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Inferring Demographic Structure with Moccasin Size Data from the Promontory Caves, Utah

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KEY WORDS footsize; footwear; stature and age predictions; Promontory Culture; Apachean migration

ABSTRACT The moccasin assemblage Julian Steward recovered from the Promontory caves in 1930–31 provides a novel example in which material culture can be used to understand the structure of an AD thirteenth century population. Several studies shed light on the relationship between shoe size, foot size, and stature. We develop an anthropometric model for understanding the composition of the Promontory Cave population by using moccasin size as a proxy for foot size. We then predict the stature of the individual who would have worn a moccasin. Stature is closely related to age for children, subadults and adult males. Although there are predictable sex and age factors biasing moccasin discard practices, moccasin dimensions suggest a relatively large proportion of children and subadults occupied the Promontory caves. This bison and antelope hunting population appears to have thrived during its stay on Promontory Point. Am J Phys Anthropol 156:76–89, 2015. © 2014 Wiley Periodicals, Inc.

Demographic data concerning prehistoric hunter-gatherer populations are critically important in understanding human prehistory, but sources of information concerning ancient population structures are often seriously constrained. Our information frequently comes from ethnographic or historic records where pre-existing hunter-gatherer populations had been heavily affected by epidemic diseases, colonial trade processes, and related factors. Burial populations are used to infer prehistoric demographic structure, but mortuary contexts are often influenced by selective processes, making it difficult to determine if the burial population truly reflects the actual population from which it was drawn (e.g., Hoppa, 2002; Paine and Vaupel, 2002).

From time to time, however, we are presented with novel circumstances in which a greater degree of precision becomes possible in assessing a prehistoric population. Hominin trackways can provide one such instance for small task groups or bands (e.g., Webb et al., 2006; Lockley et al., 2007; Webb, 2007; Ashton et al., 2014). Footwear may also provide unique insights into population structure, and such is the case for the remarkable material culture present in the Promontory caves on Great Salt Lake, Utah. Julian Steward conducted extensive excavations in Promontory Caves 1 and 2 in 1930–31, uncovering a wide array of perishable items. His singular discovery involved 250 instances of footwear, almost all made in a distinctive Promontory moccasin style. Since 2011, we have conducted additional excavations in Promontory Caves 1 and 2, enhancing Steward's sample and affirming his key findings.

Here we describe an anthropometric approach to this Promontory moccasin data that leaves us with a more refined understanding of the population structure of the A.D. thirteenth century inhabitants of these caves. The Promontory Culture (or Promontory Phase as it is more commonly known now) falls into a particularly fateful time frame in late period prehistory in western North America. Benson et al. (2007) summarized a broad range of data and literature showing that each of the A.D. eleventh, twelfth and thirteenth centuries had a profound period of drought, with the last of these effectively coinciding with the peak Promontory Phase occupation of Caves 1 and 2. While complex social and environmental factors were certainly at play, Benson et al. (2007) noted that the passing of the thirteenth century saw the end of Fremont material culture, a dramatic contraction of Puebloan society into larger, more nucleated settlements (with accompanying evidence of social upheaval), and the collapse of the major center at Cahokia on the Mississippi (see also Kohler et al., 2014).

THE PROMONTORY CAVE CONTEXT

Steward (1937) conducted his Promontory Cave 1 and 2 excavations on the north shore of Great Salt Lake because he feared that looting would destroy the remaining deposits, which held prospects for lengthy stratigraphic records extending to Lake Bonneville times (Fig. 1). It was the thick Promontory Culture deposits near

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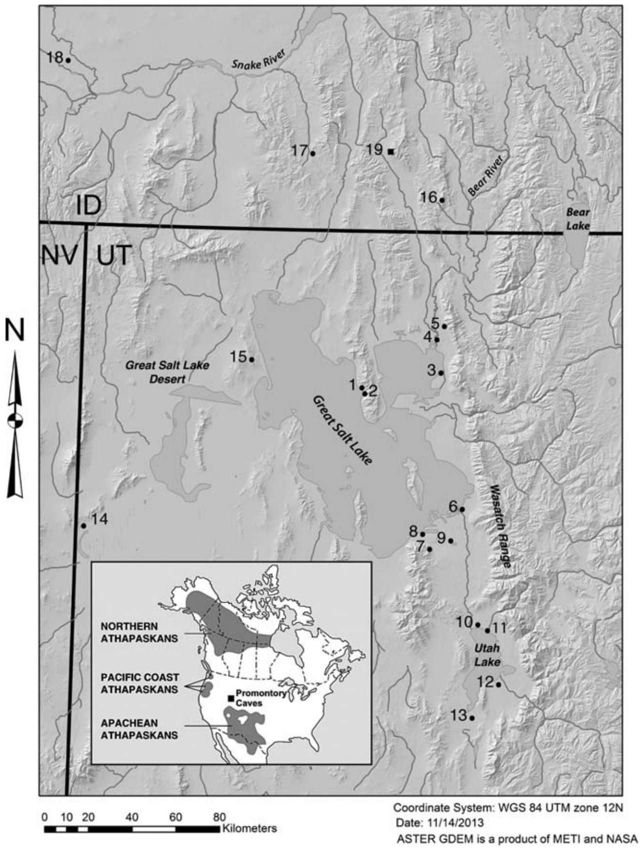

Fig. 1. Promontory Caves 1 and 2 as well as other locations mentioned in the text: 1, Promontory Caves 1 and 2; 2, Chournos Spring Site; 3, Injun Creek; 4, Bear River sites; 5, Orbit Inn; 6, 42DV2; 7, Deadman Cave; 8, Blackrock Cave; 9, Salt Lake Airport site; 10, Sandy Beach site; 11, Heron Springs site; 12, Spanish Spit site; 13, Goshen Island South site; 14, Danger Cave; 15, Hogup Cave; 16, Standing Rock Overhang; 17, 10OA275; 18, Wilson Butte Cave; 19, Malad obsidian source area.

the surface of both Caves 1 and 2, however, that provided an extraordinary array of perishables. Steward recovered 250 pieces of footwear, along with mittens, cordage, arrows, bows, matting, gaming pieces, basketry, beads, pendants, pottery, and lithics. This array of artifacts spoke eloquently to Promontory Caves 1 and 2 as residential locations, likely with fall through spring occupations (Steward, 1937; Johansson, 2013; Ives, 2014). The desirable floor space in Cave 1 would be roughly 350 m^2, and roughly 100 m^2 in Cave 2. The two caves could accommodate no more than 100 persons at any one time. Considered from the perspective of hunter-gatherer principles of group formation, it was smaller local groups or microbands that created the cave occupations, likely in the range of 30 to 50 persons between the two caves (e.g., Ives, 1990, 1998; Binford, 2001; Kelly, 2007).

Steward (1937:83, 86; 1940:473) thought the Promontory Culture cave occupants arrived roughly A.D. 1200 and vanished prior to the contact era. He thus felt that the Promontory Culture inhabitants of the caves arrived before pre-existing (Fremont) societies disappeared but persisted after the Fremont demise. There were few subsequent efforts to date the Promontory Phase occupations in Caves 1 and 2 (but see Aikens, 1966:4; Marwitt, 1973; Janetski and Smith, 2007).

Given the lack of dating reported for the Promontory Phase occupations, we have undertaken an extensive program of accelerator mass spectrometry (AMS) dating of Promontory materials, involving both Steward's collections and artifacts recovered during our 2011–2014 excavations of Promontory Caves 1 and 2. There are 48 dates for moccasins, matting, basketry, netting, a bow, an arrow, gaming pieces, and a variety of other perishable artifacts held in the Natural History Museum of Utah Promontory Phase collections (Ives 2014; Ives et al., in press). All but one of these dates (for a Shoshone winnowing basket of nineteenth century age) fall within a narrowly defined interval extending from 662 to 826 ^{14}C yr BP (a calibrated 2σ defined interval extending from A.D. 1166–1391). More than 50 other AMS dates from newly excavated Promontory Phase contexts in Cave 1 and 2 will be reported elsewhere (save for the eight moccasin instances given in Table 1 [with FS labels], below), but Promontory Phase dates from these new analyses also fall within an interval extending from 660 to 835 ^{14}C yr BP. Bayesian analyses of AMS dates from the Cave 1 and 2 Promontory Phase perishables strongly suggest that this late period occupation comprised one or two human generations, centering on the interval running from ca. A.D. 1250–1290 (Ives et al., in press). Steward was uncannily accurate in his age assessment of the Promontory Culture in the caves.

Steward (1937) further argued that the Promontory inhabitants were a specialized hunting population with Plains affinities, taking large mammals, especially antelope and bison. This was evident to him in both the osseous remains present, as well as the substantial hide-processing requirements connected with the moccasins and other clothing present. Our recent research confirms Steward's observations for osseous remains: antelope and bison dominate identifiable species; small animals are rare (Johannson, 2013). There was little evidence of groundstone technology in the caves, and no evidence of horticulture. Moreover, there is no evidence of wild seed harvesting and processing (such as parched seeds) (Rhode, 2012).

Sudden as the onset of the Promontory Culture was in the caves, it ended equally rapidly. Grayson (2006) suggested that northward shifts in the monsoonal storm track had initially made Fremont horticulture possible over significant areas of the Great Basin, at the same time improving bison forage. Both Grayson and Lupo and Schmitt (1997) noted that radiocarbon-dated Great Basin bison occurrences peak in the interval from 600 to 1600 ^{14}C yr B.P., falling off sharply after A.D. 1300. Perhaps diminished bison populations on Promontory Point figured in the end of the cave occupations. Whatever the cause, the Promontory Phase saw a subsequent strong manifestation in Utah Valley (Fig. 1, sites 3–13), between 650 $\pm$ 70 and 300 $\pm$ 70 ^{14}C yr B.P. (calibrating from the thirteenth century onward). There, Promontory ceramics are common at open air sites where wetland resources including bulrush, cattail seeds and roots, waterfowl, muskrats and fish are well represented (Janetski and Smith, 2007).

Logically, the identity of the Promontory Culture cave inhabitants could involve three alternatives. One scenario would involve a terminal Fremont group moving toward an extreme in the hunting and gathering spectrum of economic activities. A second alternative would explore a longstanding theme in Great Basin studies in which Numic speaking populations including groups

TABLE 1. AMS radiocarbon dated moccasins and moccasins lengths

Lab no.	Artifact	Description	AMS date	Median Cal date A.D.	Moccasin length (cm)
CAMS-112638	42BO1:9545	Bison moccasin	725 ± 35	1276	14.0
CAMS-112639	42BO1:10132	Deer or antelope moccasin	785 ± 40	1241	20.3
OxA-18156	42BO1:10191	Bison hide sandal	689 ± 26	1291	20.8
OxA-18160	42BO1:11582.7	Bison moccasin	753 ± 27	1265	25.4
OxA-18162	42BO1:10241	Deer or antelope leather, moccasin	784 ± 26	1246	25.4
OxA-23853	42BO1:10055	Bison moccasin	730 ± 26	1275	17.8
OxA-23854	42BO1:9750	Bison moccasin	756 ± 24	1265	19.1
OxA-23855	42BO1:9756	Bison moccasin	826 ± 26	1220	20.3
OxA-23856	42BO1:10353	Bison moccasin	767 ± 26	1258	23.9
OxA-23857	42BO1:10083	Bison moccasin	758 ± 26	1263	30.5
OxA-23886	42BO1:9764	Bison moccasin	817 ± 24	1229	11.4
OxA-23887	42BO1:10129	Bison moccasin	714 ± 23	1280	14.0
OxA-23888	42BO1:10107	Bison moccasin	811 ± 23	1234	19.1
OxA-23889	42BO1:10058	Bison moccasin	793 ± 23	1243	20.3
OxA-23890	42BO1:10270	Bison moccasin	684 ± 23	1292	22.2
OxA-23917	42BO1:11582.37	Bison moccasin	775 ± 23	1254	16.5
OxA-23918	42BO1:11582 (AR 4195)	Bison moccasin, thinner upper	734 ± 23	1274	24.5
OxA-23919	42BO1:11582.15	Bison moccasin	763 ± 23	1262	27.9
OxA-23920	42BO1:10251	Bison moccasin	735 ± 23	1273	29.2
OxA-23921	42BO1:10065	Bison moccasin	757 ± 23	1265	14.6
OxA-24002	42BO1:11582.3	Bison moccasin	731 ± 24	1274	26.7
OxA-24003	42BO1:11582.41	Bison moccasin	723 ± 25	1277	27.0
OxA-24004	42BO1:10102	Bison moccasin	782 ± 25	1248	26.5
OxA-25181	42BO1:FS311	Bison moccasin	670 ± 25	1306	22.1
OxA-25183	42BO1:FS173	Bison moccasin	706 ± 25	1283	23.1
OxA-26097	42BO1 FS799	Bison moccasin	741 ± 23	1271	15.9
OxA-26098	42BO1 FS801	Bison moccasin	777 ± 22	1253	18.4
OxA-26133	42BO1:11582.64	Bison hide sandal	766 ± 23	1260	20.8
OxA-26134	42BO1:AR815	Bison hide sandal	746 ± 22	1270	22.5
OxA-26138	42BO1:11582.43	Bison moccasin	714 ± 22	1280	12.7
OxA-28316	42BO1 FS945	Bison moccasin	708 ± 24	1282	24.2
OxA-28317	42BO1 FS969	Bison moccasin	754 ± 23	1267	25.0
OxA-28319	42BO1 FS1223	Bison moccasin	703 ± 23	1284	19.4
OxA-28321	42BO1 FS1005	Bison moccasin	700 ± 23	1285	25.4

such as the Shoshone, the resident historic population in the Promontory region, are thought to have arrived during the late prehistoric period (Madsen and Rhode, 1994). The intrusive character of the Promontory Phase assemblages might arise from an expanding Numic population. Finally, the discontinuity in the Promontory record could have resulted from a small group of migrating Apachean ancestors. The Promontory record reveals a significant occupational and material culture discontinuity inconsistent with the first option above, while the absence of objects like steatite vessels, ceramics such as Intermountain ware (normally associated with late prehistoric Shoshonean occupations), and distinctive objects like Shoshone knives make the second option unlikely (a point Steward was highly knowledgeable of and adamant about).

Steward's (1937) suspicions therefore focused on the idea that Apachean ancestors were involved. The 237 soft-soled moccasins he recovered were typical of the Canadian Subarctic and decidedly out of place in the eastern Great Basin (Driver and Massey, 1957:323, 327; Ives, 2014). Relying upon Hatt's (1916) excellent early work, Steward (1937) drew comparisons with soft-soled moccasins made in northern British Columbia by Dene peoples such as the Tahltan. These involved moccasin patterns in which a sole piece folds upward to meet a vamp and is joined by a seam at the heel. We would today recognize the Promontory moccasins as examples of 2 (Ab) and 2 (Bb) styles in the Bata Shoe Museum (BSM) classification of footwear.[1] These styles are common in nineteenth and twentieth century collections of Dene and Algonquian footwear from Subarctic Canada (Webber, 1989; Thompson, 1990, 1994; Ives, 2014). Promontory moccasins were sometimes fashioned from antelope or deer, but most were made of bison leather with the fur turned inward. Many moccasins (73.1%) had whole or half sole repairs, along with general indications of substantial wear, so that we are looking primarily at discarded footwear that was being replaced at this locus (Fig. 2).

A similar moccasin, dating to 1430 ± 40 ^{14}C yr B.P. (cal A.D. 558–663), was preserved in a southern Yukon ice-patch, suggesting that potential precursor forms existed in a region widely regarded as part of the proto-Dene (or proto-Athapaskan) homeland (Hare et al., 2012; Greer and Strand, 2012; Ives, 1990; Krauss and Golla, 1981). Fremont, hock and other moccasins in the larger Great Basin region (such as Hogup, Danger, and Wilson Butte Caves, Fig. 1) and adjacent Plains are

[1]In a BSM 2 (Ab) moccasin, there is a central seam in the lower portion that folds upward to meet the vamp, creating a narrower front portion across the toe of the moccasin; in a BSM 2 (Bb) moccasin, the lower piece joins the vamp with no central seam, creating a broader toe (Webber, 1989).

Fig. 2. Typical Promontory style (BSM 2 [Bb]) moccasins at the time of their recovery (2013) in Cave 1: (a) and (b) uppers of moccasins 42BO1 FS945 and 42BO1 FS969 respectively; (c) and (d) soles of moccasins 42BO1 FS945 and 42BO1 FS 969, respectively. Notice the whole sole patch and toe wear of 42BO1 FS945 and the heel and sole patches for 42BO1 FS969.

constructed in completely different fashions, often with little of the refined tanning and sewing seen in many Promontory moccasins (Ives, 2014).

Renewed work with other aspects of these assemblages and sites continues to reinforce Steward's belief that a northern hunting population of Apachean origin occupied the caves [a position reiterated even in Steward's (1955) last remarks on the subject]. In research reported elsewhere, we suggest that Steward's suspicions can now be bolstered by evidence of other artifacts uncharacteristic of the Great Basin but typical of Subarctic and Plains locales (such as *chi-thos* or tabular bifaces used in the final softening of leather, knotless netting identical to those found in Dene hunting bags, and sinew backed bows) (Ives, 2014; Ives et al., in press). Ongoing studies of rock art, pottery sherd geochemistry, obsidian sources (primarily Malad Peak, Fig. 1) and $\delta^{13}C$ isotopic data also reveal that late period Promontory peoples had external ties consistent with Apachean migration dynamics.

Steward's distinguished contemporary, Edward Sapir, reached similar conclusions. Using linguistic evidence, Sapir spoke of four "cultural strata" that would reflect an Apachean shift from Subarctic to Southwestern worlds (Sapir, 1936). These included a northern layer, similar to that of Dene in the Mackenzie basin, followed by a pre-equestrian Plains adaptation. His third layer reflected an initial Southwestern influence, from non-Puebloan cultures, and finally, a strong Puebloan influence. The Promontory Culture looks very much like the assemblage we would expect for Sapir's third "stratum."

The population of Promontory moccasins that we analyze therefore came from a narrowly defined time frame centering on the latter part of the thirteenth century, with an occupational focus of as little as one or two human generations. The deposits were created by a population engaged in intensive large game hunting and possessing a distinctive moccasin tradition with highly refined hide processing and sewing skills. Basketry, rock art and other instances indicate these Promontory cave inhabitants were interacting with nearby terminal Fremont populations that were themselves past the period in which maize horticulture could be conducted in the eastern Great Basin (after ca. A.D. 1150: cf. Coltrain and Leavitt, 2002). The Promontory Phase occupations in Cave 1 and 2 reflect sustained, primarily winter occupations of base camps with a range of activities that would involve both sexes and all age groups connected with a seasonal residential group.

MATERIALS AND METHODS

Our Promontory moccasin sample comes from Steward's original collection of Cave 1 and Cave 2 moccasins now curated in the Natural History Museum of Utah collections, as well as moccasins recovered during our 2011, 2013, and 2014 excavations in Promontory Cave 1. Of the 250 moccasins Steward recovered, 243 are in the BSM 2 (Bb) pattern (Fig. 3b–h). and one is in the BSM 2 (Ab) pattern The remaining six are of different construction; five are essentially rawhide sandals in which a single piece of hide (with holes along its perimeter) has been drawn together over the upper part of the foot and ankle with a hide loop (Fig. 3a), and one is simply a single piece of leather folded into a foot covering.

Steward (1937:65–68) provided a table of moccasin data, which, with minor emendations based on our direct observation of several of the moccasins (where our measurements differed from Steward's), has served as our primary data source. For the analysis below, we required each moccasin to be sufficiently complete that its length from heel to toe could be accurately determined. Some moccasins are too fragmentary for an accurate length measurement. Steward's table provided 184 length measurements in half-inch increments, which we have supplemented with metric data from moccasins recovered during our excavations (16 instances) (see Supporting Information Table 1).

We included the five rawhide sandal length metrics because they are associated with and known to be of the same age as the Promontory BSM 2 (Ab) and BSM 2 (Bb) patterns, and because their length parameters would have similar implications for stature and age predictions. This sandal-like construction is known from isolated examples extending from western Nevada, onto the Plains, and into the Ozarks, where broadly contemporaneous dates to the Promontory examples are cited (Rudy, 1953:29 and Fig. 60; Kutruff et al., 1998; Rexroth,

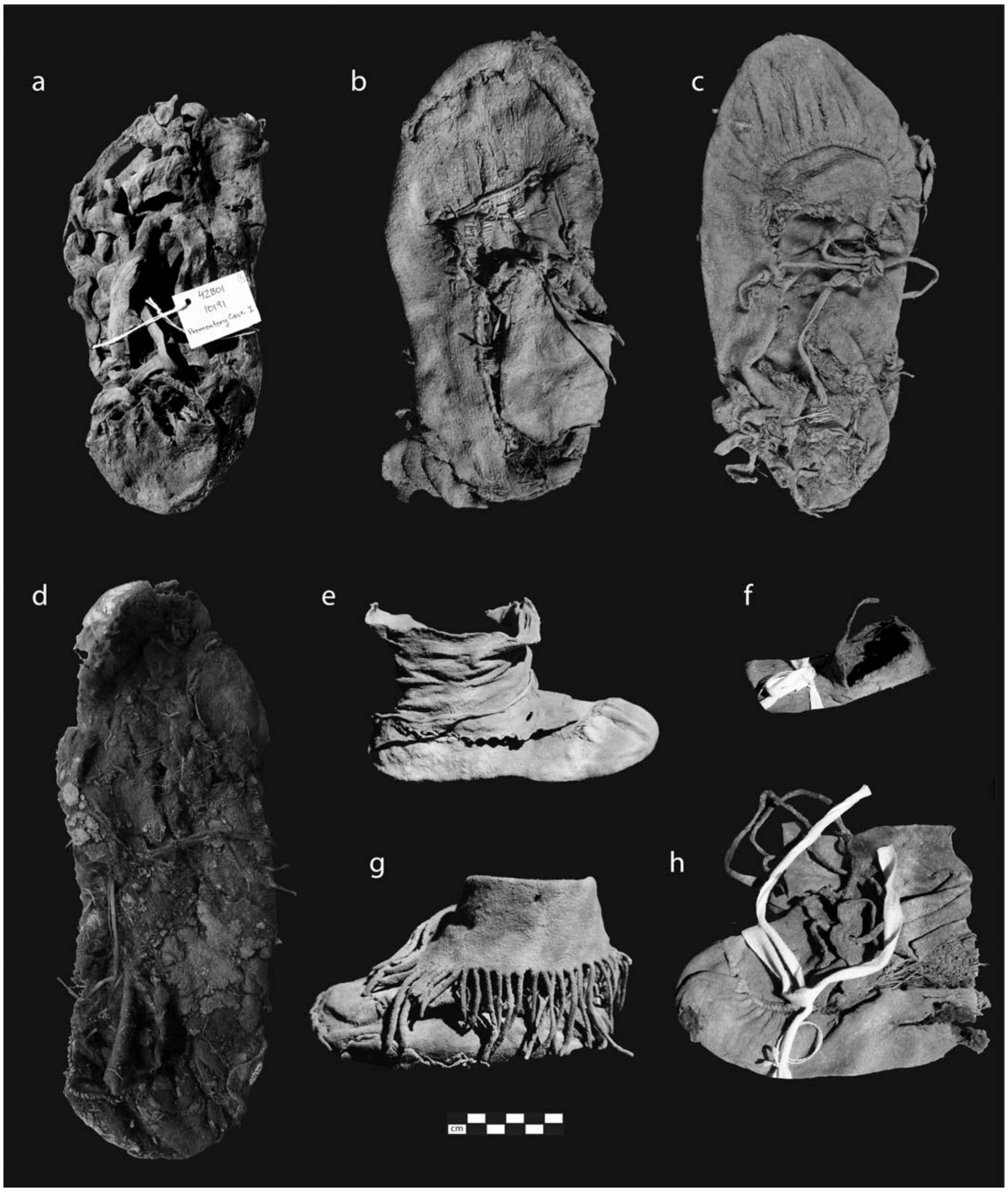

Fig. 3. Examples of variable sizes and styles in Promontory Cave 1 moccasins: (a) 42BO1 10191, one of the five hide sandals Steward found; (b) 42BO1:10241, a Promontory style moccasin made of deer or antelope leather, with remnants of elaborate quill decoration; (c) 42BO1:FS173, a Promontory style moccasin of bison leather; (d) 42BO1 11582.15, a large Promontory moccasin with disintegrating exterior leather, and fine bison fur lining; (e) 42BO1:10065 a Promontory style moccasin with ankle wrap; (f) 42BO1 11582.23, one of the smallest Promontory moccasins; (g) 42BO1:10055, fringed ankle wrap on a Promontory style moccasin; (h) 42BO1 11582.55, a Promontory style moccasin, bison leather with fur turned inward. Artifacts a, b, and d-h photographed courtesy of the Natural History Museum of Utah.

2010:173–174, 205–207; Ives, 2014; Ives et al., in press). We also included another two moccasins from Steward's Natural History Museum of Utah collections for which he did not provide tabular data, making for a total of 207 length measurements (Supporting Information Table 1; Fig. 4). The preponderance of the sample of length measurements (202 instances) therefore comes from Promontory style soft-soled moccasins.

One factor that might affect the sample could be a "doubling up" of results by counting individual moccasins whereas discarded *pairs* might be expected. Having examined both the 1930–31 and more recent collections, however, we are not aware of any moccasins that could be construed as a pair (based on size, wear, raw materials and sewing techniques). In another aspect of our research, we are making volumetric estimates of deposits in order to estimate the original number of moccasins Cave 1 might have held. Although early results provide only preliminary figures, the remaining deposits in Cave 1, numbers of moccasins in existing private and institutional collections, and the uncertain but significant impact of 20th century looting would all suggest that

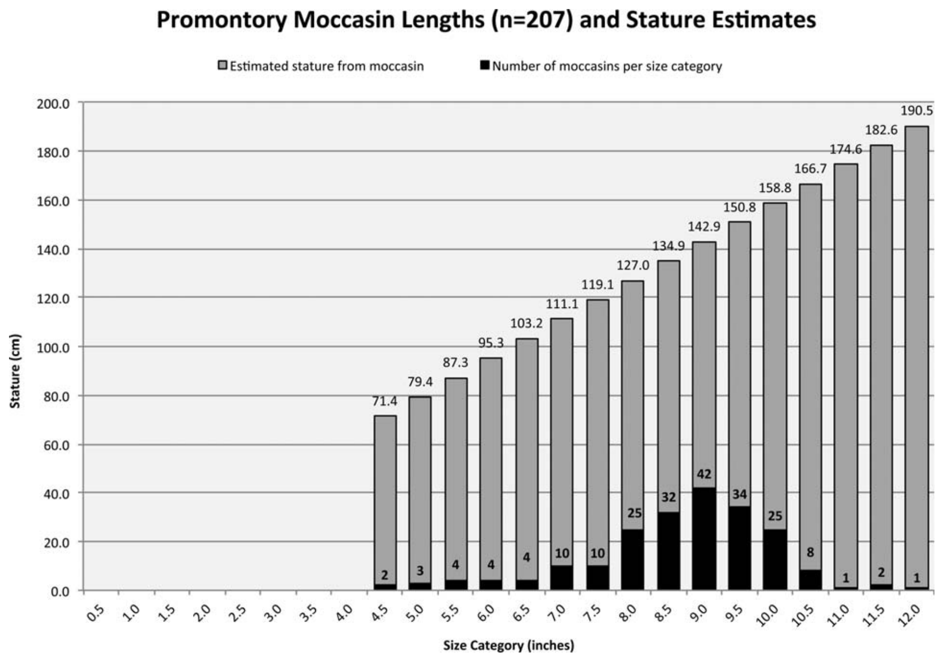

Fig. 4. The black chart bars indicate moccasin lengths from Steward's (1937) original excavations, with additional lengths from relatively complete moccasins recovered during 2011–2014 excavations in Promontory Cave 1, plotted in half inch increments (as originally measured by Steward); the gray bars indicate stature predictions (in cm) for half inch size categories.

originally, there were many hundreds of moccasins present. While internally stratified to a degree, the existing Promontory cave deposits also suggest that the churning and movement of objects one might expect to be connected within an intensively inhabited base camp certainly took place. We believe our sample is comprised primarily if not wholly of individual examples as a consequence of both factors. Even if that inference is incorrect and a number of moccasin pairs are represented, we would still be left with a rather large sample of moccasin lengths, which we believe allows for accurate estimates of both stature and age, relative to most prehistoric sources of data.

Length measurements for the moccasins are straightforward. We are aware that length measurements might be combined with width measurements in order to extrapolate body mass estimates as well (e.g., Ashton et al., 2014). However, many Promontory moccasins have not been through a restorative process, and consequently, remain flattened or folded in various orientations from their time within the Promontory cave deposits. Moccasin widths are therefore more uncertain. Because of this, and because body mass data would have little impact on our findings beyond the stature data, we have not integrated width data into our calculations.

For a smaller subset ($n = 34$) of the Natural History Museum of Utah artifacts as well as recently excavated materials, we paired length data with individual AMS radiocarbon dates on moccasins (Table 1). This subsample was purposefully chosen so that it would reflect a range of moccasin sizes, in order to determine if there were temporal trends in sizes, and therefore trends in stature and age, during the Promontory Phase occupation of Caves 1 and 2 (Fig. 5). The great majority of these dates were processed at the Oxford Radiocarbon Accelerator Unit, with protocols as described in Brock et al. (2010) and Ives et al. (in press).

Estimating age and stature from the moccasin data

Several studies shed light on the relationship between shoe size, foot size, and stature. Borrowing from this literature, we develop a model for understanding the composition of the Promontory Cave population by using moccasin size as a proxy for foot size, from which we could predict the stature of the individual who would have worn the moccasin. A number of authors have tried to predict stature and sex from foot, footprint, or shoe dimensions using regression models for forensic investigations (e.g., Giles and Vallandingham, 1991; Ozden et al., 2005; Zeybek et al., 2008). Using a simpler methodology—calculating the average foot length (F) to stature (ST) ratio in a sample of known adults—Rohren (2006) determined that a general F:ST ratio of 15% and shoe (footwear: FW) length to stature ratio (FW:ST) of 17% applied when data for both sexes was combined. This relationship existed despite factors such as sex, weight, pregnancy, nutrition, age, genetics, disease, and environmental conditions that may affect the overall size and morphology of the foot. These findings are supported by several other studies that obtained similar F:ST ratios (e.g., Fessler et al., 2005).

To predict stature from moccasin lengths (ML), we first tested whether length to stature ratios held true with respect to moccasins. With the assistance of friends and colleagues who wear moccasins, we took measurements for stature and bare foot length, substituting moccasin foot length (on foot) for shoe length in a small sample of 8 adults (4 males, 4 females), over a total of

TABLE 2. Stature, foot length, with age and sex estimates based on moccasin length

Number of moccasins	Length category (")	Moccasin length (cm)	Stature (cm)	Foot length (cm)	Age/sex estimate
0	0.5	.	.	.	.
0	1.0	.	.	.	.
0	1.5	.	.	.	.
0	2.0	.	.	.	.
0	2.5	.	.	.	.
0	3.0	.	.	.	.
0	3.5	.	.	.	.
0	4.0	.	.	.	.
2	4.5	11.4	71.4	10.7	<1
3	5.0	12.7	79.4	11.9	1
4	5.5	14.0	87.3	13.1	2
4	6.0	15.2	95.3	14.3	3
4	6.5	16.5	103.2	15.5	4
10	7.0	17.8	111.1	16.7	5
10	7.5	19.1	119.1	17.9	6
25	8.0	20.3	127.0	19.1	7
32	8.5	21.6	134.9	20.2	M8/F9
42	9.0	22.9	142.9	21.4	10
34	9.5	24.1	150.8	22.6	11
25	10.0	25.4	158.8	23.8	M12/F12-AF
8	10.5	26.7	166.7	25.0	M14/AF
1	11.0	27.9	174.6	26.2	M17-18
2	11.5	29.2	182.6	27.4	AM
1	12.0	30.5	190.5	28.6	AM
$n = 207$		$\bar{x} = 21.0$	$\bar{x} = 131.0$	$\bar{x} = 19.6$	

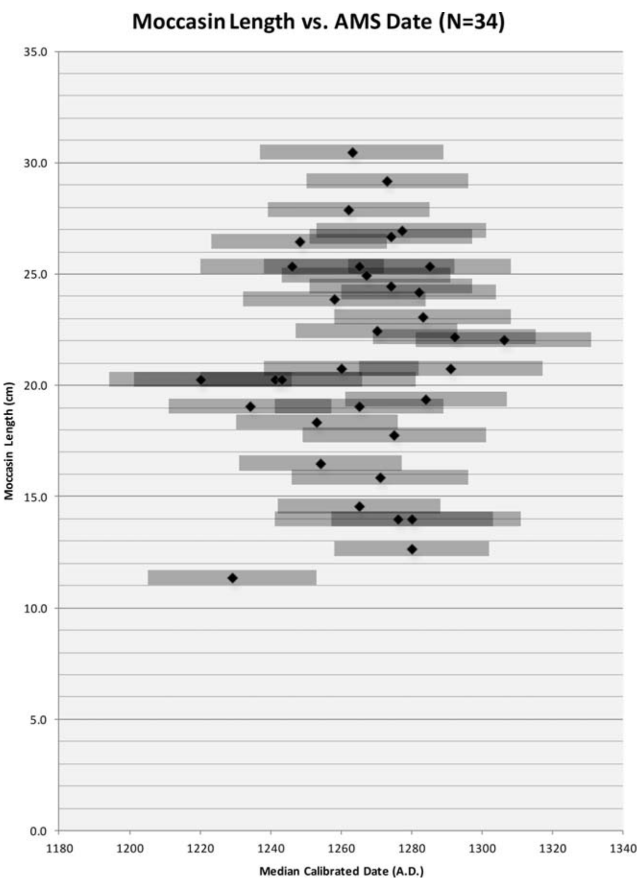

Fig. 5. A cross-plot of median calibrated AMS dates (with 2 σ error bars) versus moccasin lengths. There is no discernible temporal trend in moccasin lengths.

12 pairs of moccasins. A small degree of sexual dimorphism is apparent in this test sample, with male F:ST of 15.6% and ML:ST of 16.0%, and female F:ST at 15.0% and ML:ST at 15.9%. Pooling data for both sexes resulted in a combined F:ST of 15.3% and ML:ST of 16.0%. Our sample size is very small, but these foot length results closely parallel previous results, while showing that our moccasin length results are (not unexpectedly) intermediate between foot length and modern footwear results. All values occur within a narrow percentage range. As mentioned below, moccasins are in important respects somewhat more like stockings than shoes or other footwear.

Given the prospect that the Promontory Cave inhabitants might have been proto-Apachean Dene who migrated through the eastern Great Basin from the north, we particularly sought out anthropometric data for Apache, Navajo, and northern Dene peoples to make a trial test of our results. Hrdlička (1935) provided the only data reporting both foot length and stature for these groups [with data collected from living subjects (52 males and 31 females, totalling 83 individuals) between 1898 and 1910]. For the Apache, Hrdlička (1935:441) reported an adult male F:ST of 14.93% and adult female F:ST of 14.58%,[2] demonstrating a relatively low degree of sexual dimorphism. Closely related groups such as the Navajo showed little to no sexual dimorphism in F:ST. Having obtained a ratio of 16.0% for both sexes from our analysis of ML:ST, we therefore find that our method produces results that correspond very closely with accurate stature and age data for important comparator populations.

[2]Hrdlička referred to "percental relation of foot length to stature," which is the same relation as our F:ST referred to throughout.

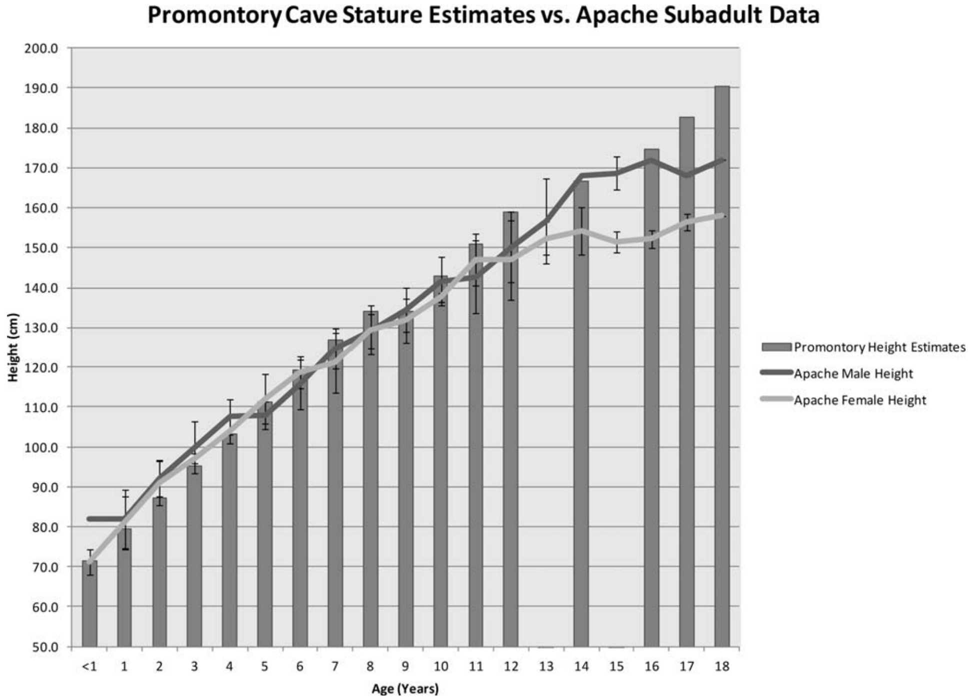

Fig. 6. Promontory cave stature estimates compared with Kraus' (1961) Apache data.

RESULTS

To predict the stature of the wearer of each moccasin, we converted the moccasin lengths (L) published by Steward (1937)[3] into cm and calculated stature using the equation ST = (L × 100)/16.0. We then predicted the age of the subadults using information from Anderson et al. (1956), in which they provided data for the growth of the normal foot during childhood and adolescence. Foot length was calculated at 15.0% of the estimated stature derived from each moccasin length category.[4] Age was then estimated by comparison to Anderson et al's (1956) foot length data. Cutoff points for ages 1–12 were developed by averaging the median foot size for each age category for both sexes, since there was little or no sexual dimorphism. For ages 13–18, sex-specific median foot size was used as the cutoff point for each age category (Supporting Information Table 3). The results were carefully compared with Kraus' (1961:228) published data for Apache children aged 1–18 years. Similar to the data published by Anderson et al., Kraus's published data shows no apparent sexual dimorphism up to 12 years of age. The results are shown in Table 2 and Figure 6.[5]

The result is a good fit, giving us no specific reason to doubt the validity of our estimates. We are still presented with the problem of determining the sex of these individuals, however. It is not possible to distinguish between males (M) and females (F) under the age of 12 years using this method. It is equally unlikely that we could distinguish between adolescent males and adult females (AF). Nonetheless, given the age-related trends in height between the sexes, divergent growth trends become apparent at 13 years of age; we can confidently conclude that any individual with a stature above 165 cm is likely to be a late stage adolescent or adult male (AM).

Population structure of the Promontory caves can best be understood by looking at the distribution of individuals in each stature category derived from Steward's original moccasin length categories, and comparing the results to average stature (and standard deviations) of other closely related populations. The stature data plotted in Figure 7 were derived from Boas' large database of anthropometric measurements recorded in the early 1900s [courtesy Richard Jantz (1995, 2003; Jantz el al., 1992)] (see also Supporting Information Table 4). Dene and Tlingit populations are marked with asterisks. From our analysis of this data, we calculated the combined average stature of the groups shown to be 156.4 ± 4.7 cm for females and 169.1 ± 5.8 cm for males, respectively. Against this data, we have indicated the age categories corresponding to our stature estimates. We obtained comparable results when we calculated the average adult stature of only the Dene populations recorded

[3]As mentioned above, we made several minor emendations to the moccasin lengths published by Steward (1937). The corrected lengths that were used in our estimates are indicated in Supporting Information Table 1.

[4]We use here the general F:ST ratio of 15.0% because our sample size is too small to invalidate Rohren's (2006) results. Anderson et al. (1956) obtained the same ratio for both sexes at full maturity. We believe we can apply this ratio to subadult data based on Fessler et al.'s (2005) finding that there is no nonlinear relationship between foot length and stature: ratio of F:ST neither increased nor decreased with stature. We note, however, that Anderson et al's (1956) data show a F:ST ratio of 15.9% for both sexes at 1 year, with the ratio increasing to 16.1 for ages 2–3 years in girls, and 12 years for boys, then decreasing to 15.0% by full maturity. The effect of this trend (if any) on our analysis would be a minor overestimation of F and ST of individuals under the age of 15 years, which would have no little or no affect on our conclusions about the Promontory Cave demographic structure.

[5]Using the same methodology, we estimated that the person who wore the Yukon ice patch moccasin was 146.3 cm in stature and 10 years of age.

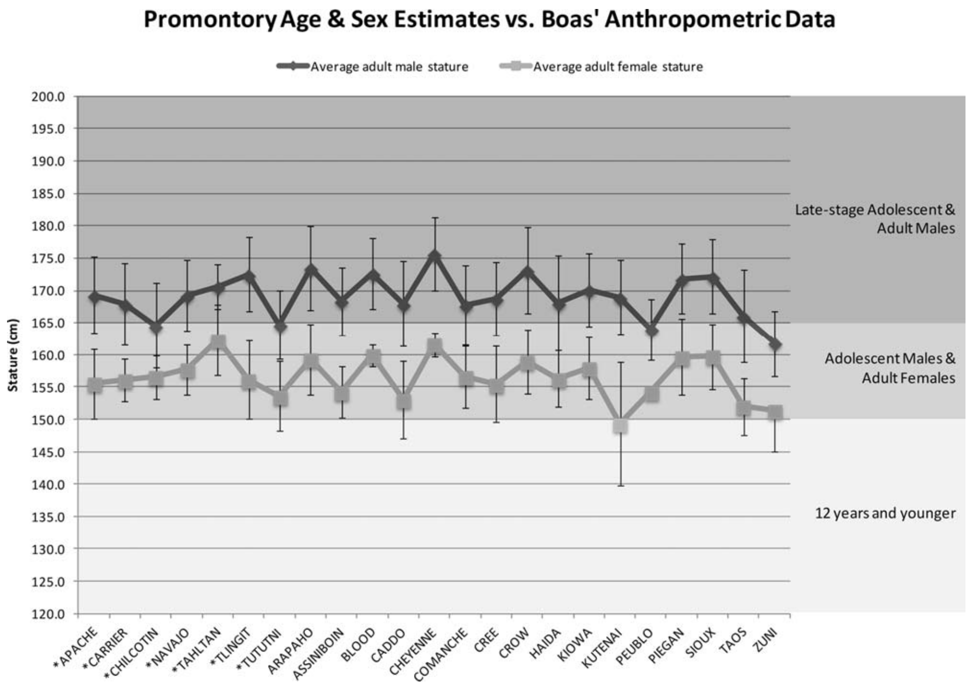

Fig. 7. Stature data derived from Boas' anthropometric measurements recorded in the early 1900s (courtesy Richard Jantz [1995, 2003; Jantz et al., 1992]). Dene and Tlingit populations are marked with asterisks. Shaded age categories derived from our stature estimates are superimposed over the Boas data (see right hand column).

in Boas' data, obtaining estimates of 156.8 ± 4.7 cm for Dene females, and 168.4 ± 5.6 cm for Dene males. The values Hrdlička (1935) reported for Apache adult females (155.5 cm) and adult males (169.3 cm) are very close to the average scores Boas reported for all Dene.

Of the total of 207 individuals represented in Promontory cave by footwear left behind, 12 were above 165 cm in stature and were almost certainly adult males (see both Figs. 4 and 7). Another 25 individuals were between 155 cm and 165 cm in stature and likely represent a combination of adult females and adolescent males (Figs. 4 and 7). The remaining 170 individuals were subadults. Although we are not able to determine the proportion of male to female subadults represented by the moccasins, we are able to draw specific conclusions about the structure of this population, since the majority of moccasins recovered belonged to subadults and children.

The size and age categories most likely to be underrepresented (see below)—those that are large adult males (above 165 cm) or very small children (under 5 years of age)—comprise 5.8 and 8.2% of the population respectively, while children 5–9 years of age account for 37.2% of the population, and individuals aged 10 or 11 comprise 36.7% of the population. The 25 moccasins that likely represent a combination of adult females and adolescent males (or possibly larger subadult females or smaller adult males), comprise 12.1% of the sample. Consequently, we can say with confidence that at least 82.1% of the population reflected in the moccasins was composed of children or subadults (under the age of 12 years). Because this is *not* mortuary data, these figures seem suggestive of a high birth rate, indicative of a growing population. There is no evident temporal trend in moccasin sizes (Fig. 5), suggesting that the demographic structure of the population arriving in the caves was relatively constant throughout the Promontory occupation.

DISCUSSION

We do not believe that the number of moccasins in Promontory Caves 1 and 2 is unusual in and of itself. Rather, it is the intersection of a moccasin-using population with phenomenal preservation conditions that has produced the large number of Promontory moccasins. Worn out moccasins were commonly encountered in recently abandoned historic encampments (e.g., Schultz, 1919, 1927). One noteworthy account comes from the Lewis and Clark expedition, where Sacajewea used moccasins from lodges in an abandoned camp to indicate that the moccasins were not made by Shoshone people, but rather by others (Moulton, 1987:216, 219). It is likely that discarded moccasins were common at many sites, but would be preserved at exceedingly few of those sites (in environments such as we see in dry cave and ice patch settings). While the absolute number of moccasins in the caves is large, it would not take that many discards for each person during a 20–40 year span of occupation to reach such impressive numbers, provided that preservation conditions would allow.

Representativeness of the moccasin data

While the abundance of the discarded Promontory moccasins makes for an unusually realistic data set, some sources of error do need to be considered. One element of bias would involve adult males. Soft-soled moccasins were comfortable, highly functional and conservatively maintained as an element of Subarctic and Plains dress long after other items of western clothing prevailed. They were nevertheless prone to rapid wear, especially where hard and rough substrates prevailed (as on Promontory Point and in adjacent regions). To contend with this, multiple pairs of moccasins were prepared and carried for lengthy journeys, for example (e.g., Schultz, 1919, 1927). In Subarctic winter settings, a pair of moccasins typically lasted a month, but wet conditions or high intensity activities (such as tracking) could consume a few pairs of moccasins in a day (e.g., McClellan, 1975; Clayton-Gouthro, 1994). Men would be more likely to discard moccasins in a broader range of locales outside the residential bases that Caves 1 and 2 reflect as the consequence of activities that could include hunting, scouting, and raiding (e.g., Schultz, 1919, 1927; Betinez and Nye, 1959; Ball, 1970). Adult women would also be somewhat more likely to discard moccasins away from residential sites than children and subadults.[6] Even so, it was common practice to carry repair materials for footwear, enhancing the chances that at least some worn moccasins used by adults would be returned to the caves, where they would then be discarded and replaced (e.g., Betinez and Nye, 1959:28; Binford, 1979).

The presence of some very large moccasins along with hunting gear affirms that adult men certainly contributed to the sample of moccasins recovered. It is difficult to determine just which proportion of the 25 moccasins falling in the projected size range where the individual might have been a larger subadult female or male as opposed to a smaller adult female or smaller adult male. Should the great majority of moccasins in this size range actually have been used by adults, roughly one in five moccasins would represent an adult (i.e., combining most moccasins in this category with those that are clearly adult male). Even with a number of polygamous marriages, this would still suggest a high proportion of children. It may well be that the biasing factor for adult moccasin discards away from camp could in this instance be affecting overall proportions. We are inclined to think that a larger proportion of smaller adults of both sexes is reflected by this ambiguous size category.

It might also be surmised that growing children could contribute a disproportionate number of moccasins to the sample as their foot sizes changed. This potential bias nevertheless conflates our perception of more durable modern footwear (i.e., hard-soled shoes and boots) with the realities of using soft-soled moccasins (which, with their internal padding are somewhat more akin to heavy, durable stockings in character). High rates of wear would also mean that children could be expected to need new moccasins before they actually out-grew them.

Finally, on ethnographic grounds, we anticipate the use of cradleboards, baby bags or similar swaddling arrangements for the Promontory population. This could have influenced the number of very small moccasins present in the sample since these children would be less likely to need footwear. For instance, the Chiracahua moccasin ceremony—in which a child received his first moccasins—was held between the ages of one and two (Opler, 1941:11–17). Consequently, the number of children in the youngest age ranges predicted from our analysis may be underestimates (especially given the predominance of somewhat older children), in as much as the very youngest children may not have worn moccasins.

Beyond these biasing factors, the high rates of wear and repair mean that the moccasins reflect a "discard" population upon which comparatively few selective processes would operate. While elements like ankle wraps or quill decorated vamps might be scavenged from a moccasin, the remainder of a worn out moccasin has essentially no practical value worth retaining. Consequently, we feel that the Promontory moccasin sample quite faithfully mirrors important characteristics of the contributing population in ways that mortuary or other data seldom do.

We also suggest that footwear is well suited to tracking demographic properties related to site function. The Promontory setting features residential base camps reflecting the entire breadth of a local group, but other instances are suggestive of different site functions. Antelope Cave in northwestern Arizona, occupied primarily in the interval from A.D. 600–900, yielded a large series of sandals that average roughly 28 cm in length, with a number of sandals extending beyond 30 cm (Yoder, 2009; Janetski et al., 2013). Although there appears to be a length reserved at the front portion of a sandal for buffering the toes, the Antelope cave function was focused upon adults (likely adult males), quite in contrast to the picture we see at Promontory.

Relevance of the Promontory demographic structure

Achieving a more refined insight into demographic structure would be a welcome opportunity for any era, but the likelihood that the Promontory moccasin data reflects demographic conditions surrounding a migrating Apachean population prompts additional commentary. Apachean ancestors are widely believed to have migrated from the Canadian Subarctic in the recent past (e.g., Sapir, 1936; Hale and Harris, 1979; Krauss and Golla, 1981; Smith et al., 2000; Matson and Magne, 2007; Ives, 2010; Rice, 2012). The East Lobe White River eruption (which deposited $\sim$50 km^3 of volcanic ash over much of the Yukon and Northwest Territories) may well have created a ripple effect among northern Dene populations ca. A.D. 846–848 (Workman, 1979; Ives, 1990, 2003; Jensen et al., 2014). This ecological catastrophe over a vast region of the western Subarctic, when coupled with the highly attractive nature of the Plains bison hunting lifestyle, very likely encouraged Apachean ancestors to move from the southern Subarctic and Aspen Parkland ecotones southward along Alberta's Eastern Slope and northern Plains regions.

Genetic and linguistic data provide a consistent picture of Apachean migration. Researchers working with multiple lines of evidence (mtDNA haplotypes, y-chromosome data, and rare mutations) have inferred that there was a founder effect connected with the initial Apachean population, which must therefore have been relatively small in size (e.g., Li et al., 1998, 2002; Holve et al., 2003; Mahli et al., 2003, 2008; Erickson, 2009; Malhi, 2012; Achilli et al., 2013). Monroe et al. (2013) further suggested that multiple fissioning events in small populations continued as Apachean ancestors progressed into the Southwest, contributing to reduced mtDNA haplogroup A diversity (haplotypes A2a4 and 5).

The genetic evidence makes it equally clear that many people were eventually incorporated into Apachean populations in the course of their journey southward. In northern Dene populations, for example, mtDNA haplogroup A occurs at levels of 80–100%; a specific mtDNA haplotype (A2a) occurs in high frequencies in both

[6]The nineteenth century Apache woman Lozen, for example, was a fierce warrior, whose activities away from camp would be difficult to distinguish from those of men in this respect (Ball, 1970).

northern and Apachean Dene populations (Malhi et al., 2003; Malhi, 2012; Achilli et al., 2013). For Navajo and Western Apache populations, mtDNA haplogroup A values drop to 50–60%, with the balance of the mitochondrial signature being made up of haplogroup B varieties common in Great Basin (including in Fremont burials) and Southwestern contexts (Parr et al., 1996; Mahli et al., 2003). This genetic finding is consistent with Navajo oral traditions in which other groups joined the emerging Navajo cultural identity; a number of clan ancestresses were Puebloan women who came from specific Pueblos (Zolbrod, 1984; Brugge, 1994, 2003, 2006). Monroe et al. (2013) demonstrated elevated mtDNA haplogroup B and C frequencies in Western Apache populations with Yavapai neighbors. Such interactions played a major role in emergent Apachean societies.

Linguistic data are also consistent with a Proto-Apachean group entering the northern Plains, expanding southward and creating a dialect chain (cf. Ives, 2003, 2014). Apachean neologisms for unfamiliar species and objects (that people leaving the Subarctic would encounter) also suggest that the founding population was small and cohesive (Ives, 2014; Ives et al., 2002; Rice, 2013:257–258). Apachean speakers all share internally innovated (rather than borrowed) terms for things like maize, lizards, turtles, wild turkeys, and tobacco, for instance (Ives and Rice, 2006; Rice, 2013:257–258). A large and dispersed ancestral Apachean population would be expected to exhibit greater variation in forming new terms, especially where geographic barriers intervened. Progressive fissioning events and geographic dispersal created conditions in which the distinctions characteristic of the Apachean dialect chain came into being.

At the broadest scale, the demographic trajectory for Apachean populations therefore extended from a small founding population to one that had grown dramatically by the time of the Spanish *Entrada* in the sixteenth century. We can anticipate two smaller scale components to this growth. First, through stochastic processes, the capacity of the Plains bison hunting lifestyle to provide abundant resources, or both factors working together, small founding groups could certainly grow and fission through internal processes (cf. Ives, 1990, 1998, 2010; Magne, 2012; Monroe et al., 2013:628). It is clear, however, that the historic size of Apachean populations can scarcely be explained by internal growth alone. Given the genetic information reviewed above, it is reasonable to consider alternatives in which the incorporation of others within nascent Apachean societies could take place.

The Promontory situation featured the sudden occupation of the caves by a population with an intrusive material culture, though one that showed signs of interaction with regional neighbors (including the terminal Fremont occupation of the nearby Chournos Spring site; see Fig. 1). This population had demonstrable success in large game hunting, to the apparent exclusion of other subsistence measures common in the region, having also the capacity to produce abundant hides that were processed into high quality leather garments. There is evidence for gaming and ceremonial activities, making it difficult to avoid the conclusion that this population was thriving. When we examine the demographic profile revealed by the moccasins, we see a population dominated by children and subadults. The Promontory situation could very well reflect a locus at which those two elements of population growth—a small group expanding through internal processes coupled with a fluid socio-environmental setting in which others might be inclined to join that group—flowed together. Migration theory does suggest that sexual asymmetries are common for migrating populations (e.g., Anthony, 1990). There would also seem reasonable grounds to suspect that a comparatively large proportion of women might have joined the Promontory population, consistent with mtDNA results to date.

The great scope of Athapaskan migration has received relatively little attention in anthropological research. Where it has, investigators have at times puzzled over why sedentary populations such as Puebloan peoples would join emergent Apachean societies, evidently in considerable numbers (cf. Malhi et al., 2008:419; Seymour, 2009). If ancestral Apachean speakers lived in the Promontory caves, the large game hunting economy and age structure reflected in the cave assemblages suggest a different interpretation. At least some early Apachean populations may have experienced notable success, making a shift to hunter-gatherer lifestyles—especially those connected with bison hunting—an attractive alternative to the stresses being experienced by sedentary horticultural and agricultural societies at the end of the thirteenth century (cf. Steckel and Prince, 2001).

However we consider the identity of the Promontory cave inhabitants, this trend has broader applicability during late period prehistory across western North America. In this time range, opportunities for hunter-gatherer populations expanded as populations that had practiced more sedentary lifestyles abandoned large areas and previous subsistence strategies. In complementary fashion, we note that sedentary lifeways with higher population densities do have unattractive qualities from human health and social perspectives (e.g., Hegmon, 2005).

CONCLUSIONS

A straightforward anthropometric technique allows the accurate prediction of stature and age from the abundant moccasins found in Promontory Caves 1 and 2. The Promontory Phase occupation of these caves took place in a sharply circumscribed interval focused on one or two human generations in the latter half of the thirteenth century. These occupations featured intensive residential or base camp activity involving small bands that undertook effective large game hunting, were well-clothed, and engaged in trade, personal adornment, gaming and ceremonial activity. While the moccasin data leave us with uncertainties in discriminating larger subadult males from adult females and smaller adult males, there is little room for doubt regarding two salient aspects of the age and stature predictions. A complete age and sex spectrum of the population was present in the caves, but children and subadults dominate this record. Apart from other archaeological indicators of socioeconomic success, the high proportion of younger individuals strongly suggests a growing population during this brief interval.

There are substantive grounds for inferring that the Promontory Phase occupation of the caves resulted from migrating Apachean populations, just as Steward thought, with the implication that extensive incorporation of neighboring populations in these societies may have been well underway at this early date and relatively northern locale. Whether or not this proves to be true, more refined information regarding prehistoric Promontory population structure provides important insights into a critical period of cultural and environmental change that swept interior North America during this interval. Though it might appear counterintuitive in some respects, opportunities for Apachean, Numic and other hunter-gatherer populations were expanding at this time. In situations where these communities were thriving, these circumstances may well have provided attractive alternatives for individuals in Fremont and Puebloan societies whose more sedentary lifestyles had become increasingly difficult to sustain.

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