cave
Franktown Cave (5DA272), Colorado (south of
Denver on the Palmer Divide; Figure 1), has
material cultural affiliations with the late
thirteenth-century Promontory caves. Like Promon-
tory, Franktown Cave’s assemblage includes
Promontory-style ceramic sherds, a netted gaming
hoop, incised wood (probably gaming pieces),
sinew-backed bows, and two moccasins of the
BSM-2(Bb) type (Gilmore 2005). According to
Bayesian modeling (95% probability estimates),
these Franktown artifacts date to AD 1180–
1280, which overlaps and slightly predates the
occupation of the Promontory caves themselves
(Gilmore et al. 2021; Gilmore, Hamilton, and
Ives 2017). Both Franktown Cave and Promon-
tory Cave 1 occupy easily defensible positions
overlooking the surrounding area, which may
reflect only partial integration with local groups
in a dynamically changing thirteenth-century
sociopolitical landscape (Lakevold 2017). The
Late Prehistoric occupants of Franktown Cave
and the Promontory caves shared a distinctive
material culture heritage (Ives, Froese, et al. 2014).

Carbon Isotopes in Bison Diets: Vegetation
Bison are herbivores and therefore derive their
carbon isotope compositions from plants.

https://doi.org/10.1017/aaq.2020.116 Published online by Cambridge University Press
Although they are primarily grazers, bison also occasionally consume sedges, forbs, and, less frequently, woody plants (Gogan et al. 2010). Bison prefer nutritious new growth, particularly C₃ grasses during cooler seasons and C₄ grasses during summer (Gogan et al. 2010). Across the Great Plains, modern free-ranging bison tissue δ¹³C values directly correlate with local abundances of C₃ and C₄ grasses (Hoppe et al. 2006).

Carbon isotope analysis can be used to distinguish between plants using different photosynthetic pathways: C₃ (cool-season grasses, forbs, and most woody vegetation), C₄ (warm-season grasses and some shrubs), and CAM (cacti and succulents). Today, northern Utah, southern Idaho, and western Wyoming vegetation is dominated by shrubs and C₃ grasses. Although substantial C₃ grasslands exist in this region, C₄ grasses are relatively rare (Cotton et al. 2016). Microhabitats that support higher abundances of C₄ grasses (e.g., Distichlis spicata, Sporobolus airoides), however, do exist (Morden et al. 1986). C₄ shrubs (e.g., Atriplex spp.) and CAM cacti and succulents (e.g., Opuntia spp.) are relatively abundant in northern Utah (Coltrain and Leavitt 2002; Sandquist and Ehleringer 1995; Ugan and Coltrain 2012), but are not known to be components of bison diets.

Modern C₃ plants have a mean δ¹³C around −27‰, with a range from about −37‰ to −20‰ (Kohn 2010). Modern plant values are lower than those of plants that grew before the onset of large-scale human industrial activities, which are continually lowering the δ¹³C of atmospheric CO₂ (e.g., Graven et al. 2017). The Holocene preindustrial δ¹³C of CO₂ was about −6.4‰ (Schmitt et al. 2012), which is 1.6‰ higher than the postindustrial atmospheric CO₂ δ¹³C of −8.0‰ used by Kohn (2010) to standardize his modern plant values. Thus, preindustrial C₃ plants should have had a global mean δ¹³C of around −25.4‰ and a range between about −35.4 and −18.4‰. In a global survey of modern C₃ plants, only plants from hyper-arid locations (mean annual precipitation <10 mm/year) and genus Pinus had δ¹³C values >−23‰ (i.e., preindustrial plant δ¹³C >−21.4‰; Kohn 2010). Because bison do not consume pine, preindustrial bison with inferred dietary δ¹³C significantly higher than −21.4‰ can reasonably be inferred to indicate consumption of C₄ or CAM plants. Given bison dietary preferences, such values would most likely indicate consumption of C₄ grasses.

There is a very clear separation between the δ¹³C values of C₃ and C₄/CAM plants: their distributions are nonoverlapping and their means differ by about 14‰ (Cerling et al. 1999; O’Leary 1988). Modern C₄ plant δ¹³C values typically fall within the range of −16‰ to −10‰, and modern CAM plants that are actively utilizing the CAM photosynthetic pathway also tend to have δ¹³C values within this range (O’Leary 1988; Sternberg et al. 1984). Modern C₄ plants from Utah fall within this range as well (Coltrain and Leavitt 2002). Accounting for a Suess Effect shift of 1.6‰, the preindustrial C₄/CAM plant range would have been about −14.4‰ to −8.4‰. A recent study of well-preserved Late Pleistocene and Early Holocene plants from Utah’s Colorado Plateau resulted in CAM plant (Opuntia sp.) δ¹³C values between −10.8‰ and −9.8‰ (mean = −10.3‰), in agreement with these global generalizations (Metcalfe and Mead 2019).

**Carbon Isotopes in Bison Tissues: Diet Estimates**

To directly compare animal tissues to one another or to plant δ¹³C values, one must account for isotopic fractionations that occur when plant carbon is incorporated into each type of biological tissue. Large herbivore bone collagen δ¹³C values are about 5‰ higher than the δ¹³C of plants in their diet (Drucker et al. 2008; Tieszen 1994). Hair δ¹³C values are on average about 3‰ higher than δ¹³C of plants in the diet (Bocherens et al. 2014; Crowley et al. 2010; Drucker et al. 2008). Dung δ¹³C values are typically 1‰ lower than those of diet (Sponheimer et al. 2003). The isotopic compositions of skin (hide) have seldom been studied, but Tieszen (1994) showed that for one bison, skin/hide δ¹³C was about 0.5‰ lower than bone collagen and about 2.0‰ higher than hair, which is broadly consistent with experimental studies of manatee and seal skin (Alves-Stanley and Worthy 2009; Ames et al. 1996; Hobson et al. 1996).
Tissues form over different time scales and can therefore provide information about animal diets over different durations of time. Bison dung represents the diet consumed 1–3 days immediately prior to deposition (Rutley and Hudson 2000; Schaefer et al. 1978), and therefore likely includes vegetation consumed in the geographical region of deposition. In contrast, bone collagen $\delta^{13}C$ values are derived from the diet consumed over a period of years (Hedges et al. 2007; Hobson and Clark 1992). A recent study found that the cortical bone of bear, deer, serow, and macaque formed primarily during adolescence (i.e., the active bone-growth phase) rather than throughout the animal’s life (Matsubayashi and Tayasu 2019). Thus, in some instances, bison cortical bone collagen may represent the diet several years prior to death. If an old animal migrated into a new area during its adolescence, its bone collagen could represent foods consumed in locations quite distant from where the bones were recovered. If animals did not migrate, bone collagen would provide a record of local diet. Regardless, bone collagen integrates diet over a long period of time. Hair contains a short- or medium-term record of diet, depending on the sampling strategy and the hair’s growth rate. When hair is sampled in segments, it is possible to recover a time series of changes over a period of days, weeks, or months. Skin is constantly re-forming and therefore represents diet relatively close to the time of death. Skin turnover rates have not been studied in terrestrial mammals. Manatee and dolphin carbon isotope “half-lives” (time to reach half-equilibrium with new values after a controlled-diet switch) ranged from about two weeks to four months, so time to reach full equilibrium would be on the order of several months or more (Alves-Stanley and Worthy 2009; Browning et al. 2014). Based on these turnover rates, bone and skin $\delta^{13}C$ values would be less likely to record brief and/or occasional consumption of isotopically distinct plants, whereas dung and hair $\delta^{13}C$ would hold greater potential for recording such brief deviations from a typical diet.

Based on the research described above, we convert bison dung, hair, hide, or bone collagen $\delta^{13}C$ to short-, medium-, and long-term diet $\delta^{13}C$ according to the following equations:

Short-term bison diet 1–3 days prior to deposition:

$$\delta^{13}C_{\text{diet}} = \delta^{13}C_{\text{dung}} + 1 \quad (1)$$

Medium-/short-term bison diet (weeks/months):

$$\delta^{13}C_{\text{diet}} = \delta^{13}C_{\text{hair}} - 3 \quad (2)$$

Medium-term bison diet (months):

$$\delta^{13}C_{\text{diet}} = \delta^{13}C_{\text{hide}} - 4.5 \quad (3)$$

Long-term diet (years):

$$\delta^{13}C_{\text{diet}} = \delta^{13}C_{\text{bone collagen}} - 5 \quad (4)$$

A further conversion is needed to make diet $\delta^{13}C$ values obtained from modern samples directly comparable to those from preindustrial archaeological samples. In this study, the $\delta^{13}C$ values of modern Antelope Island samples collected in 2017 are converted to preindustrial equivalents by adding $+2.1‰$, which accounts for the higher atmospheric CO$_2$ in 2017 (when the samples were collected; ca. $-8.5‰$) relative to the pre-industrial global atmospheric CO$_2$ $\delta^{13}C$ value of $-6.4‰$ (Graven et al. 2017; Schmitt et al. 2012).

Materials and Methods

Bison samples (dung, hair, hide, and bone collagen) used for isotopic analysis are listed in Table 1. Detailed preparation and analytical methods are provided in the Supplemental Methods and explained here in brief. Hair and hide were cleaned and bone collagen was extracted following established procedures. Carbon isotope compositions ($\delta^{13}C$) and carbon and nitrogen contents (%C, %N) were measured using an Elementar Vario Micro Cube elemental analyzer, coupled with an Isoprime stable isotope ratio mass spectrometer in continuous-flow mode. Elemental compositions were calibrated using USGS-40. $\delta^{13}C$ values were calibrated to the VPDB scale using USGS-40 and USGS-41 or 41a (accepted values $-26.39‰$, $+37.63‰$, and $+36.55‰$, respectively). Internal check standards (gelatin, methionine, red lentil, amaranth; accepted values $-15.30‰$, $-28.60‰$, $-26.12‰$, $-13.59‰$, respectively) and sample
Table 1. Isotopic and Elemental Data for Bison Tissues from Promontory (42BO1, 42BO2), Franktown (5DA272), and Antelope Island (AI).

<table>
<thead>
<tr>
<th>Material</th>
<th>Site</th>
<th>Sample</th>
<th>Element/Type</th>
<th>δ¹³C\text{tissue}</th>
<th>δ¹³C\text{dirt}</th>
<th>%C</th>
<th>%N</th>
<th>C/N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bone collagen</td>
<td>42BO1</td>
<td>FS-1</td>
<td>Long bone</td>
<td>−19.2</td>
<td>−24.2</td>
<td>38.5</td>
<td>14.0</td>
<td>3.2</td>
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<td></td>
<td>42BO1</td>
<td>FS-187.82</td>
<td>Scapula</td>
<td>−20.0</td>
<td>−25.0</td>
<td>41.6</td>
<td>14.3</td>
<td>3.4</td>
</tr>
<tr>
<td></td>
<td>42BO1</td>
<td>FS-19 #1</td>
<td>Long bone</td>
<td>−19.8</td>
<td>−24.8</td>
<td>41.0</td>
<td>14.8</td>
<td>3.2</td>
</tr>
<tr>
<td></td>
<td>42BO1</td>
<td>FS-237.1</td>
<td>Radius</td>
<td>−19.9</td>
<td>−24.9</td>
<td>41.0</td>
<td>14.8</td>
<td>3.2</td>
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<td></td>
<td>42BO1</td>
<td>FS-237.24</td>
<td>Tibia (left)</td>
<td>−17.9</td>
<td>−22.9</td>
<td>40.6</td>
<td>14.7</td>
<td>3.2</td>
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<td></td>
<td>42BO1</td>
<td>FS-237.3</td>
<td>Femur</td>
<td>−20.1</td>
<td>−25.1</td>
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<td>14.8</td>
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<td>3.4</td>
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<td></td>
<td>42BO1</td>
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<td>Femur</td>
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<td>42.4</td>
<td>15.1</td>
<td>3.3</td>
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<td></td>
<td>42BO2</td>
<td>FS-614.17</td>
<td>Femur (right)</td>
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<td>−23.7</td>
<td>40.6</td>
<td>14.8</td>
<td>3.2</td>
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<tr>
<td></td>
<td>42BO1</td>
<td>FS-623.6</td>
<td>Humerus (right)</td>
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<td>−23.4</td>
<td>40.4</td>
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<td>3.2</td>
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<td></td>
<td>42BO2</td>
<td>FS-702</td>
<td>Rib</td>
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<td>−24.6</td>
<td>41.8</td>
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<td>3.2</td>
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<td>42BO1</td>
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<td>cf Humerus</td>
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<td>−24.8</td>
<td>43.0</td>
<td>15.2</td>
<td>3.3</td>
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<td>Hair</td>
<td>42BO1</td>
<td>FS-1 Vues #1-1,3,5</td>
<td>Coarse</td>
<td>−21.8</td>
<td>−24.8</td>
<td>41.8</td>
<td>13.8</td>
<td>3.5</td>
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<td>3.5</td>
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<td>42BO1</td>
<td>FS-106-1</td>
<td>Coarse</td>
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<td>−24.7</td>
<td>41.6</td>
<td>13.8</td>
<td>3.5</td>
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replicates were included in each run to monitor measurement uncertainty. For bone collagen, hair, hide, and dung (respectively), total analytical uncertainty was estimated to be ±0.22‰, ±0.18‰, ±0.24‰, and ±0.43‰ (for error calculation method, see Szpak et al. 2017). As shown in Table 1, consistent %C, %N, and C/N ratios indicate excellent preservation of collagen, hair, and hide.

Genetic analyses of the FS-305 ankle-wrap hide sample were conducted at the UCSC Paleogenomics Laboratory (PGL) to (1) obtain a taxonomic identification and (2) determine the sex of the animal. Further details of both isotopic and genetic methods can be found in Supplemental Text 1.

Results and Discussion

Moccasin Leather Outlier: Context and Isotopic Composition

The FS-305 sample, which produced the outlying δ13C value that inspired this study, came from an ankle wrap remnant on a fragmentary moccasin recovered from Promontory Cave 1 (Figure 3a). The ankle wrap is one of three separate pieces of leather, along with the body and vamp, used in the construction of Promontory-style moccasins (Figure 4). The FS-305 moccasin was missing the toe area, but its inferred size extrapolated from complete moccasins in the Promontory caves is about 22.5–24 cm (Erika Sutherland, personal communication 2019). Based on correlations between foot size, height, and age, this moccasin was probably worn by a youth approximately 11–13 years old (Billinger and Ives 2015).

The ankle wrap of FS-305 was originally selected as a convenient (minimally destructive) sampling location for an earlier AMS radiocarbon dating study. For that study, the sample underwent the Oxford Radiocarbon Accelerator Unit (ORAU)’s routine leather pretreatment process (lab code ACJ; Brock et al. 2010) and yielded an AMS date of 725 ± 24 BP (OxA-25234), calibrated to AD

<table>
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Note: Diet δ13C values were calculated from measured tissue values using the equations in the text. An Excel version of this table is provided as Supplemental Table 1.

aValues for these samples are means are from serial sampling (see Supplemental Table 2 for values of sections).
bCarbon isotope values for these samples were obtained in the process of radiocarbon dating and previously published in Ives and colleagues (2014). Their diet values are not calculated because the calibration does not provide the necessary precision for paleodiet reconstruction.
cAntelope Island diet calculations account for a +2.1‰ adjustment to make them equivalent to preindustrial values, as described in the text.
1252–1290 using OxCal v4 (Bronk Ramsey 2009) and the IntCal13 dataset (Reimer et al. 2013). Its associated \( \delta^{13}C \) was \(-12.5\%o\) and its \%C, \%N, and C/N were 37%, 14%, and 3.2, respectively. In the present study, a new aliquot of the same sample was independently cleaned as described in the Supplemental Text 1, and its isotopic composition was obtained following a 2-point calibration that produced the accuracy and precision necessary for paleodietary analysis (Szpak et al. 2017). Duplicate analyses of FS-305 resulted in \( \delta^{13}C \) values of \(-12.93\%o\) and \(-12.87\%o\), carbon contents of 35.0% and 34.7%, nitrogen contents of 12.3% and 12.5%, and C/N ratios of 3.32 and 3.24 (means listed in Table 1). The quality-control indicators and reproducibility both within and between labs indicate excellent preservation and support the validity of the isotopic measurements. Converting the mean of the measured \( \delta^{13}C \) value obtained from the leather (\(-12.9\%o\)) to a diet \( \delta^{13}C \) value results in an estimate of \(-17.4\%o\) for the plants consumed by the animal while the skin was being formed.

After confirming the ankle wrap’s unusual \( \delta^{13}C \), we tested the body portion of the same moccasin. The FS-305 moccasin body leather produced a \( \delta^{13}C \) value of \(-20.0\%o\), which results in a dietary \( \delta^{13}C \) estimate of \(-24.5\%o\) (Table 1). The moccasin body \( \delta^{13}C \) is distinctly different from that of the ankle wrap but is consistent with all 171 other northern Utah bison samples (Table 1).

**Local Bison Eating \( C_4 \) and/or CAM Plants?**

The thickness and general appearance of the FS-305 moccasin leather were consistent with bison. Our genetic analysis supports this species attribution (see Supplemental Text 1).

Figure 3. (a) Promontory Cave 1 partial moccasin FS-305, whose ankle wrap fragment (arrow), still stitched to the moccasin body, yielded an outlying \( \delta^{13}C \) value; (b) Promontory Cave moccasin FS-969, with arrows illustrating the location of cuts that severed its ankle wrap; (c) magnified image (30X) of the cut ankle-wrap surface (arrow) on moccasin FS-969, the remnant of which remained stitched to the moccasin body; (d) a fully severed ankle wrap from Promontory Cave 1 (artifact FS-238), with arrow indicating the cut edge. Photographs by J.W. Ives.
The FS-305 ankle wrap was the only northern Utah bison tissue sample with clear evidence for C_4/CAM plant consumption. All of the other carbon isotope measurements for Promontory bison tissues are consistent with purely C_3 diets (Table 1; Figure 5). Even bison dung, which would be most likely to record short-term dietary deviations from the norm, clearly reflects a C_3 diet. (We note that a single dung sample has a δ^{13}C value 0.3‰ higher than our C_3 cutoff, but...
because analytical uncertainty for dung was ±0.43‰, this sample does not provide solid evidence of C₄ plant consumption.) Serially sampled Promontory bison hair, including several long hairs that likely record at least a year of growth, show no evidence of temporary short-term consumption of C₄ or CAM plants. Instead, each individual hair shows variations of ≤1.8‰, all of which fall firmly within the C₃ range (Figure 6; Supplemental Table 2). Medium- and long-term bison diet records, including the bone collagen and hide/leather values, also show no evidence of C₄ or CAM plant consumption (Table 1; Figure 5). Fourteen modern Antelope Island bison dung and hair samples further show no evidence of C₄ or CAM plant consumption along the shores of Great Salt Lake (Table 1; Figure 5).

The FS-305 leather sample clearly has a much higher δ¹³C value than any of the other Promontory samples (Figure 5). In contrast to the abundant evidence that local Promontory bison diets were entirely C₃, the FS-305 ankle wrap has a δ¹³C value that indicates the animal consumed a large amount of C₄ (and/or CAM) plants. A linear %C₄ estimate can provide a general approximation of the relative amount of C₄ versus C₃ plants that would have had to have been consumed to produce a particular δ¹³C value. If we assume a pure C₃ dietary endpoint of −24.3‰ (the mean derived from typical Promontory bison values obtained in this study) and a pure C₄/CAM endpoint of −10.3‰ (the mean of ancient Colorado Plateau CAM plants, which overlap with C₄ plants; Metcalfe and Mead 2019), the FS-305 diet value of −17.4‰ suggests a C₄/CAM contribution of approximately 50%. For roughly 50% C₄/CAM to be recorded in a relatively slow-forming tissue such as skin, the C₄ and/or CAM plants must have comprised a significant proportion of the diet for several weeks to months. Yet, there is no unequivocal evidence for C₄ or CAM plant consumption in any other Promontory bison tissue, even those that formed over short timescales and would therefore record brief temporary changes in diet. We conclude that the FS-305 sample came from a bison that was not native to the Promontory region.

Wandering Bison?

Could the outlying δ¹³C of the FS-305 ankle wrap be the result of a bison migrating into the Promontory area after spending an earlier part of its life in a high-C₄ grass area? As demonstrated by the C₃ signals obtained from 171 samples of Promontory and Antelope Island bison dung, hair, hide, and bone collagen, this would have been a highly unusual occurrence. But if it did occur, what locations would have had sufficiently high grass δ¹³C values to produce the FS-305 value?

Cotton and colleagues (2016) predictively modeled the distributions of C₃/C₄ grasses and mean grass δ¹³C values across modern (preindustrial) North America. Given that this model was based in part on measured bison δ¹³C values that were not included in the present study, it provides an excellent baseline for determining possible regions of bison origin (Figure 7). Local Promontory bison diet δ¹³C estimates from dung, hair, hide, and bone collagen are in good agreement with one another and with the predicted values for the Promontory region (Table 2; Figure 7). The nearest areas on the grass isoscape with mean δ¹³C values similar to that of the FS-305 bison are about 500 km to the south, in southwestern Utah/northwestern Arizona, and about 700 km east, around Franktown Cave in Colorado. We cannot exclude the possibility that closer locations might include microhabitats with high C₄, particularly during the summer when C₄ grasses flourish. It is clear from our baseline isotopic data, however, that if such areas existed near the caves, local Promontory bison did not utilize them.

To determine whether a bison could feasibly have traveled under its own power from one of these faraway locations to Promontory while retaining a strong C₄ signal in its hide, we consider the distance traveled (estimated using a least-cost path approach), the isotopic turnover rate of skin (because continuous replacement would gradually “dilute” the C₄ signal as an animal switched its diet during the journey), and the feasibility of traveling the required distance in the required time (based on modern bison observational studies). Supplemental Text 2 provides details of these inferences. We conclude that it may have been physically possible...
for a bison to travel those distances in the required amount of time, but it would have been highly unlikely—particularly because genetic analyses indicates that the leather was from a female bison, which would typically travel with calves (Supplemental Texts 1 and 2). Altogether, it is unlikely that the FS-305 ankle wrap came from a wandering bison.

**Procurement of Hide via Trade?**

If the FS-305 ankle wrap leather was not from a local bison or a bison wanderer, then it must have been procured in a faraway location and transported to Promontory Cave 1. It is possible that the FS-305 ankle wrap leather was obtained through trade. In this scenario, the Promontory people would have obtained the leather from other individuals or groups who had been in a location far to the south or east (or who had traded for bison leather from these areas).

However, based on the ready availability of local bison to Promontory people, we believe that trade in bison products was very unlikely. In a less than 3 m² area of Cave 1, more than 30,000 whole and fragmentary bones were recovered. These are completely dominated by large game animals, with bison the most common genus for identifiable specimens (Ives, Johansson, et al. 2014; Johansson 2013). The presence of large, difficult-to-transport skulls and low-utility lower limbs and hooves suggest that a kill site was nearby. Indeed, the landscape above the caves funnels prey into a narrow area that is ideal for ambush strategies and remains an active game trail today. Furthermore, Promontory Cave 1 occupants were not heavily comminuting bones to extract greases as they would if food were scarce. Strata consisting of charred and calcined bone burned at variable temperatures suggest that greases and fats were present...
and served as accelerants for a fire rather than being extracted for food (Ives, Johansson, et al. 2014). Based on the number of discarded moccasins in the caves, Reilly (2015) estimated that about 250 bison hides would have been required to replace them. In combination with the skeletal evidence, this suggests that the minimum number of bison individuals (MNI) for the entire cave contents would be huge. Thus, multiple lines of evidence indicate that bison were abundant around the Promontory caves and that the Promontory people were highly adept at hunting them. It would have been highly unnecessary for Promontory people to trade for bison leather. Although we cannot completely exclude this possibility, we consider the explanation in the next section more likely.

**Procurement of Hide via Long-Distance Travel**

The final and likeliest possibility to explain how the FS-305 ankle wrap leather ended up incorporated into a Promontory Cave 1 moccasin is long-distance travel to/from an area far to the south or east. Below, we will first explore potential areas of origin and then discuss possible mechanisms of transportation, including a long-distance round trip, a meeting with individuals from distant regions at an intermediate location, or a visit from outsiders who left behind the hide or leather.

It is not possible to pinpoint a precise location of origin for the FS-305 ankle wrap leather because its $\delta^{13}C$ value of $-17.4\%e$ is characteristic of a vast region from South Dakota through Nebraska, eastern Colorado, southeastern New Mexico, and southern Arizona (Figure 7). We also cannot exclude the possibility that the bison inhabited a microhabitat with high C$_4$ some distance from the caves but closer than the areas identified in our regional isoscape. Based on our current knowledge, however, northwestern Arizona and central Colorado are the closest locations to have $\delta^{13}C$ values consistent with that of the FS-305 ankle wrap (Figure 7).

The northwestern Arizona region with modeled $\delta^{13}C$ values consistent with the FS-305 ankle wrap sample is known to have supported bison during the Late Prehistoric period (Martin et al. 2017). Open-air sites with Promontory material culture associations dating approximately 100–200 years later than the Promontory
Figure 7. Modeled mean δ¹³C values of Late Prehistoric grasses based on previous studies of bison and mammoth δ¹³C and nine climatic variables, including growing season precipitation and temperature (adapted from Cotton et al. 2016). Areas in white have few grasses of any type and are therefore not included in the model. Stars indicate the locations of the Promontory caves and Franktown Cave. Circles indicate other locations with Promontory-style moccasins, as described in the text.

Table 2. Carbon Isotope Compositions (means ± one standard deviation) of Promontory Caves and Antelope Island State Park Bison Tissues.

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<th>Location</th>
<th>Tissue</th>
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<th>δ¹³C diet</th>
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aCarbon isotope offset used to convert tissue to diet values, as described in the text.
bModern (Antelope Island) diet values were converted to preindustrial equivalents by adding +2.1‰, as described in the text.
cSerially sampled hair results were averaged to produce a single value for each individual hair before being included here.
dIncludes only data obtained in the present study, using a 2-point calibration suitable for paleodiet reconstruction, as described in the text.
cave deposits occur on the eastern shore of Great Salt Lake and Utah Lake (Janetski and Smith 2007), along the least-cost path route to this part of northwestern Arizona (Supplemental Text 2). With the cessation of Fremont maize agriculture around AD 1150 (Coltrain and Leavitt 2002), travel along the Wasatch Front and into northwestern Arizona during the late thirteenth century may have been relatively easy. Given that later Promontory Phase assemblages are situated in geographically intermediate areas, it would not be surprising if late thirteenth-century Promontory cave occupants had connections with regions as far south as northern Arizona. We note that Promontory-style moccasins have recently been identified near Mesa Verde (Figure 1), supporting the idea of a connection with the Southwest (Fewkes 1909; Osborne 2004; Yanicki and Ives 2017).

Alternatively, the isoscape model and Franktown Cave bison δ¹³C values are consistent with a potential origin for the FS-305 ankle wrap leather in central Colorado. Franktown bison hide and hair samples had highly variable δ¹³C values, ranging from purely C₃ to purely C₄ (Figure 5). The much larger variability in bison δ¹³C at Franktown compared to Promontory reflects the site’s location in an area that rapidly transitions from C₃- to C₄-dominated grassland (Figures 5 and 7)—that is, all of the Franktown bison could have been procured relatively close to Franktown Cave, with higher values among bison who had grazed in areas further east and/or were killed after the summer months. The Promontory Cave FS-305 moccasin leather may therefore be evidence of contact between northern Utah and central Colorado. The assemblage similarities between the Promontory and Franktown caves support the possibility of contact in various forms: travel between the two locations, a rendezvous at a geographically intermediate location, or a rendezvous with yet another population that shared this material culture heritage. We note that Promontory-style moccasins are also present in Daugherty Cave (48WA302) and Ross Rockshelter (48NA331) in Wyoming, which are intermediate in longitude (although at higher latitudes) relative to Promontory and Franktown (Figures 1 and 7; Frison 1968; Garling 1964).

It is significant that the only extralocal leather identified to date in the Promontory caves was used to construct a moccasin ankle wrap. Unlike moccasin bodies—which quickly become worn, patched, further worn, and discarded—ankle wraps can be reused and recycled into new footwear. Within the Promontory caves assemblage, the great majority of moccasins are heavily worn, patched, or both. Cuts that indicate the severing of ankle wraps from the moccasin body are common (Figure 3b–d). Repurposing of leather also occurred at Franktown Cave, where three fringed-seam artifacts dating to the Promontory occupation had been cut from larger leather objects (Gilmore et al. 2021). Although some leather scraps occur in both the Promontory and Franktown caves, their occupants were frugal, generally discarding only worn-out moccasin bodies and bison robe edges. Given its longer use life and potential for reuse, an ankle wrap is the one portion of a moccasin most likely to survive a long-distance journey, precisely because it could be usefully reincorporated into new footwear.

Historic sources show that it was essential to carry and repair additional moccasins during a lengthy journey. The distances to origin documented here would require wearing and replacing several pairs of moccasins, which were common discards in abandoned camps (e.g., Ewers 1955:182, 184; Moulton 1987:216, 219; Wilson 1924:212, 232, 283–284). We consider it plausible that the leather was obtained at a distant source and recycled in a series of usages as an ankle wrap over the course of the journey to the Promontory caves. It is also possible that the FS-305 ankle wrap leather was brought to the caves as a piece of clothing, bison robe, or lodge covering that was repurposed (although the larger the original object, the greater the possibility of detecting other anomalous values, which we have not). As discussed above, however, obtaining such items from other groups or individuals would have been like carrying coals to Newcastle. The Promontory cave occupants had access to a genuine abundance of bison products, including fine leather, and they would have had no need to acquire it from others while residing in the caves. It therefore seems unlikely that a visitor to the caves would leave behind leather...
that would later become incorporated into a Promontory moccasin. Instead, it seems more likely that the leather was obtained at some distance from the caves and reincorporated into the moccasin during travel. This implies that Promontory people had either traveled to one of these faraway locations themselves or met with others at an intermediate location where the leather changed hands. Either way, the ankle wrap came from far away and was not obtained in the vicinity of the caves, which implies long-distance connections and knowledge of faraway locations.

**Independent Evidence for Long-Distance Connections of Promontory Caves Inhabitants**

Although the ankle wrap δ^{13}C value is a unique piece of evidence for human movement, it is far from the only evidence for long-distance connections of Promontory people. In addition to the Promontory material culture evidence at Franktown Cave and Promontory’s northern artifact associations, gaming and obsidian source studies also provide support for long-distance interactions. The Promontory caves inhabitants were familiar with a diversity of games whose distributions span much of western North America, suggesting a wide range of social interactions and possibly long-distance movements (Yanicki and Ives 2017). X-ray fluorescence indicates that the majority of obsidian artifacts recovered from Promontory Caves 1 and 2 were constructed from Malad obsidian sourced in southern Idaho (Hughes 2011, 2012). Around the time of the Promontory and Franktown cave occupations, material from Malad and other northern obsidian sources increased by an order of magnitude on the central and southern Plains (Gilmore, Hedlund, and Clark 2017; Hoard et al. 2008; Hughes et al. 2019). Promontory groups may have been involved in the distribution of Malad obsidian through direct migration, down-the-line trade, or trade involving more distant redistributive centers. Whichever alternatives were involved, the late-period obsidian distribution and gaming evidence support the hypothesis that Promontory Phase communities participated in long-distance interaction spheres from north of Utah far to the south and east.

**Implications for Promontory Lifeways**

For hunter-gatherer groups, Seymour (2012:378) recommends reserving the term “migration” to describe movement to a new region that was not previously utilized, and “mobility” to describe movements within regularly used territories. Given the fact that only one Promontory caves specimen has been discovered with a C_4 isotopic signal, it is unlikely that regular Promontory mobility encompassed regions with abundant C_4 grasses. Several lines of evidence support geographically widespread interactions, however, and the isotopic evidence suggests that at least one long-distance voyage was likely made. Anthony (1990) has identified categories of long-distance activities associated with migration that may have detectable material correlates: scouting (to facilitate long-distance “leapfrog” migrations), return visits to a previous occupation, long-distance movements for seasonal or task-specific purposes, stream migration (movement of successive groups along a well-defined route), and counterstreaming (returning to a former occupation after migrating away). If Promontory people had traveled to a faraway location, long-distance scouting seems the most plausible purpose for such a voyage. Establishing familiarity with distant regions would be an essential strategy for highly mobile groups infiltrating the changing thirteenth-century social landscape of the American Southwest and central/southern Plains. Scouting for new economic, trading, or raiding opportunities could have served as a precursor to a shift in regularly used territories, equipping the Promontory people with broad landscape knowledge that could be mobilized to facilitate migration (Seymour 2012). The latter seems to have occurred at the end of the thirteenth century, when Promontory people ceased intensive occupation of the Promontory caves (Ives, Froese, et al. 2014).

**Conclusions**

Exceptional organic preservation allowed us to establish a uniquely strong isotopic baseline for bison in the area around the Promontory caves during the late thirteenth century. Analysis of 171 bison samples (dung, hair, hide, bone) that...
formed over short, medium, and long timescales suggests that Promontory bison consumed purely C₃ diets. In contrast, the ankle wrap of one Promontory moccasin was from a bison that consumed a large amount of C₄ plants over a period of several weeks or months. Based on the local Promontory isotopic baseline along with our current knowledge of skin turnover rates and C₄ grass distributions, we argued that it was unlikely the leather came from either a bison with an unusual local diet or a bison that migrated to Promontory from a distant location. Instead, this animal was killed far to the east or south of the Promontory caves. We argued that trade in bison leather was unlikely given that bison were abundant in areas around the caves. Therefore, we consider long-distance travel to be the likeliest explanation, with a scrap of leather procured in the south/east recycled into an ankle wrap over the course of the journey, as would have been common during long-distance voyages. Possible source regions for the ankle wrap leather include northwestern Arizona, central Colorado, and areas farther to the south and east. Regardless of the precise location, the evidence suggests a connection with an area far from the Promontory caves. Knowledge of distant locations, whether obtained through long-distance scouting or contact with other groups, would have ensured that Promontory people were well prepared for relocation to a new “home territory” when the need arose. It appears that this occurred at the end of the thirteenth century, when intensive occupation of the caves ceased (Ives, Froese, et al. 2014).

This study has demonstrated an approach for investigating long-distance connections that is viable for organic remains in regions with minimal local isotopic variability (i.e., C₃-dominated grasslands), where the local isotopic baseline is well constrained and considerably different from potential extralocal source regions. This approach is not useful for areas with highly variable local plant δ¹³C values (i.e., abundant C₃ and C₄ plants), such as Franktown Cave. Crucial to our approach was the availability of different “time records” from animal tissues preserved in dry cave contexts (dung, hair, hide, bone), and the integration of multidisciplinary lines of evidence (isotopic, genetic, ecological, archaeological). We echo Seymour’s (2010) argument that “anomalous” data can be sources of valuable information rather than errors to be averaged away, especially for highly mobile populations.

Acknowledgments. We thank Paul Stavast, Vandy Bowyer, Harvey Friebe, Evangeline Bell, and Amy Sky for sampling and laboratory assistance; Jennifer Cotton for access to isoscape data; Kathy Lemberg, Gabriel Bowen, and Rhy McMillan for map assistance; Joel Janetski for manuscript comments; Steven Bates for permission to sample in Antelope Island State Park; and Wes Olson, Johan du Toit, and Tom Seaton for insights into bison ecology. This research was funded by a Social Sciences and Humanities Research Council of Canada (SSHRC) Banting Postdoctoral Fellowship (awarded to IZM), and by SSHRC Standard Research Grant 410-2010-0480 and SSHRC Insight Grant 435-2012-0140 (awarded to JWI). We are grateful to landowners George and Kumeroa Chournos for the opportunity to conduct research in the Promontory caves.

Data Availability Statement. Isotopic data presented in this article are available in the Supplemental Materials associated with this manuscript. Genetic data are available on the online data storage platform Dryad (DOI:10.7291/D18Q23).

Supplemental Materials. For supplemental materials accompanying this article, visit https://doi.org/10.1017/aaq.2020.116.

Supplemental Text 1. Supplemental materials and methods.
Supplemental Text 2. Supplemental discussion (wandering bison).
Supplemental Table 1. Excel version of Table 1.
Supplemental Table 2. Results from serially sampled Promontory Caves bison hair.

Notes

1. In a forthcoming publication, we will provide details of the Daughtery Cave and Ross Rockshelter moccasins, including their dating and association with artifacts that include incised cane dice, incised stone tablets, and moccasin pattern cutouts as also occur in the Promontory caves.
2. Newcastle was long a major British center for coal mining, leading to this usage as an idiom for a redundant or pointless action.

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Submitted January 23, 2020; Revised August 29, 2020; Reviews completed October 5, 2020; Accepted October 5, 2020